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Using Virtual Reality and Remotely Sensed Data to Explore Object Identity and Embodiment in a Virtual Mayan City

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USING VIRTUAL REALITY AND REMOTELY SENSED DATA TO EXPLORE

OBJECT IDENTITY AND EMBODIMENT IN A VIRTUAL MAYAN CITY

By

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3D visualization, LiDAR (Light Detection and Ranging), and 3D modeling are not new concepts in archaeology, however when combined they represent a growing body of research that seeks to understand both how these tools can help us to study the people of the past, and the past itself. Recently, archaeologists have been creating large amounts of 3D digital assets because of new and more advanced technologies. Along with these digital assets has come a myriad of single object viewers—both web and desktop based. These platforms specifically focus on visualizing individual objects (i.e., artifacts or buildings). In contrast, 3DGIS and Virtual Reality (VR) software employ recreated landscapes with multiple 3D objects rather than single 3D models. The MayaCityBuilder Project (http://mayacitybuilder.org) employs Geographic Information Systems (GIS) and LIDAR data to simulate the ancient Maya city of Copan in a virtual space for immersive exploration. Using this environment as a virtual lattice, we embed object data into the actual simulated space of Copan, which users can explore using a virtual reality headset. I propose that such an environment allows us to explore the concept of object identity. Wherein the "objects" in the environment (i.e. 3D models of both remotely sensed extant objects and reconstructed buildings) are immersively evaluated by users who can better perceive the relationships between themselves and the "objects" with which they are interacting; resulting in insights that can push archaeological inquiry in new directions. Further, applying such an approach opens the door for 3D data reuse providing a platform that serves a unique database structure holding intuitive and perceptual data. In order to test these ideas, I embed multiple kinds of 3D models into the Copan VR platform and use the relationships between both the environment and the objects to explain object identity.

ACKNOWLEDGEMENTS

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Chapter 1: Introduction

1.1. 3D Visualization

The first references to Virtual Archaeology began in 1990 in response to the concept of using 3D computer animations and models of ancient structures and spaces (Barcelo, 2000; Reilly,1990). The quickly growing fashion of using these visualizations as a draw for public and academic eyes alike spawned a very "generic" and sometimes inappropriate use of the term Virtual (Barcelo, 2000). Virtual archaeology, according to Barcelo, requires literal stimulation of the human senses that results in immersion by the program in question. As Forte (2016) describes, there is a clear delineation between platforms designed to position the participant as a relatively static observer, and platforms that afford interactive immersion (Forte, 2010; Forte, 2016). Forte contends that truly immersive and interactive programs enter into the realm of "cyber-archaeology", a discipline requiring the active role of cognition, and leave behind the less acted upon "virtual-archaeology" (Forte, 2016).

Early virtual projects in archaeology tended to focus on creating representations of space that acted like physical reconstructions in a glass display (Barcelo, 2000; Forte, 1997). These computer-based models were heavily criticized for their artistic rendering of archaeological objects, features, and landscapes, as well as their disconnection from the viewer, which was seen as antithetical to a realistic approach to a new archaeological discipline (Barcelo, 2000; Gillings, 1999; Miller & Richards, 1995; Pietroni, 2016; Pujol, 2004). These digital spaces developed into detailed simulations of archaeological spaces generally depicting topography and terrain in ever increasing accuracy with modeled structures populating the terrain. Despite an uncertain beginning, "virtual" explorations

have developed into an invaluable tool for experiencing immersive environments and exploring spaces derived from both real data and interpreted simulation (Barcelo, 2000; Forte, 2016; Richards-Rissetto 2012).

1.2. Embodiment in Visualization

The use of data, acquired through a practice, very generally referred to as remote sensing, in virtual environments has perhaps increased the realistic sense of place that these environments possess but without immersion they still lack an interactive component. In this thesis, I refer to "remote sensing" or "sensed" data in relation to information acquired about an object or the surface of the earth without physically engaging it (Schott 2007). This term, used here, exclusively refers to data acquired through satellite imagining, LiDAR, terrestrial laser scanning, and photogrammetry. In contrast to remotely sensed data, I refer to "simulation" or things that are "simulated" and this concept denotes any 3D objects or images that are derived from archaeological interpretations of past environments. For example, most ancient Maya structures exist as unexcavated mounds; however, we use various lines of data such as maps, test excavations, and comparison to extant structures to create 3D structures that we situate within their larger spatial context using topography and other mapping data. The remotely sensed data often serve as base models for virtual simulations of landscapes and cities.

Cognition, or the creation of knowledge, requires the action and experience of a lived body (Bruner, 1962; Forte, 2016). Embodiment refers to the cognitive use of "embodied action" in our memory and experience (Csordas 1990; Gibbs 2005). Meaning

that the way we perceive our bodies in action reflects on how we experience the world (Gibbs 2005). In archaeology, action refers to the practice of archaeological interpretation involving the physical presence of archaeologists in the field, lab, or otherwise, who experience objects and features as part of, and yet independently from in their surroundings, for example, an archaeological landscape. The ways people process, input, and respond is unique among individuals based on background, expertise, cultural affiliation, and more as well as technology.

In archaeology, new technologies are affecting every aspect of the discipline from excavation to lab and archival analysis as well as interpretation and dissemination, which reflects a meaningful change not only in how the practice is carried out but importantly in the experiences of practitioners (Forte, 2010; Forte, 2016). The push for an experiential component of the newly available 3D visualizations in archaeology has sparked a surge of digital projects aimed at presenting digitally collected, for example, using laser scanning or photogrammetry, and "born" digital data that has no physical counterpart in 3D environments. However, rather than presenting more static demos for virtual environments that offer a single interpretation of the past environment, scholars are using remotely sensed data to build virtual worlds that are both interactive and immersive (Richards-Rissetto 2015; Richards-Rissetto 2017). Digital initiatives such as the DARKlab (Digital Archaeology Laboratory) at Lund University, which promotes the study of archaeological sites using combined 3D data tools (Buckland 2018; Dell'Unto 2013; Demetrescu 2016), or the DiVE-CAVE at Duke University, uses VR and multi-platform 3D analysis to explore sites and reconstructed environments (Forte 2015; Forte 2016), bring embodiment to the foreground and stress the necessity for interactive

systems. Such embodiment stems, in part, from the critical role of the first-person participant, which, frames the world as not separate from users like in a conventional computer display. Instead, participant's perceptions develop through an interactive and immersive experience that can closely approximate the real world, evoking multiple senses through sight, sound, movement, and even haptic touch. The use of virtual reality headsets (e.g., Oculus Rift, HTC Vive), which use head tracking and magnified compact displays to immerse the user in a pseudo-physical space, have elevated the potential for virtual projects in archaeology allowing much more intensive and interactive immersion that translates to embodiment (Chessa 2019; Desai 2014; Forte 2016).

