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FROM PHOTOGS TO MODELS: DIGITAL ARCHAEOLOGY OF PRE-HISPANIC PACBITUN, BELIZE

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Introduction

Since its inception in 2008, the Pacbitun Regional Archaeological Project (PRAP) has experimented with an array of digital technologies for more comprehensive documentation and better data presentation than has been possible with traditional recording methods such as hand-drawn maps, photographs, and written descriptions. In this paper, we discuss our use of photogrammetry and virtual site tours. Specifically, we focus on the benefits of this technology for archaeology in a variety of commonly encountered contexts including, architectural and landmark mapping, unit and archaeological feature modeling, rock art identification, and artifact analysis. This discussion is centered on three sites at Pacbitun—Slate and Crystal Palace caves, and the El Quemado structure—and archaeological materials and features associated with them. At Slate Cave, we employed photogrammetry for unit and feature mapping, modeling artifacts, and documenting the only known rock art panel in the Pacbitun region. At Crystal Palace, we used this technique for modeling the entrance chamber, mapping small stone wall terrace features and a vessel cache, and for modeling and illustrating a ceramic bowl from that offering. Lastly, in Pacbitun’s site core, we used it to document the El Quemado structure, a Middle Preclassic period ceremonial structure.

Introduction to Photogrammetry

Photogrammetry is the art and science of obtaining precise geometric measurements of an object, including position, shape, and surface attributes, without making physical contact with them. Traditionally, photogrammetric processes results in three-dimensional, mathematically computed positions using two or more overlapping photographs of a subject taken with cameras located in known unique locations. Early processes required location of cameras and control points within the scene for the aerial triangulation algorithms used to compute model positions. Structure from motion (SfM) is a recent advance in photogrammetry where no
reference information is required, resulting in a relatively unscaled and non-oriented model. Using SfM methods and software, an object is photographed with an overlapping series of digital images from which the software determines the geometry of 3D positions and camera locations (Westoby et al. 2012). A 30 percent overlap in photos is ideal. Models may be subsequently referenced using 3D similarity transformation based on a small number of control points and then exported for further post-processing in GIS, 3D, and graphic software programs.

Photogrammetric and SfM techniques used at Pacbitun can be categorized as Close-Range Photogrammetry, which is defined by an object-to-camera distance less than 300 meters (Mathews 2008). In contrast, Aerial Photogrammetry is typically aviation based and requires ground-control survey and results in highly accurate surface terrain models and orthoimagery. Close-Range Photogrammetry in combination with SfM provides a high degree of flexibility in choice of cameras, camera mountings, photographic techniques, ground-control (if required), and software, making these methods ideally suited to archaeological fieldwork.

Taking advantage of high-resolution digital single lens reflexive cameras (dSLR) capable of producing sharp, high-resolution photographs, producing models with minimal ground sample distances (GSD), or pixel resolution of the object surface is possible. For example, models generated using a 10 megapixel dSLR with a 20 mm lens can produce a GSD less than half a millimeter with a shooting height of 1.4 meters (Mathews 2008). There is a direct correlation between the increased resolution of photographs and GSD of resultant models. With the affordability of dSLR cameras capable of capturing images in excess of 30 or 40 megapixels, producing extremely detailed models with GSD below 0.1 millimeters or even 0.01 millimeters is possible depending on the camera height. While such resolution may exceed requirements of mapping features exceeding one meter, it is of great benefit to artifact documentation, where the resolution allows for modeling of individual temper grains in ceramics and flaking patterns in lithic artifacts allowing for hands-off analysis.

