Reconstructing Tebtunis: Assembling a Site Model Using Archived Aerial Photography

Todd Brenningmeyer[1] and D. J. Ian Begg[2]

[1]Department of Art and Design
Maryville University
Saint Louis, MO USA
[2]Trent University
Peterborough, Ontario Canada
tbrenningmeyer@maryville.edu

Abstract

Excavations conducted at the site of Tebtunis, Egypt between 1929 and 1936 uncovered architecture and cultural deposits representing over 1,000 years of possibly continuous occupation. Unfortunately, the results of these excavations were never fully published. Wind, sand, and time have since buried or eroded much of the architecture identified during these excavations. In 1998, two series of overlapping stereo pairs covering the site and the surrounding area were discovered within the archives of Gilbert Bagnani at Trent University in Peterborough, Ontario. The aerial images offer a unique opportunity to examine the site as it appeared during the 1934 and 1935 field seasons. A project to reconstruct the site's architecture using the overlapping stereo pairs, softcopy photogrammetric tools, and GIS began in the fall of 2003. This paper discusses the methods and techniques employed in this project as well as the results of this work.

1 Introduction

Between 1929 and 1936, a team of Italian archaeologists excavated the Greco-Roman town of Tebtunis, located on the desert fringe of the Fayyum depression southwest of Cairo. Their excavations uncovered a remarkable concentration of papyri as well as numerous well-preserved Greco-Roman and Coptic structures. The most prominent architectural feature, a rectangular walled sanctuary roughly 110 m by 60 m, can be seen in Figure 1. The sanctuary was approached by a 200-m-long processional avenue which is flanked by multi-storied houses to the east and large public structures to the west. Frescoed churches and subsidiary buildings of a Coptic monastery also were identified to the northeast of the town closer to areas of cultivation.

The results of the Italian excavations were published as brief preliminary reports following the field seasons of 1930 through 1935. The results of the 1936 season were not published and a final publication was never completed. While the reports provide some information about the progress of the excavations, they do not address the character and architectural details of the many structures that were uncovered at the site. Since the original excavations, the site has been reclaimed by the desert. Many of the mud brick buildings have eroded or suffered damage following decades of exposure to environmental processes and human activity (Figure 2).

Figure 1. Aerial photograph from 1935 showing the sanctuary and outlying buildings.

In 1998, notebooks, diaries, correspondence, and photographs dating from the Italian excavations were discovered among the archives of Gilbert Bagnani, who worked at Tebtunis and served as field director from 1933 through 1936. Bagnani's extensive correspondence details the day-by-day progress of the excavations through January 1935. His notes describe the excavation of Coptic churches northeast of the sanctuary and the clearing of a large rectangular complex termed "The Insula of the Papyri" after the numerous preserved Papyri found within. The numerous photographs discovered within the archives have proven particularly informative. Hundreds of terrestrial photographs and 48 overlapping aerial photos taken in 1934 and 1935 document the site as it appeared during the original excavations. The photographs provide a unique snapshot of architectural remains which in many cases no longer exist in the state first observed by Bagnani and his colleagues.

2 Photogrammetric Processing

In the fall of 2003, work was undertaken to re-examine the aerials from the Bagnani archive. The project's goal was to photogrammetrically reconstruct the site's architecture and topography as it existed at the time of the Italian excavations. Wall heights, room volumes, and building configurations not previously documented and no longer in existence would be mensurated and made available to scholars for further study. During the initial phase of this work, the aerials were catalogued and examined to determine their quality and characteristics. The surviving aerial photographs are contact prints made from the original large format film negatives. The prints were in remarkably good condition and were scanned in the archives for further examination. Of the 48 images inventoried, only 22 from the 1935 season retained the burned-in image of the altimeter and frame number along the film border. Two separate missions are represented in the set of photos from 1935. The first group consists of 19 images flown in three flight lines with a north-south orientation (Figure 3). The average flying height based on the altimeter reading was approximately 1,200 ft.

