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Animating Past Places in Time: Applying Close Range Photogrammetry to 4D Stratigraphic Excavation Data

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Animating Past Places in Time: Applying Close Range Photogrammetry to 4D Stratigraphic Excavation Data

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Abstract:

The complexity of the ancient modified landscapes of the Classic Maya of Mesoamerica demands unique mapping techniques for documentation, interpretation, and presentation for field projects in this densely-forested environment. In the past, numerous methodologies have been carried out in archaeological documentation to better define ancient settlement patterns and localized occupation through conventional excavation and topographic land surveying. The following paper highlights a new method of documenting complex land modifications, architecture, and ritualistic deposits at the commoner site of Chawak But'o'ob in northwestern Belize. By applying close range photogrammetry, 3D modeling, and animation methodologies to topographic survey data, the authors propose an integrated 4D archaeological documentation technique. Compared to conventional recording methods which require meticulous hand-measured and hand-drawn records, this new strategy will increase the efficiency of field investigation and the precision of its documentation for post-fieldwork analysis and dissemination.

1. Introduction

Data recording and documentation are among the most important components in archaeological investigations. Thanks to recent advances in photogrammetry, computer vision, 3D object modeling, animation software, and CAD mapping, archaeological projects can enhance both the accuracy and detail of recording cultural heritage data, which facilitates interpretation and presentation, while reducing the cost and time required in comparison to previous methods. The following paper will highlight the results of implementing these multiple methodologies at an archaeological site located in a protected, tropical rainforest in Belize. The environmental conditions and conservation area location are two crucial variables which will also be discussed.

Two excavations conducted during the 2013 field season were recorded with straightforward photography methods following the completion of each lot or significant stage of excavation. Highly-detailed, quantifiable 3D models were then created with photogrammetry software and imported into modeling software for data processing. These scaled lot models were then united and used to create an animation which illustrates the excavation process through time by both highlighting important features and fading through each stratum. Compared to conventional recording methods which require meticulous hand-measured and hand-drawn plan and wall profile drawings, this strategy will increase both the momentum of investigation and precision of its documentation. Moreover, traditional recording methods cannot provide the precision, depth, and color-coded representation for post-excavation analysis, interpretation, and presentation which a photogrammetric workflow can deliver.

2. Study area

The site of Chawak But'o'ob, an ancient commoner farming community, is located on the face of the Rio Bravo escarpment two kilometers from the ceremonial center of Dos Hombres in the Three Rivers Region [1], as shown in Figure 1. Archaeological investigations at the site have been carried out since the mid-1990s by Stanley L. Walling as part of the Rio Bravo Archaeological Survey (RBAS) and the Programme for Belize Archaeology Project [2].

The site covers an area of about 1 kilometer north to south across a 450-meter wide escarpment that climbs from the floodplain, east to west. Archaeological evidence indicates a dense, yet short, occupational history during the Late Classic period (600-850 C.E.), most likely centered on the eighth century. Population density has been calculated to more than 2000 inhabitants per square kilometer at the site, which represents a 200% population density increase over average figures for the same period in the surrounding region [4]. Surprisingly though, Walling et al. [5]

Figure 1. Three Rivers Region with site location highlighted (modified from Garrison [3], Figure 2)

have found a very low density of material remains, which along with other evidence, suggests its inhabitants were economically-limited, commoner agriculturalists. Over the course of investigations, unusual, even unique architectural and cultural remains have been discovered at the site, which provides new evidence regarding the complexity of Classic-period Maya commoner life and how ancient commoners fostered a distinct identity within the cultural landscape of the Three Rivers Region of Mexico, Guatemala, and Belize [6].