Close-Range Photogrammetry results in a variety of products, ranging from simple 3D models to printed solid models. During the 2016 PRAP field season, we created several photogrammetric workflows to capture 3D data, each of which were determined by specific mapping goals we created for each of the subjects. When illustrating a feature for presentation purposes, we generated unreferenced moderately high-resolution 3D models of the subject. For the most part, we uploaded these models to the senior author’s SketchFab website, https://sketchfab.com/jonspenard, exported them as PDFs, added them as interactive figures in reports, and used them in presentations for conveying a sense of place to the audience (Spenard et al. 2017). With mapping grade models, we produced a low resolution spatially referenced 3D model, which were converted to orthoimagery and elevation models, and used to generate plan and profile maps of individual features. Archival and analytical 3D models are generated in high-resolution and could be used to document artifacts removed during excavations, unmovable or threatened features, and/or objects with fine or complex details. Such models allow analysts to take measurements on the digital object, out of the field, potentially alleviating the need for export permits. The high resolution of this last class of models also permits accurate 3D printing that can provide tangible representations of artifacts for use in the classroom, in museums, or Archaeology Day celebrations, and other public venues.

A second photogrammetric visualization tool, photosphere, was used to create virtual tours of several caves surrounding Pacbitun. Virtual tours, created using linked and spherically projected panoramic photographs, can provide a practical way to convey, scale, feeling, morphology of the environment, and a sense of place, both large and small. Much like Google Streetview, a virtual tour consists of a series of interactive photospheres allowing a user to “look” around the cave and “walk” from one sphere to the next with the click of a mouse. Within each sphere, a user can select hotspots
containing informational text, photographs, close-range 3D models, maps, video, sound, and other media providing details on objects within view.

We created photospheres using a tripod mounted dSLR camera with a fisheye lens. Photographs were taken every 60 degrees at three inclinations (-45, 0, and +45 degrees) as well as nadir. Using panorama software, each set of photographs representing a sphere was stitched together into rectangular images with a spherical projection that appears highly distorted. When loaded into a viewer, the images lose their distortion and provide an accurate view of the subject cave chamber. Photographs were taken with a relatively high-resolution camera resulting in the production of a very high-resolution panorama allowing users to zoom in on details in the scene. In addition to viewing virtual tours on a computer monitor or television screen, tours can be viewed using the stereoscopic headsets such as Google Cardboard viewer or Oculus, creating a more immersive virtual environment. Ambient sounds recorded from the location of the camera can also be added to these tours, increasing the phenomenological sense of place.

We reiterate here, such models are comprehensive photorealistic representations of everything in the environment photographed, including potentially highly sensitive archaeological features such as burials, caches, whole ceramic vessels, rock art, etc. Therefore, great care and attention to preservation and protection must be taken when creating and, especially distributing such models, as they do show exactly where these archaeological materials are located and how to navigate to them. Placing password protections on online models can help alleviate some of that concern, yet hosting websites often retain irrevocable perpetual rights to any models uploaded. For example, Sketchfab, the website we use for hosting models, states in its Terms of Use, Section 4.2, “By using the Services, you grant Sketchfab a worldwide, non-exclusive, royalty-free, perpetual, irrevocable, sub-licensable (through multiple tiers) right and license to use and adapt the User Content for the purposes of developing, distributing, providing, improving, and promoting the Services” (emphasis added) (Sketchfab 2017). Thus, while the archaeologist may use passwords to protect such models from being openly accessible, we cannot guarantee the hosting company will follow suit.

One of the benefits of photogrammetry is that it is relatively cheap, in fact, most of us now carry around with us the basic tools necessary for doing it. For starters, all that is required is a decent digital camera, preferably a dSLR, but it can be successfully executed with a smartphone. For the photogrammetric models in the caves, we used a Nexus 6p smartphone with 12.3 mega pixel camera, an iPhone 7 also with a 12-mega pixel camera and, a tripod mounted Nikon D3000 dSLR. All photogrammetry lighting was achieved with diffuse sunlight or LED video lights placed out of site yet positioned to illuminate chambers in their entirety. This latter technique required a significant time investment, sometimes several hours, for determining the best position for ensuring comprehensive coverage, and invisibility of the light panels. During the 2017 field season, we experimented with placing two, slightly side-facing LED light panels on a dual bracket mounted to the top of the camera as suggested by Dominic Rissolo of the Cultural Heritage Engineering Initiative of University of California, San Diego (Dominic Rissolo personal communication). Employing this lighting technique proved to be a great success and recuperated several hours of the work day for photography and other archaeological endeavours. Since the lights were placed above the camera, shadows were no longer an issue, and the scene was always perfectly lighted for each image captured with only minor adjustments for brightness needed. For the models of the El Quemado structure, we used a Nikon D800 DSLR and diffuse sunlight. For software, we used AgiSoft Photoscan to make photogrammetric models, which runs $550 for an education license, and Pano2VR for the virtual tours, costing $350, a total budget of $900 dollars (US).