In this project, I place a user in the virtual space as a mobile observer, responsible for their movement, interaction, and interpretation of the environment. They can enact embodiment of the space through their movement, not necessarily via actual walking, but rather via head-tracking, gesture-based interaction (with or without controllers), and spatial sound. The virtual environment provides an embodied experience that evokes multiple senses similar to real-life. This interactive immersion into an embodied space is leading to alternative perspectives resulting in a new cognizance of place and personal presence not available in other digital tools (Champion 2010; 2012; 2016).

1.3. Cyber Archaeology and Virtual Space

Only relatively recently has it been possible to combine large amounts of quantitative data with platforms for visualization due to incompatibility of data formats (e.g., proprietary formats) and large files sizes (particularly of remotely sensed data)that conflict with the infrastructure and power the platforms trying to integrate and use these

data (Limp 2016; Richards-Rissetto 2017). With changes in technology, allowing for the integration of more diverse and larger data sets, scholars across disciplines can create much more intricate virtual spaces in which the physical reality of our observed world is set into virtual space like a cornerstone, guiding the design and development of virtual environments to afford higher levels of realism in a previously abstracted medium.

Recent capability to create vast (spatially expansive) virtual worlds has sparked efforts to populate these environments with greater numbers of archaeological artifacts and buildings within natural and built landscapes or archaeological spatial contexts (Dylla 2008; Frisher 2008; Richards-Rissetto 2018). Using new programs like CityEngine (a program for procedurally modeling structures in a 3D dataset using GIS data), projects like MayaCityBuilder or "Rome Reborn" can rapidly generate urban environments within the bounds of predetermined parameters (Dylla 2008; Frischer 2008; Richards-Rissetto 2018). Integrating these georeferenced models (i.e., with real-world spatial reference) into virtual programs collides reality and realism. On one hand, archaeologist reconstruct past (ancient) environments from archaeological data derived from analog (often legacy) data and digitally acquired remotely sensed data (reality); on the other hand, archaeologists often add non-extant features and aesthetic details (such as color) to reconstruct the ancient environment that provides a sense of realism, and yet introduces various levels of uncertainty. However, adding realism to the virtual environment creates a greater sense of past place and enriches embodied immersion increasing analytical functionality since the models and environment are representations of real data (Barcelo 2000; Kantner 2000; Dylla 2008; Frischer 2008; Richards-Rissetto 2015; Forte 2016).

Using this paradigm, I contend that we can explore a concept I call "Object Identity" wherein the models that populate an immersive setting can be evaluated perceptually and understood by their relationships to other perceived things. The "things" that are tied to the models I incorporate include other remotely sensed or simulated models (standing objects like structures and sculpture) including the environment itself, which is this case study results in a virtual environment of the ancient Maya city of Copan. This project has three main components: pedagogical, methodological, and theoretical. First, project explores pedagogy because the recording of data, in part, was a part of a teaching effort. The main objective of fieldwork was to instruct students in the use of photogrammetry, and thus the objects selected, i.e, individual remotely sensed 3D models, were constrained by teaching and conservation efforts. Second, the project focuses on methodology, and represents the main emphasis of my research. I needed to modify existing methodologies in order to make 3D models and develop new methodologies to use these models in unique ways in a virtual space. Finally, the third component is theoretical and examines the utility of VR as a tool for exploring the concept of Object Identity, how it relates to archaeology, and how we could use the concept along with new technical innovations for innovative applications.

Chapter 2. Case Study: Copan

2.1 Copan, Using Archaeological data to visualize an Ancient City

The case study is the Ancient city of Copan, located in the Copan Department of modern day Honduras. Copan, in an ancient context was a hub for a Maya kingdom situated in the southeast corner of the Mayan world (Bell et al. 2004). Today, Copan is a

UNESCO world heritage site that represents a vital cultural resource for Honduras that attracts national and international scholars and tourists. Previous research from the MayaArch3D (http://www.mayaarch3d.org/language/en/sample-page/) and MayaCityBuilder (http://mayacitybuilder.org) Projects provided many of the data for the case study, specifically GIS data and a reconstructed virtual environment (simulation) of late eighth-early ninth century Copan.

The city of Copan contextually comes of age for us beginning with the reign of Yax K'uk' Mo' (Ruler 1) 427-437AD, who began an overhaul of the cities structures and a dynasty of 16 rulers that would span over four hundred years (Fash 2000; Sharer 2006). This line eventually ended with the reign of Yax Pasaj, 763, whose cultural influence included a major renovation of Copan's main civic-ceremonial precinct (the Principal Group)—the last at Copan and is what exists today at the site (Fash 2000; Richards-Rissetto 2017). The Copan VR program visualizes the city at this time period (late eighth century) and just before the decline of Copan's influence during the early ninth century (Fash 2000; Richards-Rissetto 2017).

The primary goal of the digital projects surrounding this thesis namely, MayaArch3D and MayaCityBuilder, is to use (and develop) 3D tools and virtual environments to understand ancient Maya landscapes and interactions in Maya civic spaces (Richards-Rissetto 2014; 2017; von Schwerin et al. 2013). Additional goals include using such technologies to explore concepts such as 3D data use and reuse, sustainability, innovative infrastructures, and now, as examined in this study, object identity. MayaArch3D provided the 3D data required to map and reproduce the Copan

valley terrain, and MayaCityBuilder utilized, and built upon, this data to construct the modeled city structures, vegetation, and urban centers.