The Classic Maya concept of landscape is directly related to the holistic approach archaeological investigations must take to mapping and modeling for posterior analysis. Although it is beyond the scope of this paper to consider in detail, the prevailing view within the discipline is that the Classic Maya had a complex, inclusive, multi-layered relationship with the natural and artificial landscape based on pragmatic and ideational factors. This relationship extended from the humble domestic structures they built to the large hydrological land modifications they employed [7,8,9,10,11]. Consequently, since the Classic Maya perceived their environment as an interconnected system, archaeologists must record not just the architectural features, but the modified landscape features and natural topography as well because they must all be documented and interpreted as one large dataset [12,13,14]

This archaeological project operates within the Rio Bravo Conservation Management Area (RBCMA), the largest private reserve in the country of Belize, which is directed by the non-profit organization Programme for Belize (PfB). With an area of over 1000 square kilometers, the RBCMA is host to one of the most bio-diverse protected areas in the country. Archaeological sites within this area are palimpsests of natural and anthropogenic deposits, with many of the latter severely altered by a millennium or more of natural processes. Within this context, archaeological investigations must abide by strict regulations of conservation to promote cultural and natural heritage preservation.

Finally, the importance of environmental conditions for archaeological fieldwork is a crucial factor that determines the rate of investigation and documentation. Periodic tropical storms can inundate excavations in progress, which can modify the context of recently exposed cultural materials in situ. Therefore, photogrammetric documentation also provides archaeologists with a tool to quickly record data. This benefits both the preservation of cultural remains as well as the recording accuracy of the field project.

3. Excavation data recording

RBAS excavation data recording reflects the step-by-step procedures from the project's comprehensive field manual [15]. Stratigraphic excavation, based on following the artificial or natural soil layer contours, or strata, is carried out by an excavation team of four or fewer people. Each stratum is given a lot number and corresponding lot record form which is used to record soil types, descriptions, observed and collected materials, illustrations, and opening and closing elevations.

The team uses line levels, plumb bobs, folding rulers, and graph paper to produce schematic lot profiles and plan view maps. The results are detailed but the entire process is very time-consuming, especially in tropical conditions. Moreover, this procedure is executed based on field observations at that time and the team's initial interpretations. Therefore, photogrammetric recording was tested during the 2013 field season in order to both enhance excavation documentation and reduce tedious strategies.

Digital SLR cameras were used to capture photos from multiple stations throughout the duration of excavation at a number of units to test the hypothesis of incorporating photogrammetric documentation on the project. Several staff members, using different cameras, which were not previously calibrated, took photos following basic instructions to record each stratum. It's important to note that none of the photographers had any previous experience with photogrammetric recording. Two of the excavation operations were used as case studies to evaluate the practicality of utilizing this method in future fieldwork and, most importantly for this paper, to illustrate how a 4D representation can easily be produced to document cultural remains during archaeological excavation.

3.1 Structure H-8, OP142-W

This excavation was carried out under the supervision of Christine Taylor, the Director of Ballcourt Complex Investigations at the site. It was done to assess the characteristics of the structure which is located near an unusual hydrological feature. An excavation unit of 2.5 m by 1 m was positioned to traverse the northern side of the structure. Photographs of the unit were taken at a variety of angles upon the completion of each lot over several weeks. Unfortunately, after the field season was completed, a number of photos were unusable due to focus or coverage. However, when the photos were processed, the amount and quality of the remaining photos proved sufficient to produce dense point clouds and 3D textured models.

3.2 Structure B-48, OP141-N

This 4 m by 1.5 m operation unit, which was initially excavated in 2007, was reopened in 2013 under the field supervision of Jonathan Hanna, the Director of Residential Terrace Investigations at the site. It was situated to investigate the southern portion of a stairway. During investigations in 2007, a "possible ceramic mask fragment and a fragment of a small round-cheeked anthropomorphic bowl" [16:3] were discovered in the northwestern section of the unit and shown in Figure 2.

Figure 2. Anthropomorphic bowl fragment (Walling et al. [16], Figure 3. Photo by Bruce Templeton)

Due to the discovery of significant cultural material in 2007, it was decided that the resumed excavation in 2013 would be an appropriate context in which to test photogrammetric recording. During the investigation, an unusual collection of material remains were retrieved including a mature Conch shell, obsidian, chert, and ceramic artifacts. Moreover, their disposition has been interpreted by the excavator as representing a reoccurring cultural theme found at a variety of scales and locations in the Maya region, the quincunx [17]. A large number of photos were taken from a variety of angles and stations over the course of excavation.