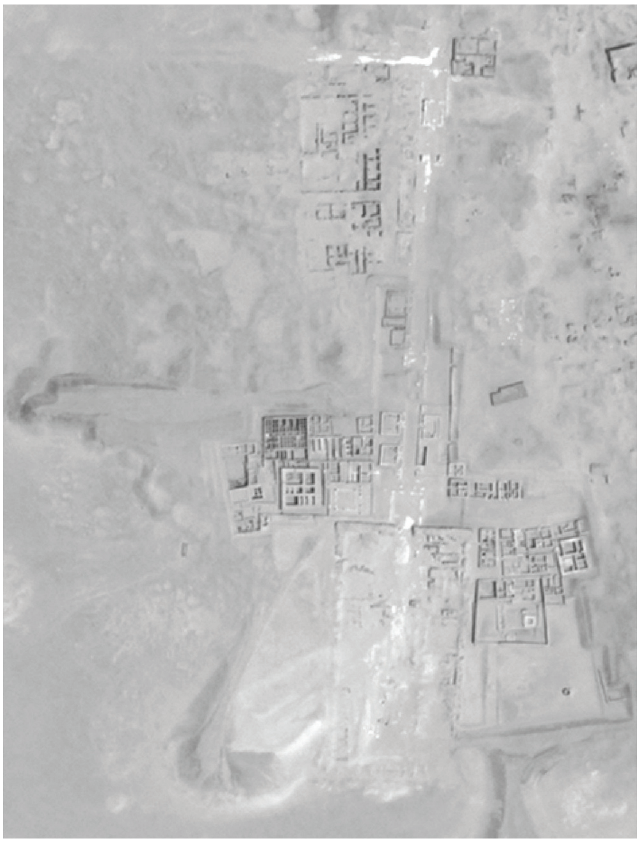

Figure 2. Quickbird image of site from 2005.

The mission was flown with an average 60 percent forward overlap and at least 30 percent side lap, which is ideal for stereo compilation. The second mission was flown with an east-west orientation and consists of three images that cover the sanctuary and processional way (see Figure 4). A subset of the 1935 aerials was selected for use in this study. The 1934 images, which no longer retain the altimeter readings, were not used.

2.1 Data Gaps

Although the aerial photos were collected with adequate overlap for stereo collection and at a flying height appropriate for at least ~200 scale (1"=200') compilation, there remained numerous gaps in our knowledge of the source material. In traditional photogrammetric projects, a well-surveyed system of ground control is laid out prior to mission flight. Large and easily identifiable markers are captured in the photos, providing reference points necessary to tie the photos to their correct geographic and topographic locations during aerial triangulation (hereafter AT) (Slama 1980:441-443). In some instances, well-known points that are visible in the photography can be substituted

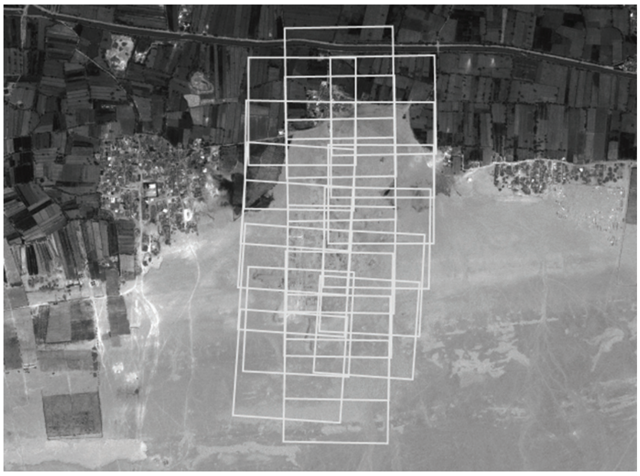

Figure 3. 1935 N-S flight line.

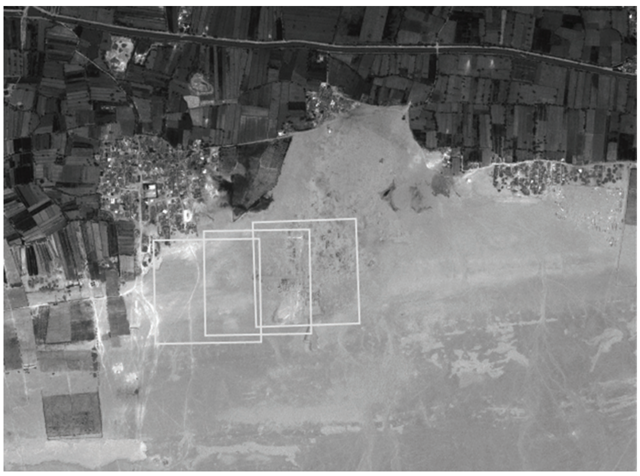

Figure 4. 1935 E-W flight line.