2.2. MayaCityBuilder

Specifically, my research is a part of the MayaCityBuilder project (http://mayacitybuilder.org/) that uses multiple data types, software, and platforms to build a 3D architectural library of ancient Maya architecture along with infrastructure schema to investigate landscape, social interaction, and ritual performance in ancient Maya cities (Richards-Rissetto 2014; Richards-Rissetto 2017; Richards-Rissetto et al. 2018). Currently the project has created the Copan VR environment by combining post-processed airborne LiDAR and GIS data with legacy data from published sources and unpublished materials from archives at the Regional Center of Archaeological Investigations (CRIA) in Copan Ruinas, Honduras. The Copan VR runs in Unity—a 3D gaming engine—and is populated with procedurally generated 3D polygon structures (using shape grammar Computer to build scripts), extruded GIS data, and a few structures created using combined remotely sensed and CAD (Computer Automated Design) data that are transferable to other projects for visualization and interaction in GIS and VR (Richards-Rissetto et al. 2017; Richards-Rissetto 2018).

The project's remotely sensed data primarily comes from the MayaArch3D Project (2009-2015), which developed an early VR prototype in Unity linked to an open source PostgreSQL database with a PostGIS extension (Agugario 2011; von Schwerin 2013). Subsequently, MayaArc3D developed an open source 3D WebGIS (von Schwerin 2015; von Schwerin 2016) (see MayaArch3D website for other publications

http://www.mayaarch3d.org/language/en/research/publications/?lang=en).

MayaCityBuilder builds on this previous research to acquire additional 3D data and create 3D models for developing VR simulations that researchers can "readily" use and reuse in various software (rather than restricted to a single software or platform). To contribute to the broader goals of this project and to investigate my concept of object identity, I have acquired photogrammetric data and created 3D models of artifacts and extant architectural sculpture to incorporate into the Copan VR.

2.3. 2017 Field Season

In June 2017, members of the MayaCityBuilder team ran a workshop at Copan to teach terrestrial photogrammetry to Anthropology students and Geosciences faculty and students from the Universidad Nacional Autónoma de Honduras (UNAH), Tegucigalpa. As part of this workshop, we coordinated with the Honduran Institute of Anthropology and History (IHAH) to identify high-priority models to assist in conservation efforts at the archaeological site. These objects served two purposes: (1) the primary subjects for workshop participants and (2) objects for my research on object identity. For each object (architectural sculpture, museum piece, or restricted artifacts from CRIA), we guided participants through the process of (1) data acquisition (taking proper photos, (2) post-processing the photos to create 3D models, and (3) exporting these 3D models for use outside of the software (i.e., Agisoft Photoscan) (Fig 2.1.). Prior to the student's arrival, I captured data sets (photos) for several objects and checked the data quality in order to post-process it back at the University of Nebraska-Lincoln using a more powerful set of computer components than available in the field. These high-resolution 3D digital

objects comprise the finished models used for the MayaCityBuilder VR integration. (For a detailed report of the 2017 field season, see Appendix B)

Fig 2.1. Students from the 2017 field season in the CRIA library.

2.4. 2018 field season

In the summer of 2018, we carried out a second field campaign at Copan with similar goals to the 2017 season. Although the second trip had a smaller crew (myself and Dr. Richards-Rissetto) and lasted only of two weeks, UNAH only had one group of Anthropology students for our class and one larger Geosciences group and staff from IHAH for a two day workshop (fig 2.2). Therefore, instead of being absorbed in lectures and hands-on workshops, I had more opportunities to focus on acquiring additional data, i.e. reshoots, for objects that performed poorly in the error estimation process as well as

carry out additional archival research in the CRIA library on the objects captured in the 2017 season. (For detailed reports of the 2018 field season, see Appendix C).
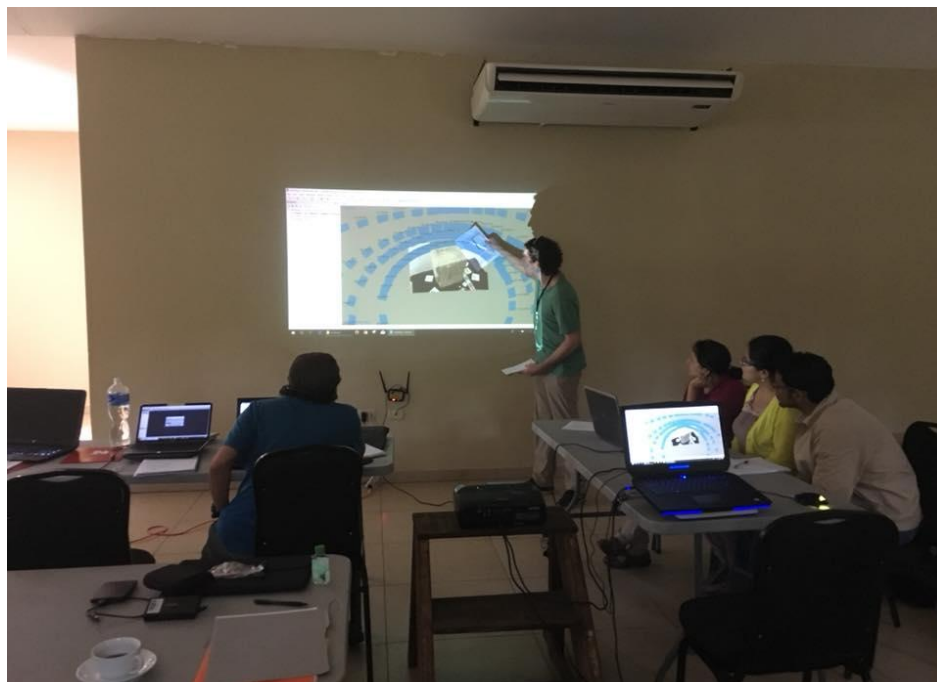
Fig 2.2. Photogrammetric workshop 2018 held at Copan Archaeological Park, Honduras.

2.5. Educational Outcomes and Goals

While working with students and faculty from UNAH and staff from IHAH, we set a goal to instruct them on how to use photogrammetry to capture different kinds of objects in varied settings. Our objective was to provide instruction on capturing proper photos in (1) uncontrolled settings including a museum (with open-air lighting, i.e., Sculpture Museum) and the archaeological site (Copan Archaeological Park) and (2) a controlled lab setting (CRIA). Given the often less than ideal circumstances in archaeological fieldwork, it is essential that participants learned how to acquire photos in diverse settings.