4. Data processing

4.1 Agisoft Photoscan

Upon the completion of the 2013 field season, all of the photos were organized and imported into Agisoft Photoscan [18]. The photos from each stratum of OP142-W and OP141-N were grouped together in separate chunks for each station, which were taken from different orientations around the unit. Each chunk was then aligned and produced a dense point cloud. A greater variety of angles and stations was accomplished for the OP141-N unit. Next, 3D meshes were created for each chunk independently to help identify areas of the object with scarce coverage or erroneous data. The final procedure was the creation of orthophoto textures for each associated mesh

4.2 Meshlab

Following the creation of 3D models with Photoscan, each model was then imported into MeshLab [19] where the Fill Hole feature was used in only a small number of instances. Subsequently, using the Align tool each stratum was aligned, but not combined, to their corresponding excavation unit. The final aligned models were then exported independently.

4.3 Blender

Finally, each stratum model was imported into Blender [20]. This freeware software package was chosen due to its flexibility in terms of modeling capabilities and animation production. With each stratum aligned to the others of the same excavation unit, the ability to fade consecutively from each stratum to the next, thereby reproducing the excavation procedure, was realized with the manipulation of the Alpha Transparency variable. The last step was the addition of a camera to produce the rendered model as an animation with text labels.

4.4 Results

OP142-W was the first excavation where this procedure was employed, as shown in Figure 3. As shown in the following figures, which are screenshots of the final animation, the operation of bisecting the structure wall is clearly illustrated in two images. Figures 4 and 5 display the remains of the structure wall as it was originally constructed on the bedrock. Due to fluctuating environmental conditions during the field

Figure 3. Rendered view of OP141-N unit in closing lots, north is up (Original photos by Christine Taylor)

season, the light source was irregular when photos were taken. This is apparent in the color difference observed in Figures 4 and 5, which was later corrected by using the Match Color tool in Adobe Photoshop [21]. Finally, Figure 6 demonstrates the wall after it was bisected during excavation.

Figures 4 and 5. OP142-W animation screenshots of structure wall with original and color-matched mesh (Original photos by Christine Taylor)

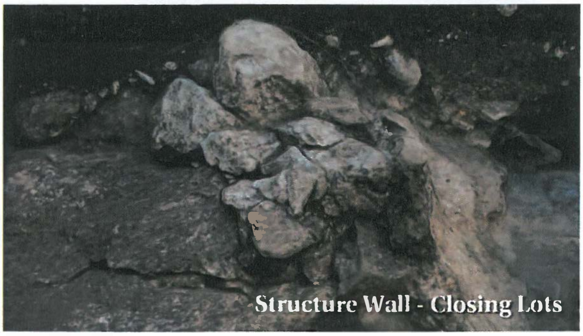

Figure 6. OP142-W animation screenshot after bisecting structure wall (Original photos by Christine Taylor)

This procedure was then repeated and augmented for the larger OP141-N unit. Upon first inspection of the textured strata models in Blender, it was determined that a complex, data-enriched animation was required to best illustrate the 4D excavation process for presentation purposes. Due to the large file sizes of the 3D textured modes, a set of two strata models per file where imported together to create separate scenes of the complete animation. Finally, a combination of new features were added to this animation including freeze frames, zooming in to features as in Figure 7, displaying photos of recovered cultural items, contextual text descriptions, and multiple transition steps of the 3D strata models as in Figures 8 and 9. Finally, as illustrated in Figure 10, due to the special Conch (Labutus gigas) feature identified during excavation, the lot dimensions were subdivided, which added additional steps for the strata transition in the animation.