We believe one of the common frustrations of archaeology is offering compelling and satisfying descriptions. Due to technological limitations, cave descriptions in the archaeological literature and presentations, are commonly restricted to a few lines noting total length and/or depth, number of chambers,
height of ceiling for each, presence of archaeological features, etc. of the landmarks studied. These narrative descriptions are bolstered with a few representative photographs and a plan view map. Yet, in our experience, we have found that such descriptions lack the ability to truly capture and convey the character of the underground places we investigate. But, with the digital recording technologies such as those we discuss here, we are able to provide a visual aid that brings the caves alive.

**Crystal Palace Cave**

Traditionally we would describe Crystal Palace cave as a collapsed, ovoid-shaped sinkhole with six chambers, each separated by
large collapse boulders or walls of columnar formations (Figure 1). The ceiling ranges from about 1.5 m tall at the entrance, to nearly 8 m tall at its highest. The entrance slopes sharply downward, but the Maya constructed several terraces and low walls, forming a path through the entrance. Beyond the entrance, the cave floor is covered in mud, and several modern stacks of Late Classic period sherds can be found along elevated ledges. Though this may be an adequate overall description, it fails to capture the essence of the cave.

We are currently working on completing the virtual tour of this cave, but we have also spent a great deal of time modeling these features using photogrammetry, which we will be incorporating into the virtual tour once the models are processed. One of those we have processed from the 2016 field season is a five-piece ceramic bowl cache on a newly discovered ledge (Figure 2). Not only do we see the vessels in the cache, but by exploring the model online (https://skfb.ly/6vyYK), the reader can move it around to observe the topography of the ledge, study the positioning of the vessels in relation to one another, zoom in or out onto specific details, etc. We also note here the chamber ceiling is about 0.5 m above the bowls, and is heavily populated with cave formations, but we were able to mask those out, allowing for more unfettered viewing of the entire feature than is possible in reality. Simply put, none of these actions are possible with a simple photograph, a series of them, or plan-view map of the ledge.

In addition to spatial data, this technique can have sub-millimeter precision for reasons discussed above. The model linked above was processed at a low resolution, thus, small details are a bit obscured; nevertheless, if the reader zooms in on any one of the bowls, they can see that the contents of each are topographically modeled. But we can gather even more data from these models. By exporting a model of one of the bowls into a program such as ArcGIS, we were able to produce true-to-form profile of the vessel with sub-millimeter measurements (https://skfb.ly/6vz7t) (Figure 3). It is through this same technique, but at a different scale, that we can produce plan and profile maps of caves and other karst features, and unit profiles, as discussed below.

Returning to the model of the ledge, the reader can see a few of the issues with this technique (https://skfb.ly/6vvYK; see also Figure 2). Notice that all the bowls have large holes in them. These could have been caused by a number of factors, either there was not enough overlapping coverage with the photos, or as is more likely the case, the computer program was unable to find any common points in those areas between the series of photographs, and thus simply could not reconstruct them. This point leads us to another downside of photogrammetry, which is that complex models require a significant amount of computer processing power, in some cases more so than is commonly available in field laptops. This has often meant that all but the simplest models must be processed after returning back home from the field. Thus, any issues with the photography can result in data loss if modeling an excavation or in the case of a surface feature, would need to wait until the next field season to reshoot.