Moreover, the potential implications of collaborating with the first-generation of Anthropology students in Hondurans (an Anthropology major was only established in 2013) as well as IHAH staff was far more important. Currently, no opportunities exist through their own programs to learn terrestrial photogrammetry methods; thus, these workshops provide an opportunity to acquire new digital skills to assist with national efforts to conserve cultural heritage, carry out research, and disseminate data and interpretations to broader audiences.

Chapter 3. Fieldwork

3.1. Research Goals and Obstacles

In this section, I detail the goals of my research in Copan. To begin the process, I needed to identify objects of interest, capture them and then process them into finished 3D models., The fieldwork took place in Copan, which presented certain challenges for data acquisition.

Working at Copan at times can be difficult and even hazardous. The wettest season in terms of rainfall and severe thunderstorms occurs from May-November encompassing the time best suited for students or academic faculty to travel to the country for fieldwork. Since Our primary method of acquiring data is taking 2D photographs, the quality and success of our data captures relies on good weather. Heavy rains make acquiring photos outdoors impossible without some kind of cover (which was not available to us) and potential lightning strikes make fieldwork and transporting equipment on foot perilous. In addition to the outdoor concerns of rain or lightning, indoor conditions can have their own challenges. Thunderstorms are extremely likely to

knock out power for several hours, making it difficult to carry out data acquisition (i.e., photo shoots) or process photo data in the late afternoon and evening hours. Additionally, planned power outages to conserve energy or fix transmission lines reduces acquisition or post-processing time in the field.

While the CRIA facility was a completely adequate laboratory setting, we encountered challenges with trying to research some of the artifacts in the study. The on-site library houses archival records for many contemporary archaeological surveys and excavations; however, documentation of the objects in my study comes from early excavations before IHAH was established (in 1952) or shortly after. For the architectural sculpture and artifacts that were uncovered or excavated prior to the founding of IHAH, documentation is often spotty. This situation arises because of several potential factors: (1) poor or non-existent documentation (some in-situ architectural sculpture was excavated in the early 1900s); (2) missing or lost documentation (sometimes deriving from the lack of best practices for digital data, especially in the 1990s, or lack of official policies), and/or; (3) changes in the mid-1980s to the catalog system (implemented by non-local archaeologists) leading to inconsistencies in catalog numbers and associated information in the library.

3.2. Objects of Interest

While running the workshop in Copan, we coordinated with IHAH to identify archaeological objects of special importance to the site's cultural resource managers. These pieces include in-situ architectural sculpture comprising two architectural reliefs known as "Dancing Jaguars" (Fig. 3.1. & 3.3.) and a flanking relief depicting the Maya Sun God

(Fig. 3.3) positioned on an east-facing staircase in the East Court of the Acropolis at Copan (fig. 3.2).
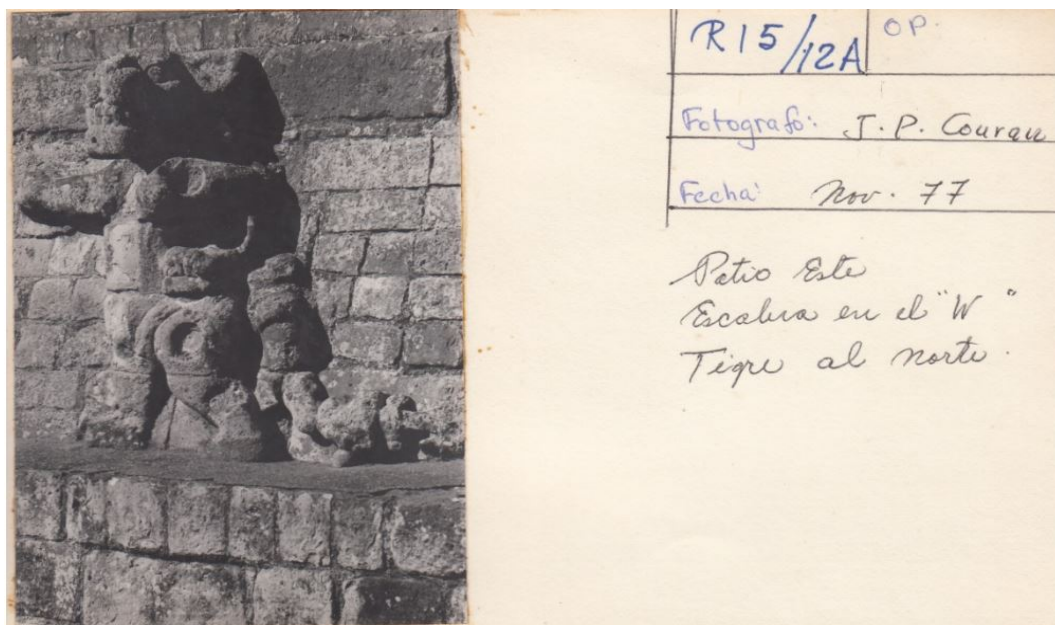
Fig 3.1. Catalogue card for jaguar (Right), courtesy of CRIA library.