for surveyed ground control (Slama 1980:443-445). In the case of the Tebtunis imagery, no such data exists. Surveyed ground control was not placed prior to the 1934 and 1935 missions and the current condition of the site obscures many of the buildings that were captured in Bagnani's photos. In early 2005, a series of high-resolution QuickBird images (with a pixel resolution of approximately 60 cm) were purchased to provide horizontal coordinate information for the area. Tie points extracted from the relatively few buildings that remain visible, allowed a rough affine adjustment of the imagery covering the central complex and adjacent topography. The aerials located beyond the processional way and sanctuary had insufficient control to be of use in this study. As with the horizontal control, precise elevation data was not available to provide secure control for the site at the time of the excavations. An average ground elevation of 0.0 m was used based on an understanding that the site rests near or slightly below sea level.

A second gap in our knowledge lay in establishing camera parameters for the instrument used in the 1935 mission. Bagnani's notes do not preserve information about the type of camera used in the acquisition of the photographs and it is unlikely that calibration records would still be available for this specific instrument. We were therefore forced to make some educated guesses based on traditional photogrammetric practices. The assistance of Edward D'Sousa and Karl North, a certified photogrammetrist and software developer from Surdex Corporation, was invaluable for this phase of the project. The camera parameters selected for the AT process were those of a standard mapping camera with a 9"X9" film format and 150 mm focal length. The camera parameters and average ground elevation used in the aerial triangulation process were educated guesses and most likely introduced some scaling error in the output data. Although we experimented with different ground elevations in the early stages of the AT process, varying the elevation by increments of 5 m on either side of mean sea level, the results did not visibly improve the quality of the stereo pairs. We did not test alternate ground elevation and camera parameters beyond this initial stage as quantitative improvements in the data could not be verified without accurate ground control data. What was important for our purposes was that the positions (and dimensions) measured from the dataset were internally consistent. While scaling errors are difficult to avoid given the uncertainties in the process, such issues can be corrected easily through a simple scaling to real-world coordinates when more accurate control is acquired.

Using the assumptions described above as well as a series of corresponding image points that were measured on the scanned photos, we were able to produce an AT solution through bundle adjustment in the ImageStation® Automatic Triangulation (ISAT) software package that was mathematically plausible. Further, when the results of the bundle adjustment were exported and viewed, the resulting images exhibited no visible y-parallax. The resulting stereo pairs, therefore, were capable of supporting measurements that were internally consistent, enabling the reconstruction of the site using traditional photogrammetric compilation processes.

2.2 Compilation

Extraction of Architectural Features. Stereo compilation was an absolute necessity not only for reconstructing wall dimensions and elevations, but also for accurately distinguishing walls, columns, and other features from shadow and film distortions. Objects in the stereo window have a sense of mass, height, and other unique characteristics that are not visible when the scanned images are viewed individually. We quickly realized that many of the features that were originally interpreted as walls in the scanned images were actually shadows or low lying debris that did not tie to another feature.

The collection methodology was designed to expedite the accurate collection of architectural features. This phase of the project owes much to the work of Brad Barker of Surdex Corporation, who offered his time and expertise as a photogrammetric specialist to complete the collection of the architectural data. Photogrammetric compilation is time intensive and the type of features and details that were of interest were beyond what is typical for 200 or even 100 scale (1"=200' and 1"=100', respectively) collection. The goal of this study was to understand the wall widths as well as their elevations. These objectives were difficult to attain given the clarity and resolution of the source images. As described above, our images were scanned from contact prints which are secondary products derived from the original film negatives. The prints have greater limitations than the film negatives, particularly in terms of the amount of over scanning that will produce beneficial results in the output images. There is little gained in scanning prints beyond their intended resolution which means that the images, at best, were appropriate for approximately 200 scale collection. The extraction of detailed architectural elements, however, requires a larger mapping scale. For example, the U.S. Army Corps of Engineers photogrammetric mapping guide recommends a mapping scale of at least 1"=10' for archaeological site plans and 1"=40' for general building or structure design (Department of the Army, U.S. Army Corps of Engineers 2002:15-18). To extract the width of walls required the compilers to zoom well beyond the intended scale of the photographs, and therefore well beyond the threshold where stereo preserves its crispness and clarity. Data extracted in this manner would not have created a more accurate product. It also was quickly evident that zooming significantly beyond this threshold to extract both edges of every wall would significantly slow the project's progress. We therefore developed an approach that streamlined the process and avoided a false sense of precision in the output data. Unique feature codes were developed and used to mark walls with widths measuring approximately 0.5 m and 0.25 m. Walls with these dimensions could be easily distinguished by the stereo compilers. A single polyline, with a unique feature code, was collected along the center of the upper surface of each wall (measuring 0.5 m or less). This provided measurements for wall heights based on elevations measured during compilation and an approximate value for wall widths based on the feature code selected.

