Architectural Reconstruction of Tebtunis, Egypt using Photogrammetry and GIS

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Abstract

Excavations conducted at the site of Tebtunis, Egypt, between 1929 and 1935 uncovered numerous architectural features representing more than 1,000 years of 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, a series of overlapping stereo pairs of the site were discovered within the Archives of Gilbert Bagnani at Trent University. The aerial images provide a photogrammetric snapshot of the site as it appeared when fully uncovered during the 1934 and 1935 field seasons. A project to reconstruct the site's architecture using these overlapping stereo pairs and ArcGIS and Stereo Analyst software is currently underway. Architectural details, as well as wall heights, widths, and excavated room volumes, are reconstructed using photogrammetric techniques and GIS software.

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. X 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. Several Coptic churches also were identified to the north-east of the town closer to areas of cultivation.

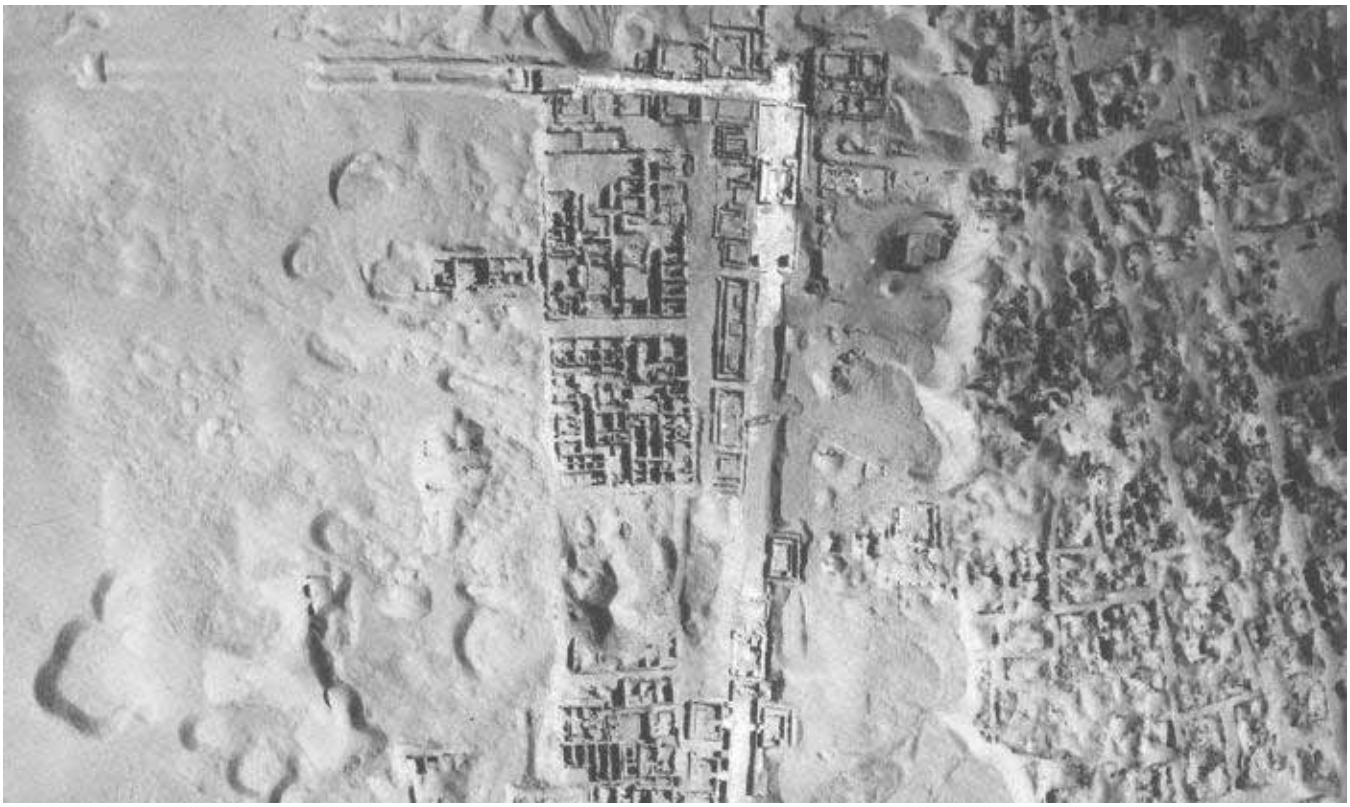


Figure 1.