Slate Cave

In Slate Cave, we experimented with photogrammetry in a variety of contexts, demonstrating its utility on multiple scales. This cave was chosen for modeling because it has the only known rock art in the Pacbitun region, a series of simple faces and geometric shapes carved into an active flowstone formation protruding from the ceiling near the cave’s entrance (Figure 4, see also https://skfb.ly/6vvYG). Most 3D viewers allow the user to rake light across the model, and in doing so, we discovered a here-to-for previously unrecognized figure carved into the formation, likely a spider monkey.

As the opening of this cave received ample daylight, and we were excavating in it, we also modeled the floor and entrance area. With these data, we created an orthophoto, digital elevation model (DEM), and hillshade, all of which were used as base layers for a new true-to-form map of the Entrance Area. The photography took approximately one hour, while processing the different maps and drawing the final map took a total of about three hours. A similar hand-drawn field map with equal
Figure 3. Vessel profile produced from 3D digital photogrammetric model of one of the Crystal Palace Ledge 1 cache vessels.

Figure 4. Screen capture of digital model of Slate Cave petroglyph panel. Tags 1-8 show the monkey’s head, left fist, left elbow, tip of tail, right elbow, crotch, left foot, and right foot respectively.
precision and detail of this area would have taken at least a full day in the field to produce. With the ability to draw the map in the lab after the field season, we were able to devote more time to our excavations. As well, a side-by-side comparison of our original hand-drawn map and our new map of this area shows the level of accuracy and detail using photogrammetry is unmatched (Figure 5).

Photogrammetry excelled in mapping unit excavations in this cave. We excavated a pit feature in a low alcove against the cave wall containing a human cranium surrounded by a cluster of bone tubes. The pit was covered by slate and limestone slabs with possible human remains found beneath (https://skfb.ly/6vz79). Each layer and mapped object was documented using photogrammetry in lieu of creating hand-drawn maps. The models were then imported into ArcGIS and these features were digitized into highly precise plan and profile drawings of the feature.

We also used the technique to make a fully navigable model of the entrance area. Such models can be uploaded to software and apps for use with virtual reality goggles, which allow the user to become fully immersed in the scene. Nevertheless, the end product was less than desirable. Many spots in the chamber walls were unable to be reconstructed by the software, leaving large, vacant holes. Moreover, due to changing light conditions as we moved from direct to indirect sunlight, the resulting photographs of the same areas varied in color, leaving the model appearing blurry.

**El Quemado Structure**

Exposed in 2013 beneath the main plaza at Pacbitun, the large ceremonial platform, El Quemado, or Q, has been the primary focus of the site core investigations up to the 2017 field season. Radiocarbon dates indicate the platform was constructed in the Middle Preclassic period around 600 BC and was eventually terminated around the onset of the Late Preclassic period (ca. 400 BC) (Powis et al. 2017). Sealed below marl and dirt filled task units and capped by several plaza floors, El Quemado had been entombed for over two and a half millennia. Excavations to this point have revealed an architectural layout unlike any other documented in the Belize Valley region (Micheletti et al. 2017; Micheletti et al. 2016; Micheletti and Powis 2015). The structure’s pristine state of preservation is likely owed to the severely burned plaster surface derived from either a single termination event or long-term ritual use. Because of Q’s rare architectural form, nearly flawless condition, and buried state, we decided to digitally curate the structure as first exposed. A three-dimensional model of Q will allow us to further investigate its construction methods, structural attributes and features, as well as the unusual method of deposition. A model will also aid those researching early monumental architecture of the ancient Maya and can serve as a visual aid in educational and public settings.