Walls with widths exceeding 0.5 m were captured as outlines. These larger walls had widths that varied along their length and typically represent load bearing or enclosure walls. It was important to capture these walls carefully to preserve the form and outline of the original structure. We also made the decision to only collect walls that were above the excavated surface level. This assured that only standing walls and not secondary debris was compiled. Likewise, walls were shown as connecting only if they were visibly connected in the stereo window. Our aim was to collect what was visible in the imagery and not what we assumed should be present.

The resulting dataset illustrated in Figure 5 was a network of polylines that captured the centerlines of interior walls and polygon outlines that preserved the form and dimensions of the larger architectural features at the site. A post-processing step was developed to create polygonal features from the compiled polylines. This step was needed to properly visualize the relative dimensions of walls and buildings in a virtual environment. This post-processing step was undertaken within ESRI's ArcView software package. The 3D polylines were exported as shape files and imported into ArcView. An application, developed in Visual Basic, constructed polygon features with correct dimensions from the simple 3D polylines stored in the shape file. This application traces the vertices of a selected line and copies the elevation of each vertex to positions offset perpendicularly from the original point. A left and right offset distance is set by the user to create vertices separated by a distance equal to the wall's width (as described by the attached feature codes). After a wall has been traced in this manner the vertices are strung together by the application to create a true three-dimensional (3D) polygon. This application allowed us to quickly post process all of the walls compiled at the site.

Surface Extraction. A second objective of this study was to understand the relationship between standing walls and the excavated and unexcavated topography of the site at the time of the Italian excavations. This entailed the development of a highly accurate digital terrain model that captured the topography of the site and the excavated depth of room interiors. Additional feature codes were developed to distinguish the architectural features from the breaklines that modeled the ground surface. Breaklines were compiled around the perimeter of the site, providing an elevation that was assumed to model the surface elevation at the time of the Italian excavations. Additional breaklines were compiled throughout the site, with great care taken to capture the observed base elevations along the interior walls of each room and corridor. The elevation of the processional way was also captured in this manner. This provided a model of excavated surfaces throughout the site. The unique