The results of the Italian excavations were published as brief preliminary reports following the field seasons of 1930 through 1934. Nothing was published for the 1935 or 1936 seasons 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 as you can see in this recent satellite image **(figure 2).**

Figure 2.

Many of the mud brick buildings have eroded or suffered damage following decades of exposure to environmental processes and human activity. Little remains of the grand architecture first uncovered during the excavations of the 1930's.

In 1998, notebooks, diaries, correspondence and photographs dating from the original 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 north-east 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.

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 during 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. The first step in this process involved examining the quality and characteristics of the existing aerials to determine whether they were adequate for stereo collection. 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 twenty two 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 1935 aerials. The first group consists of 19 images flown in three flight lines with a north-south orientation. The average flying height based on the altimeter reading was approximately 1200 ft. 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. A subset of the 1935 aerials was selected for use in this photogrammetric study. The 1934 images, which no longer retain the altimeter readings were not used.

Although the images were collected with adequate overlap for stereo collection and at a flying height appropriate for at least ~200 scale 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). In some instances, well known points that are visible in the photography can be substituted for surveyed ground control. 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 centimeter) were purchased to provide horizontal coordinate information for the area. As you can see in the pan sharpened image of the site **(figure 2)** few of the buildings uncovered during the original excavations remain visible from the air. The buildings at the south edge of the photo are recently excavated structures that were not previously uncovered. 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, there was no available data to

securely determine the ground elevation for the site. An average ground elevation of 0m 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 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 may result in some scaling error. What was important for our purposes was that positions (and dimensions) measured from this dataset be 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 if more accurate control is acquired

Using the assumptions described above as well as a series of conjugate image points that were measured on the scanned photos, we were able to produce an AT solution through bundle adjustment in ISAT (an automatic aerial triangulation 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 were capable of supporting measurements that were internally consistent, enabling the reconstruction of the site using traditional photogrammetric compilation processes.

The work that followed involved the painstaking process of extracting feature information from the stereo pairs. 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 absent in the original scanned images. We quickly realized that many of the features that we 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 features. Traditional photogrammetric compilation is time intensive and the type of features and details that we were interested in capturing were beyond what is typical for 200 or even 100 scale collection. We were interested in understanding the wall widths as well as their elevations, and this level of architectural detail is not typically captured in commercial photogrammetric projects. These objectives were also difficult to attain given the clarity and resolution of the source images. As mentioned above, our images were taken 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 overscanning 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 good for approximately 200 scale collection. To extract the width of walls accurately required the compilers to zoom well beyond this scale, 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 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 A single polyline, with a unique code, was collected along the center of the upper surface of each wall (measuring 0.5m 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 seen in **figure 3** was a network of polylines that capture the centerlines of interior walls and polygon outlines that preserve the form and dimensions of the larger architectural features at the site.