Fig 3.2. East court of Copan (Aerial View).
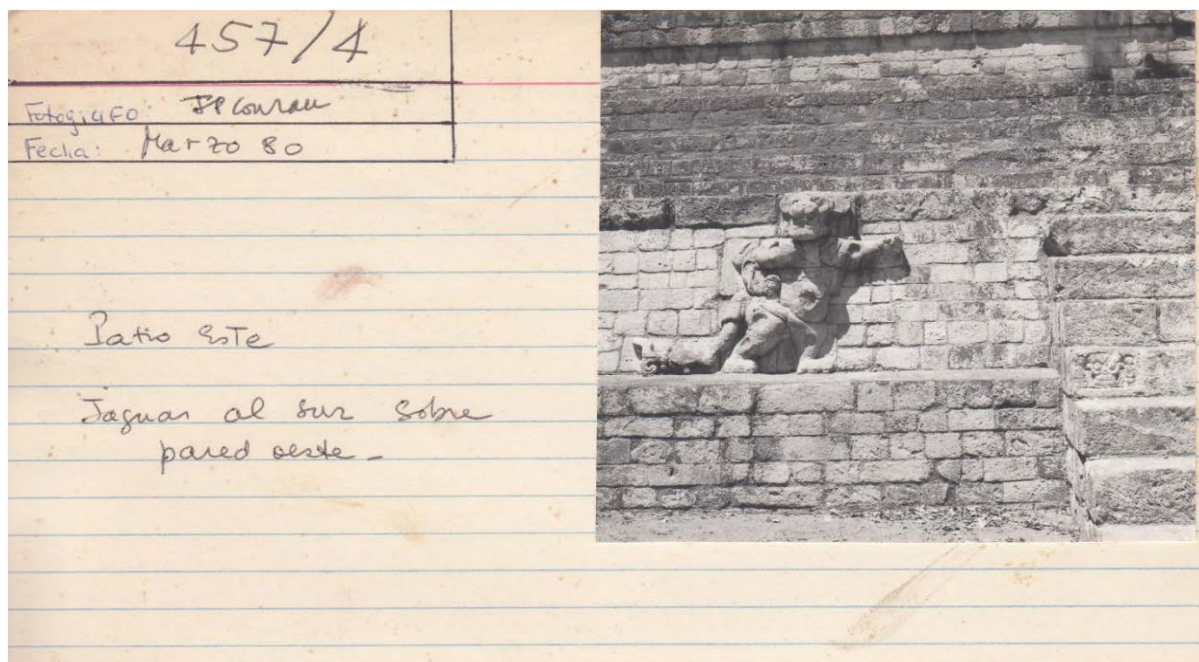
Fig 3.3. Catalogue card for jaguar (left), courtesy of CRIA library.
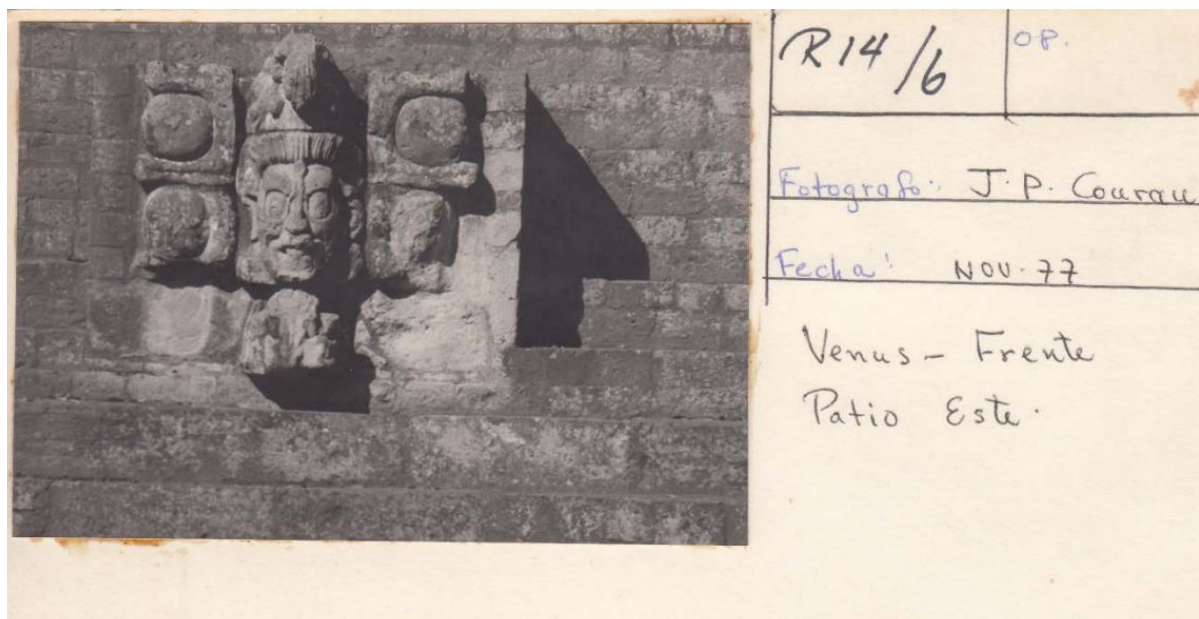
Fig 3.4. Catalogue card for the Sun god (Venus mask) relief, courtesy of CRIA

The staircase and the reliefs align with the floor of the court to form a perambulatory

route symbolic of the setting or "old" sun descending into the underworld and its eventual

renewal through conflict and sacrifice (Baudez. 2015). The two jaguars are marked with

spaces where obsidian discs would have been placed in antiquity to denote their "spots" and are adorned with ribbons. Arms outstretched and in the process of movement the jaguars seek to guard the entrance to the court floor (Baudez 2015). The "old sun" further up the stairs is within the jaws of a snake and is symbolically descending to the floor and forms the center of the perambulation aligning with the setting sun (Baudez 2015).

Additionally, three isolated, and most likely relocated, artifacts including two stone *incensarios* (Fig. 3.5.) that functioned for burning incense during daily or ceremonial activities (Rands 1978) and an architectural block depicting the face of an "old man" (Fig. 3.6.), possibly a *Bacab* (Baudez 2015), which currently rest on the eastern stairs of the East Court near Temple 22.

Fig 3.5. The two stone *incensarios* from the East Court of Acropolis, Copan

In addition to these five pieces located outdoors in the Copan Archaeological Park, there were several smaller artifacts stored at CRIA for which IHAH wanted to create 3D

digital models included in this study. The artifacts comprise several ceramic pieces including clay whistles, drinking vessel, an *incensario* bust as well as four pieces of a stone bench, and a jade figurine—an experimental piece that was successfully modeled using a low-light photography technique to maximize surface details and minimize glare (Pattee 2016). I have not included photos of this jade figurine due to its sensitive context and a request by the CRIA lab to withhold images or 3D models from published works.

Fig 3.6 Architectural block depicting the face of an "old man", East Court, Copan

3.3. Methods- Photogrammetry

Photogrammetry is, as used in this project, an image-based remote-sensing method that uses SFM (surface from motion) technology to extrapolate surface geometry

(Fig. 3.7.), texture, and color from photos. I use many 2D photographs (50-300) of an object in the field taken at a single focal length from as many possible angles as I can manage to acquire the 3D geometry of the object later using software. Photogrammetry does not necessarily require the use of more than two photos to acquire 3D data about objects; in fact, even two aerial or terrestrial photos can be used to triangulate measurements (Karras 1996; Opitz 2018). Terrestrial and some aerial photogrammetry, particularly from Unmanned Aerial Vehicles (drones) take photos of objects or a landscape from several different angles and heights to construct digital 3D models (Sapirstein 2016).