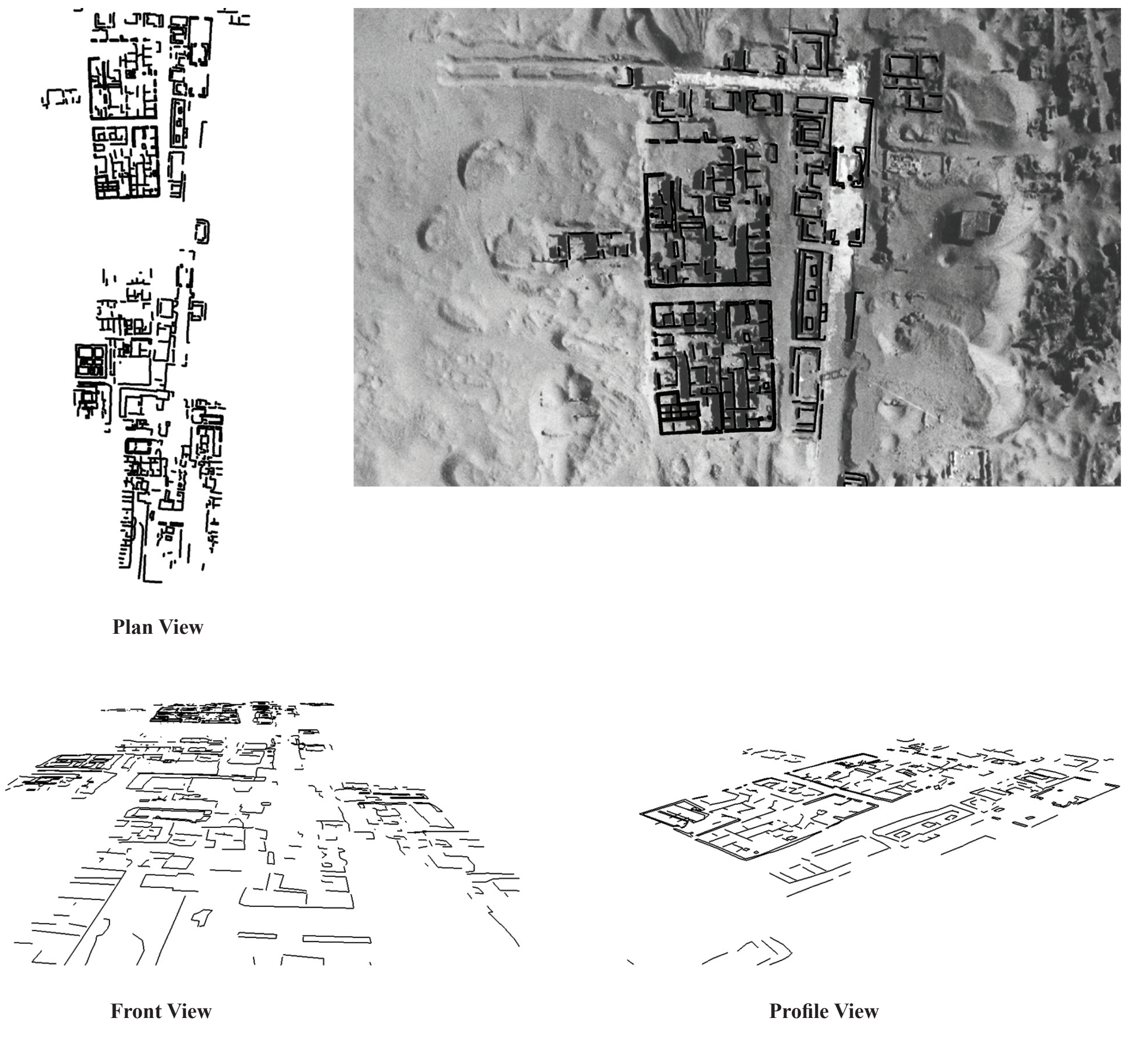

Figure 5. Screen capture showing elevation model and profiles extracted from the digital terrain model.

feature codes used to model the surface breaks allowed us to quickly separate architectural and topographic features. The data has proven useful for both analytical observations and site visualization. Cut-and-fill volumes and sections can be constructed for excavated features. Approximate starting elevations are derived from unexcavated surfaces measured along the site's perimeter. These measures and the model of the excavated surfaces are then input into terrain modeling applications to calculate fill by selected room or across the entire site. An example cut-and-fill calculation and section plan is shown in Figure 6. The sections and volume measurements may be beneficial for future re-excavation and analysis of the architecture and the original excavations.

3 Assembling the Site Model

The terrestrial and aerial photographs, compiled architectural data and digital terrain model are separate but complimentary datasets that document the site and its excavation uniquely. The collection methodology, therefore, was designed to maintain distinctions between each data type so that independent models could be generated to examine different elements of the site and its surrounding landscape. As described above, the digital terrain model documents the site's topography as well as the depth and volume of the original excavations. These data provide a 3D foundation that illustrates both natural and excavated topographies. Architectural features, captured during compilation, compliment this data. The dimensions and elevations of structural elements are documented as 3D polygons. When examined in stereo, walls that join or have similar elevations were distinguished and their elevations captured in the plan. These data have allowed us to better document and understand the configuration of rooms and building units. The terrestrial and aerial photographs have their own advantages. Each provides a visual record of the buildings uncovered during excavation including construction materials and textures. The terrestrial photos are particularly useful since views of building facades are unavailable in the aerial views.