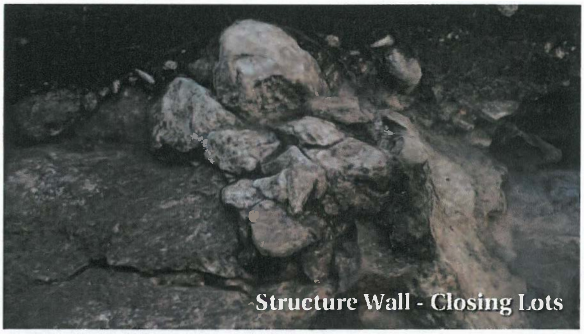

Figure 7. OP142-W animation screenshot at 3:12, north follows scale to right (Original photos by Jonathan Hanna)

Figures 8 and 9. OP142-W animation screenshots at 3:46 and 4:10 (Original photos by Jonathan Hanna)

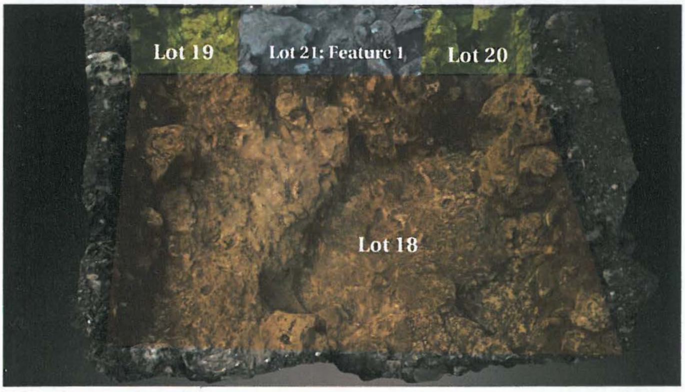

Figure 10. OP142-W animation screenshot at 2:36, north is right (Original photos by Jonathan Hanna)

Imperfections in the final animations were caused by a number of factors. One was the placement of north arrows or a photo board in various locations at different times of photo acquisition as shown in Figures 8 and 9. The resulting juxtaposition occurred when multiple strata models are aligned during data processing. As mentioned previously regarding OP142-W, since the photos were taken at different times with the light source and environmental factors influencing color, some of the textures of the strata models didn't exactly match the others during animation transition. However, these issues will be taken into consideration in future investigations. In general, the integration of the multiple 3D models into animations has established the foundation for further development of 4D excavation documentation.

5. Conclusions

Archaeological excavation is by its very nature destructive and can only be done once. Therefore, as researchers of cultural heritage, we are obligated to balance conservation with investigation when documenting, interpreting, and presenting our findings. When new developments arise which benefit this equilibrium they must be rigorously tested for their overall potential impact. Photogrammetry, 3D/4D object modeling, and animations are quickly becoming more widely-implemented in the field of archaeology [22,23,24]. As a result, this paper has aimed to evaluate these new applications for economically documenting excavation with close range photogrammetry.

Such an evaluation is appropriate given the trend toward improved recording in archaeology, which occurs at a time of increased loss of physical cultural patrimony around the globe due to environmental degradation, looting, and development, among other factors. In this regard, close range photogrammetry takes its place next to laser scanning as increasingly being used to record ancient remains in their original context, often shortly before they are removed or otherwise altered. In addition to factors of economy and detail, this technique has the advantage of being done in most instances by the investigator himself or herself, the person most familiar with the material being recorded and its historic importance.

As a follow-up to this last point, it should be noted that the photos were taken without the attendance of the corresponding author, who was the one responsible for processing the data upon the conclusion of the field season. Although this is not the optimum scheme for close range photogrammetric recording, it is significant because it proves that photos can be used which were taken without preplanning for photogrammetric purposes. A significant point here is that photos taken during past fieldwork programs can potentially provide archaeologists with new, supplementary data. For example, the following 3D model shown in Figure 11 was created with only four photos taken at the conclusion of an excavation in 2012, before photogrammetry was ever considered to be utilized on the project.