SFM photogrammetry used at close range, when successful, results in a digital surrogate; that is, a 3D model that constitutes a near to exact replica of the original object (or scene) with highly accurate metric data that can serve as an interpretive replacement (Rabinowitz 2015; Sapirstein 2016). However, researchers often criticize this definition because it assumes that photogrammetric models require no interpretation in the creation process but this is perhaps not a severe enough critique of the practice (Olsen 2016; Rabinowitz 2015). For example, some scholars contend that individuals highly inform the process of making 3D models, and scholarly paradigms, research objectives, and interpretation affect all stages as well as the final outputs (Dell'Unto 2016). In the Copan VR the digital processing of both the 3D models and their integration into Unity requires input and interpretation from archaeologists to develop simulations useful for scholarly analysis and interpretation.
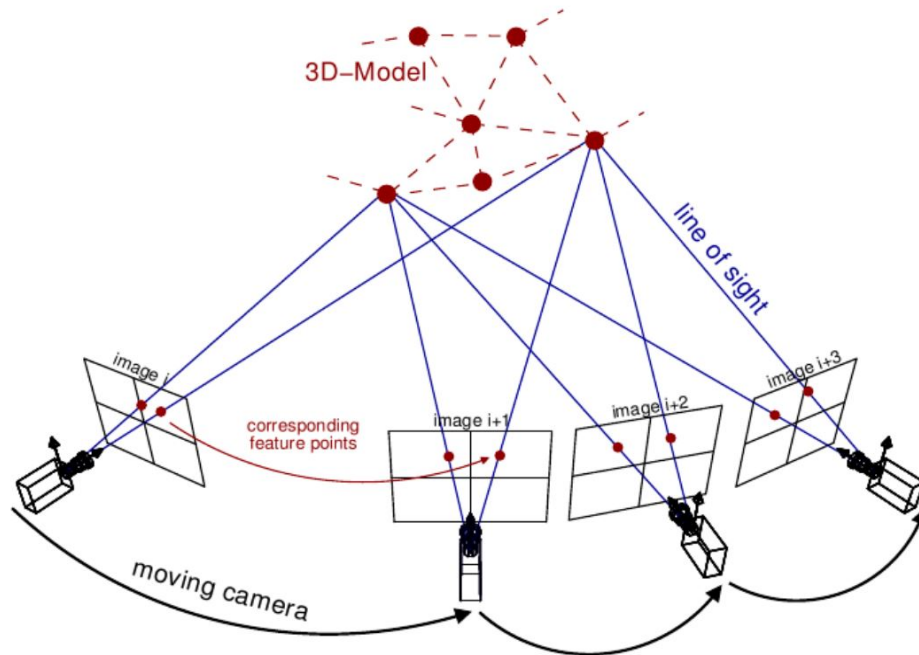
Fig 3.7. Example visual of SFM matching points between cameras.

We chose photogrammetry for this project as opposed to structured light or terrestrial laser scanning because it is a much more cost-effective method demonstrated to achieve similar and sometimes more desirable outcomes (depending on scenario and objectives) than these other two technologies (Dell'Unto 2016; Garstki 2017; Koutsoudis 2014; Pattee 2016; Sapirstein, 2016).

The objective for each model in this research, focused on acquiring detailed textures in exchange for time and larger area scans. In general, there are three stages to conducting photogrammetry scans: subject selection, data acquisition, and data post processing. While all steps were initially completed in the field to ensure appropriate data quality, an additional stage of post-processing was carried out at UNL after the field season to achieve higher quality 3D models.

3.4. Methods- Photography

To acquire photos in the field and lab, I used a Nikon D5500 DSLR camera with 24.2 megapixels. For outdoor conditions (Fig. 3.8), I calibrated the camera for intense sunlight, using a lower ISO (200-400), an aperture setting to let in a moderate amount of light (f11-14), and a fast shutter speed (set to automatic, but usually operated around 1/500s). For many of the outdoor objects, the light was bright enough to allow for extremely quick shutter speeds that negated the negative effects of operating the camera by hand (i.e., potential blurring) (Garstki 2017), which was often necessary in the absence of usable scaffolding or a camera boom to acquire photos at a higher vantage point. I determined these settings using principles of photography and then checking the photos in the field.

Fig 3.8. Example of outdoor setting for photography, East Court, Acropolis, Copan

When acquiring photos indoors, I applied a controlled approach to achieve the best possible results (Fig. 3.9). This approach uses a turntable to rotate objects rather than rotating the camera, which helps to stabilize both the camera and focal length while reducing shadows visible on the object after processing.

Additionally, I employed LED lights to create ideal lighting scenarios for each object, which requires reducing shadows, applying camera settings to increase the effective depth of field and reduce focal blur. Additionally, I positioned the camera on a tripod allowing for longer exposures without motion blur. All of these factors contributed to the method of "best practice" that was central to not only to capturing photos for accurate 3D model generation but also for instructing Honduran students.

Fig 3.9. Example of a laboratory setup for photogrammetry with a light box, turntable, tripod, and artificial lighting.