Although there are benefits to examining these datasets independently, it was important to integrate this data within an overall site model. The intent was to understand the site and its topographies as a complete entity. The digital terrain model served as the foundation layer within this reconstruction. A Triangulated Irregular Network (TIN) was generated from the breaklines of the terrain model. Since breaklines are designed to model breaks in slope, they are well suited to the creation of TINs. During the generation of the TIN, triangle edges are forced along the edge of the breaks, creating distinct topographic features that are often obscured in point based models. Triangles were constrained by breaklines compiled along the building interiors, preserving depths along the room interiors and setting these features apart from the surrounding surface (Figure 7). Likewise, breaklines placed along the edge of the processional avenue, the edge of enclosure walls, and at the upper and lower boundary of balks forced the generation of triangle edges at these locations (Figure 8). This approach preserved distinct cultural features that were present within the surface. When draped over this surface, the aerial photography conformed to the underlying features and reinforced the distinctions between natural and cultural surfaces that were apparent in the stereo models.

The 3D polygons were then added to the model and extruded to the TIN surface. Vertices contained with the polygons modeled the height of walls and columns captured during compilation. This provided a 3D model of the architecture that preserved the varying elevation of walls along their length, thereby illustrating their state of preservation at the time of the Italian excavations (Figure 9). A coarse surface texture was applied to the architecture (Figure 10).

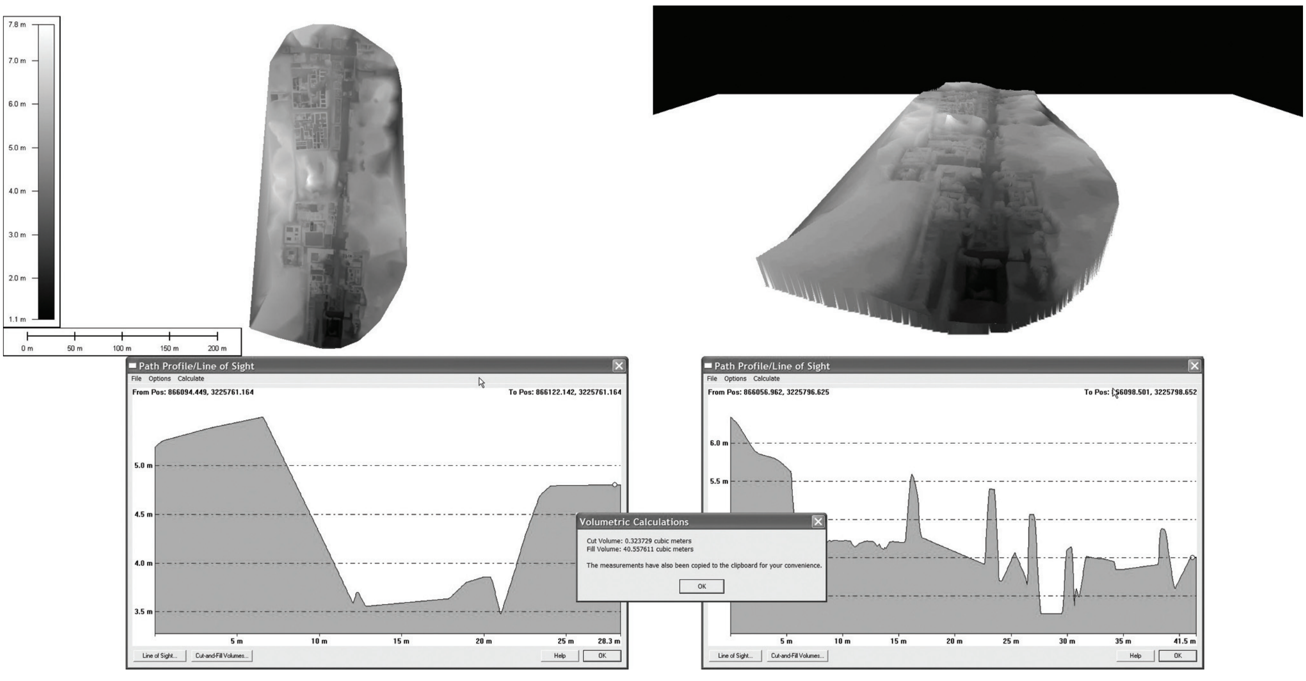

Figure 6. Screen capture with 3D polylines capturing architectural features.