Our first efforts at the digital preservation of El Quemado was in 2013 through the use of terrestrial laser scanning (TLS) (Weber and Powis 2014). While this was an effective method, it proved to be too costly, and thus not a practicable means of annual documentation. As a low-cost alternative, yet just as effective method, we decided to use photogrammetry. In 2015, after excavations had uncovered the south face of El Quemado, project members Jeff Powis and Andrew Vaughan photographed the sub-plaza structure and produced the first 3D photogrammetric model using Agisoft Photoscan software (Vaughan et al. 2016). As the project resumed excavations in 2016, we planned to continue producing photogrammetric models of the newly exposed areas (Figure 6). Our ultimate goal was to add these newly-exposed areas to the model of Q produced in 2015, which could be done by either processing photos in the Photoscan software or by manually connecting each of the models using other 3D processing software.

After the 2016 excavations located and exposed Q’s east and west sides and southern plaza floor, each of these areas were photographed and modeled. To ensure that each model would join together, back dirt was removed from previously excavated areas to re-expose modeled architecture adjacent to the newly exposed 2016 units. Doing so uncovered recognizable features and attributes used to align the previous photos with the new ones. Another strategy we experimented with was creating a photogrammetric modelled path that would
Figure 5. Side-by-side comparison of (a) portion of hand-rendered plan view map of Slate Cave’s entrance area, and (b) plan view map produced from digital model. Note that the maps are oriented in different directions.
Figure 6. Photogrammetric models of El Quemado’s architecture exposed in the 2016 field season (a) east side, (b) west side.

Figure 7. Composite digital model of El Quemado from 2015 and 2016 field seasons.
serve to spatially link each of the 2016 units. This helped to preserve the spatial (orientation and scale) integrity of the separately exposed areas of architecture to aid with the processing. It would also aid in the manual connection should the alignment not work in Photoscan. In this case, any manual processing would be done using the 3D processing software, 3DReshaper. The primary purpose of the 3DReshaper software was to integrate the photogrammetric models with the TLS data acquired in 2013.

After processing each year’s photosets in Photoscan, we were able to successfully align the east edge of Q with the south face model. This was likely due to the re-exposed cut limestone blocks of the south facing wall, photographed in both 2015 and 2016. The only visible issues were minor changes in lighting and soil color. The poor preservation of the summit had also resulted in gaps in the final model. On the other hand, the west edge had completely failed to align due to an insufficient number of photographs in overlapping area. Simply stated, there were not enough recognizable, overlapping points in this area in either photoset for Photoscan to properly merge the two models. Also, while the modelled path linking each exposed area was able to create an accurate spatial layout of the exposed architecture, Photoscan was unable to properly orient the west edge due to the lack of overlapping points.

Although there were only minor issues with the eastern edge and the south face of Q, we experimented with manually attaching each of the models using 3DReshaper. After re-orienting, scaling, and cropping and smoothing edges, each of the models fit together and were able to be merged into a single compound mesh. Nonetheless, minor issues with light and soil coloring, and small gaps in unpreserved areas remained. Although the results were not as detailed and defined as with the model produced with Photoscan, the manually attached model created in 3DReshaper was more expedient and could be physically manipulated (Figure 7).

All in all, with our photogrammetric work of Q, we learned that models from multiple years were able to be reconnected with sufficient overlap between excavated units; however, a more effective approach would be the creation of permanent, completely immobile datum markers the software can use as recognizable points. Moreover, recreating similar lighting conditions over the years, (photos taken during the same time of day, in the shade, beneath tarp, etc.) would allow for the creation of cleaner models.

**Conclusion**

To sum, we have found that photogrammetry excels with small-scale commonly encountered archaeological contexts such as surface caches, rock art, and unit excavations. Producing mapping grade models saves valuable field time, increases map accuracy, and produces moderate quality models that are easily sharable electronically. This ability to share electronically, and online, as we hope to show with virtual tours and photogrammetric models, allows us to bring our work to the public, and make it as accessible to as wide an audience as possible. Additionally, while photogrammetry worked well for modeling settlement architecture, it only fared moderately well mapping cave chambers. Even smaller rooms and chambers required many photographs to ensure proper overlapping, and lighting had also proved to be a challenge initially. Nevertheless, maps with higher detail and precision than are able to be drawn by hand could be created from the models, saving significant field time for other endeavors.

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References