The average number of photos taken for each object ranged greatly depending on the size of the subject or area, its geometric complexity, and the image quality desired for the object. For the larger objects shot outdoors, roughly 100-250 photos were taken, often with portions of the session that focused on smaller areas of detail apart from the larger scene (Fig. 3.10). In the indoor setting, 75-120 photos depending on size, was often adequate to reach the targeted 70% overlap described by the Agisoft manual.
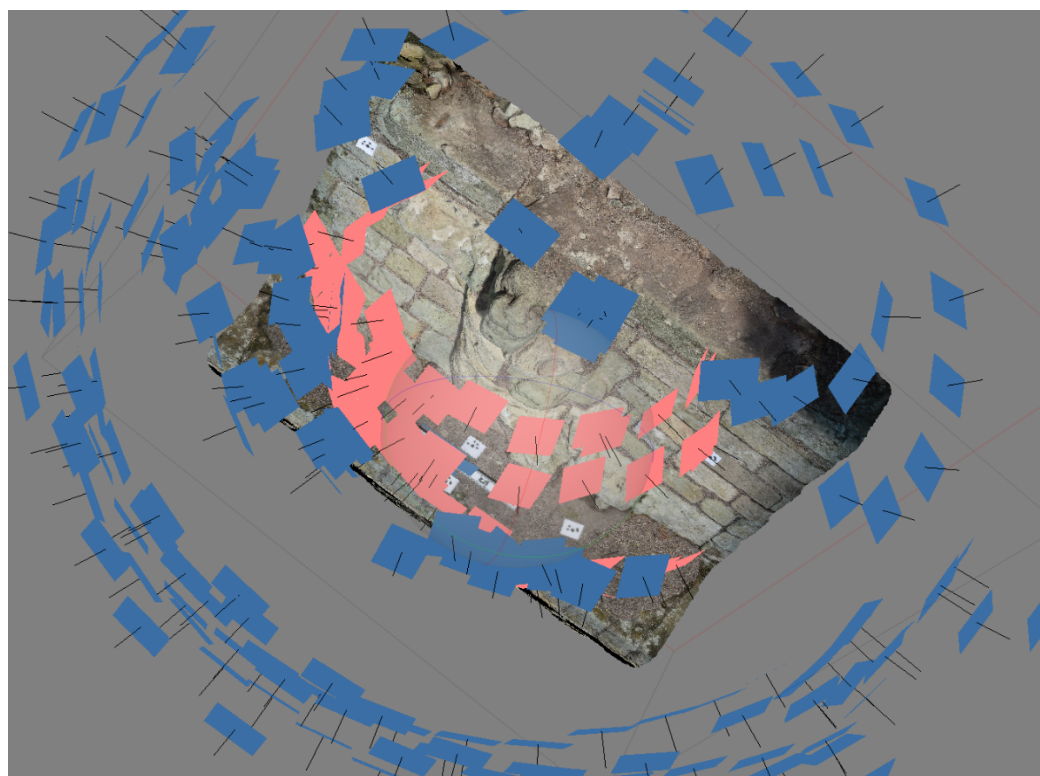
Fig 3.10. Tighter interior group of photos to enhance detail of a larger object.

3.5. Methods- Post-processing data

I chose Agisoft's Photoscan Pro as the software for processing the photo data, because, while it is a paid for commercial software, it is a highly robust, industry standard program, and in addition, demo versions were available for students (Plets 2012;

Koutsoudis 2014; Sapirstein 2016). For each object or scene, we employed printable

Agisoft markers (targets) to increase camera position accuracy and apply a measurable

scale to each object. In all scenes, I placed an additional measuring scale in view to

ensure the availability of a scalable object. (Fig. 3.11)

**Fig 3.11. Screenshots showing calibrated Agisoft markers (left) and a rectified scale
in scene (right).**

To begin processing smaller objects, the photos are separated into two "chunks"

one containing photos of the object oriented normally (e.g., top) and one of the object

oriented in reverse (e.g., bottom). These chunks are combined later to create a whole

object (for example, combines top and bottom into a single object) . Larger sets, like

structures or ceramics that cannot be inverted safely are captured as is and do not require

a second "chunk". During processing, the software scans and aligns photos pixel by pixel

to identify matching pixels between overlapping photos (Fig. 3.12) in order to generate

camera positions for each photo in relation to the central object. Next, the software

evaluates alignment accuracy, and removes photos with error values of one pixel or more

(error measured in average number of pixels shifted for the camera position to match the

aligned geometry) from the set. Next, I generate a dense cloud from the sparse cloud

created from the alignment. I initially run the dense cloud on the lowest possible setting

and clean the model scene to remove unnecessary data points, i.e. points not part of

object. I run the lowest possible resolution dense cloud initially because if the sparse

cloud (alignment) stage is successful I don't need a very detailed dense cloud to make a

low poly version of the model.
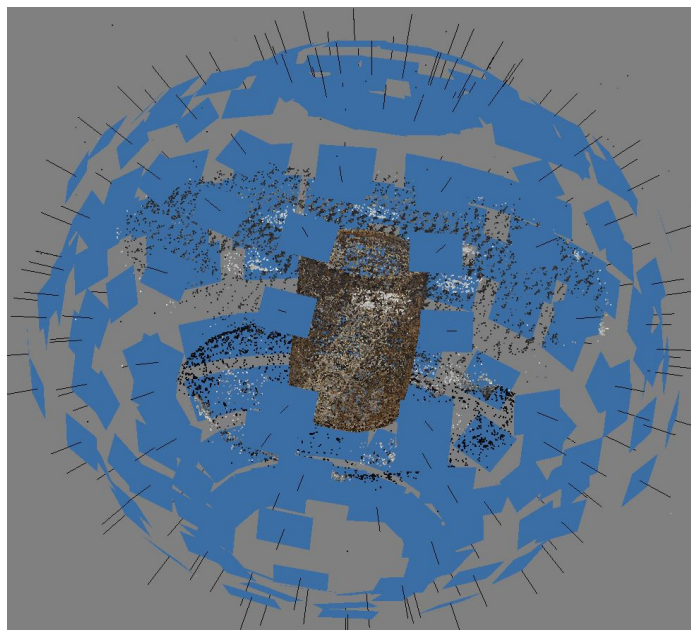
Fig 3.12. Camera positions visualized after alignment.

At this initial stage, I generate a low-quality mesh in order to generate a "mask".

In Agisoft, the process of creating a poor-quality model, i.e., masking, to capture the

object's basic shape creates a 3D shape to refine processing, applies a null field around

the object in every photo (Fig 3.13). This step is important because it allows the program

to ignore any data that not taken from the surface of the object, which drastically cuts

down the processing time in a later step of generating a high resolution dense cloud

needed for better geometric detail (Pattee 2016).