More detailed information about building facades and construction materials will be extracted from the terrestrial photography to further refine the reconstruction and visualization of the architecture.

4 Conclusion

The photogrammetric study presented in this paper represents an initial step in the analysis and virtual reconstruction of Tebtunis. The character and elevation of walls, columns, and pathways have been restored through photogrammetric analysis. Room dimensions, volumetric calculations, and sections extracted from the model provide additional information about the character of the site and the extent of the Italian excavations. Initial examination of the site model suggests that the dimensions and forms of recovered rooms fall within expected tolerances. In most cases, mensurated room dimensions correspond with measurements of extant architecture noted during a preliminary visit to the site in 1999. Measurements along the Z axis, however, maintain the scaling issues noted above. Despite the limitations of the source data, the material from Bagnani's archive has allowed the documentation and exploration of archaeological features and architecture that in many cases no longer exist in the state first observed. Further field visits and examination of terrestrial photos from the original excavation will aid in the refinement of the reconstruction presented in this study and will provide a point of reference for future work and excavation at the site.

References Cited

Slama, Chester C. 1980. *Manual of Photogrammetry 4th Edition.* Virginia: American Society of Photogrammetry.

Department of the Army, U.S. Army Corps of Engineers. 2002. *Engineering and Design Photogrammetric Mapping.* Engineer Manual No. 1110-1-1000. Electronic document. http://www.usace.army.mil/usace-docs/eng-manuals/em1110-1-1000/.

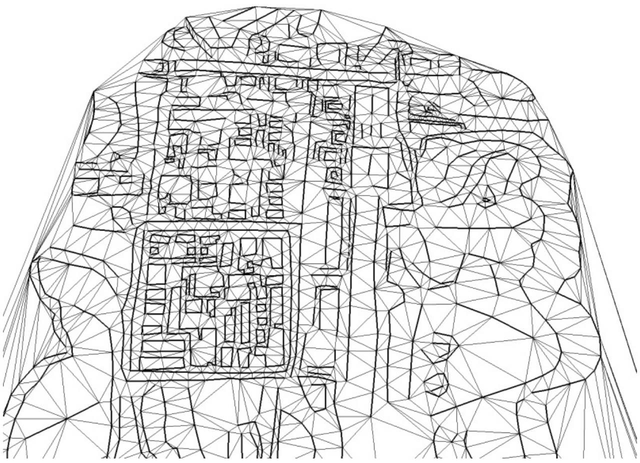

Figure 7. Triangles forming along breaklines.

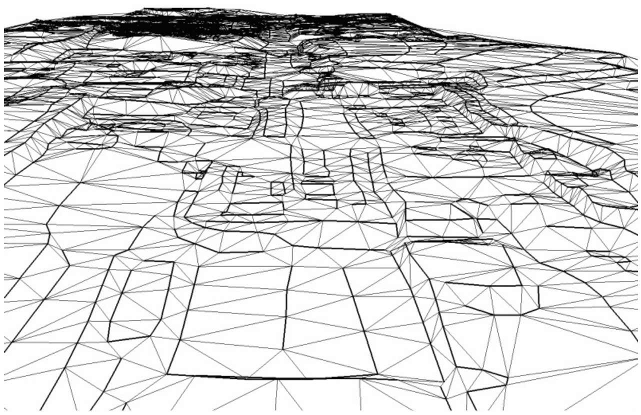

Figure 8. Breaklines captured along room interiors and surface.

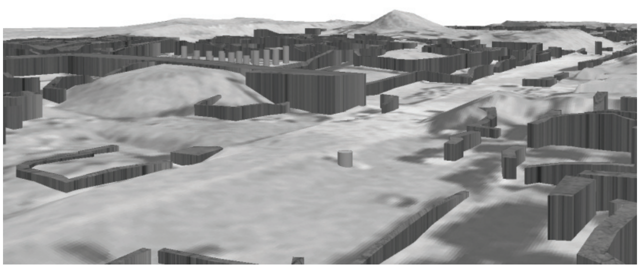

Figure 9. Reconstruction illustrating wall elevations and topography.

Figure 10. Tebtunis reconstruction showing sanctuary and processional way.