Figure 11. Cave 2 Entrance Extension, OP142-T (Original photos by J.N. Stanley)

Photogrammetric modeling an excavation has many advantages as previously illustrated yet one of the most important factors is the accurate measurements that can be made once the data has been processed. Archaeologists now have the ability to measure objects in 4D space after the completion of excavation as illustrated in Figures 12 and 13. The power to reconstruct an excavation from the very beginning with such a great degree of precision promises to be invaluable for future archaeological projects. Moreover, photogrammetric documentation at this site is ideally suited to the broad scope of world cultural heritage preservation. Not only does it provide archaeologists with the ability to ideally record as much data as possible during the destructive process of excavation, but long-term application of this workflow decreases the time and, consequently, the cost of fieldwork.

6. FUTURE WORK

The next step to take in 4D documentation and modeling is to visually highlight significant cultural objects, debris, and construction material in 4D space. For example, construction phases of architectural remains can be illustrated and used for interpretation and presentation as recently demonstrated by software such as TeleArch [25]. The 3D models generated from photogrammetry will also provide the base model for later work in reconstruction designs of how the object or architecture may have looked in the past, offering multiple theorized models.

Figures 12 and 13. Top view of rendered 3D models of OP141-N (Lot 17 and 21-22) (Original photos by Jonathan Hanna)

This form of archaeological documentation can be expanded on by multiple techniques. First, photogrammetric documentation of an excavation should start before the first trowel strikes the ground. Surface features on and within the proximity of the unit should be well documented because excavation results may be prudent in later interpretations. In densely-forested environments, for example, small structures or modified landscape features only become apparent after clearing the area of investigation as witnessed in Figures 14 and 15. Moreover, photogrammetric acquisition before excavation presents another opportunity to preserve the original cultural heritage data as well as document minute topographic changes that may be useful in hydrological considerations. These 3D models can be used as the principal data to situate all posterior models of each stratum as shown in Figure 16.

The following protocols will be considered for the next field season. Project members will be introduced to photogrammetric excavation recording to better understand how to take appropriate photos for processing. At least four ground control points will be recorded with a total station to connect the data to the site's survey network [26]. Finally, a cloud storage system will be utilized for all project participants to upload photos at the conclusion of the field season as the utility for them may be useful, however not obvious yet, to provide 3D/4D documentation in the future.

Lastly, two routes of development for this project are currently being investigated. The first is an automated workflow to accelate the management, processing, and classifying of these 4D models. While at the same time, in order to broaden both the functionality and adaptibility of this system for archaeological investigations of spatial features, future work must be accomplished by using the MayaArch3D project of Copan [27] as an exemplary framework of integrating a GIS database into a virtual research environment with the Unity3D [28].

Figures 14 and 15. Before and after clearing vegetation on structure, note position of north arrow and measuring rod in each photo (Photos by Stanley L. Walling)

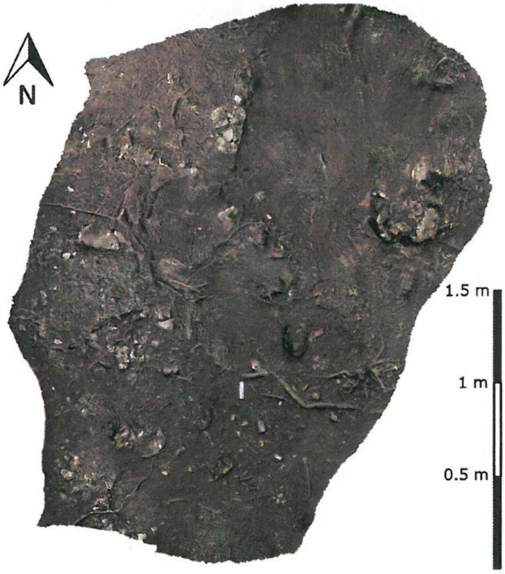

Figure 16. 3D model top view of theorized hydrological feature for future investigation (Original photos by Chance Coughenour)

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