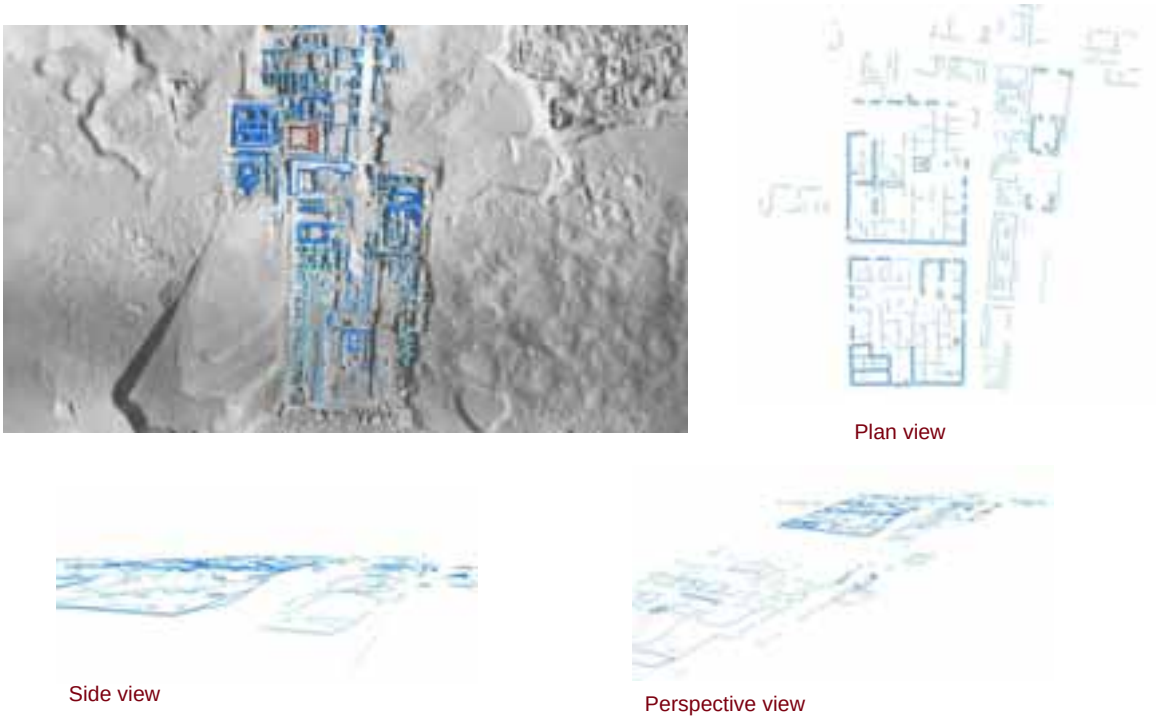
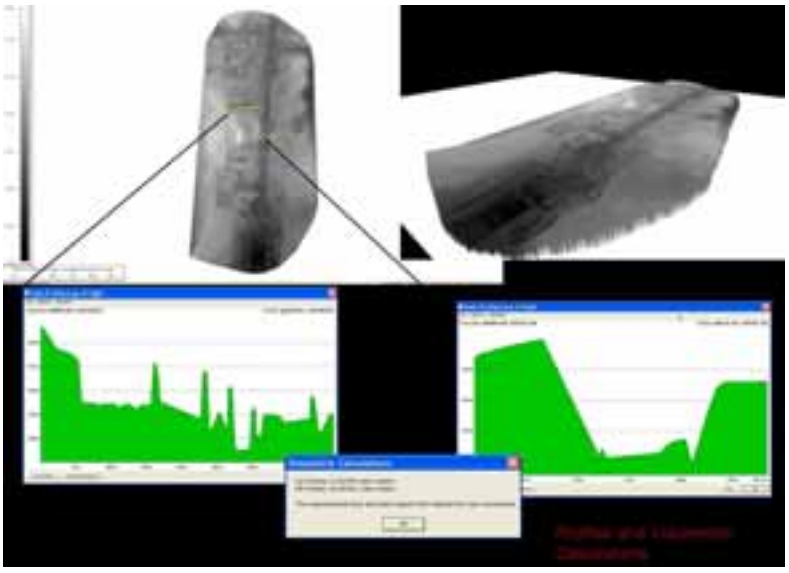


Figure 3.

A post-processing step was developed to create polygonal features from these captured polylines. This step was needed to properly visualize the relative dimensions of walls and buildings in a virtual environment. The 3D polylines were exported as shape files and imported into ArcView 9.1. An application was then developed in Visual Basic to construct polygon features with correct dimensions extracted from these 3D polylines. 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 3 dimensional polygon. This application allowed us to quickly post process all of the walls compiled at the site.

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 site's surface elevation prior to 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 very accurate model of excavated surfaces throughout the site. The unique 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 are being constructed for numerous rooms. 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. Figure 4 depicts just one such volumetric calculation.

Figure 4. 

These measurements may be beneficial for future re-excavation and analysis of the architecture and the original excavations.

The terrain model has been used to create a preliminary 3D visualization of the architecture and topography. In ArcScene, 3D polygons, derived from the compiled wall centerlines and outlines, are layered above the terrain and extruded to the surface of the terrain model, providing a three dimensional view of walls, columns, and site topography that can be explored and queried by the user **(figure 5)**.

Figure 5.

The data compiled through this study is allowing a re-examination of architecture that in many cases no longer exists in the state first observed by Bagnani and his colleagues. The next phase of this study will involve refining elements of the reconstruction presented in this paper.

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