Fig 3.13. Masked photo that restricts point generation during the dense cloud process, note the white outline on the object, everything outside it is left out of processing.
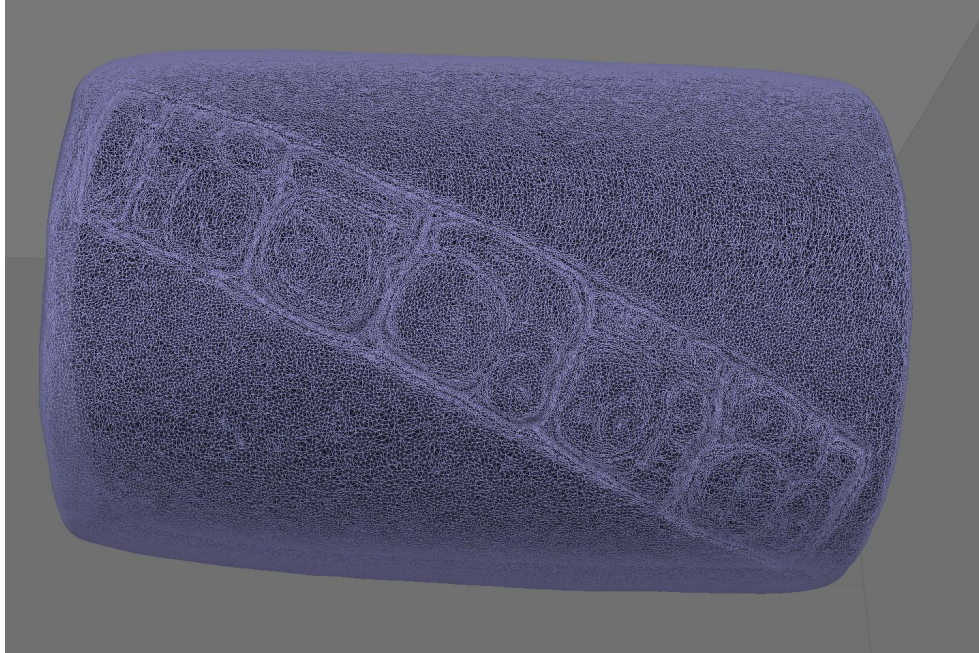
Fig 3.14. Mesh reconstruction in Agisoft

After masks are generated for an object, an alignment is processed that "constrains features by mask" and combines any "chunks" into a single 3D model. Once the secondary alignment is complete a dense cloud can be processed again on a much higher setting without wasting processing time on points or geometry that are not connected to the subject in the scene. From the larger dense point cloud, a 3D mesh is generated (Fig. 3.14), transforming the point cloud into a "solid" 3D object, or surface, that can then be draped with a photorealistic texture with minute pixel level details aggregated from the photos (Fig. 3.15).

(For a full explanation of the procedure used and the effects of each step on the data including scaling, see Appendix D)

Fig 3.15. Finished model of a drinking vessel showing the texture component.

In a Lab setting at UNL the standard processing is fairly straightforward and simple to complete using the Universities resources. However, in the field it is extremely difficult to generate the same kind of high quality models, but testing the photo data I collected was vital to ensuring that the same data would yield good results when processed in the lab. As mentioned before, working in Copan could be difficult at times and it was especially trying when attempting to run long sessions of computer processing. I could not bring a powerful desktop computer, but I did have the use of a powerful mobile laptop from the University, and I could not afford to let large data sets process for twenty hours, but I could effectively shorten the time by using smaller sets of data and lower processing settings. In the field, each photoset was tested on lower accuracy and detail settings on an Alienware 15, equipped with a four core CPU (Central Processing Unit), 16GB of RAM (Random Access Memory) and a GTX980M GPU (Graphics

Processing Unit) which could process one model fully with medium and low settings in an average of eight to twelve total hours. The lower resolution scans were
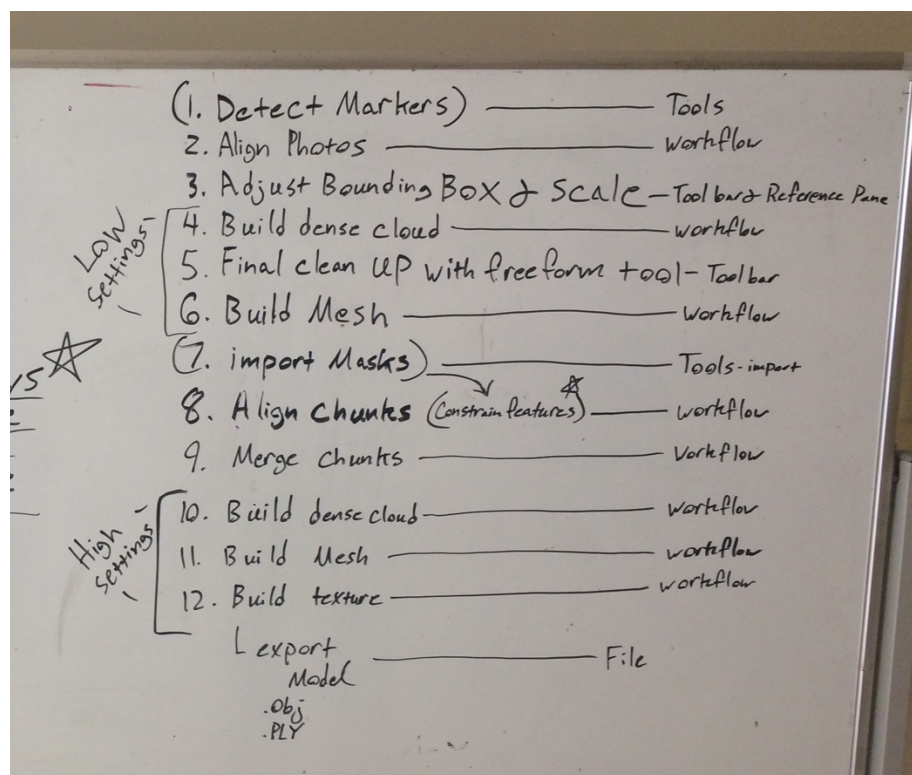
Fig 3.16. Processing "cheat-sheet" from lecture with students.

necessary due to the RAM constraints of the laptop (16GB) and a slower core clock speed for both the CPU and GPU. In spite of such constraints, the full process of model building was completed as a test run and then again for students, so they could practice running the myriad different processes from start to finish (Fig. 3.16). Once the photosets were taken from the field back to UNL, they were processed again on a computer with a much faster 8 core CPU, 64GB of RAM, and a GTX 1080 Ti GPU, which meets the hardware parameters for Agisoft's "extreme" configuration. With this boost in raw computing power, the models were able to be processed on much higher settings resulting in much more detailed and intricate photorealistic textures and geometry in a roughly longer amount of time. While these higher resolution models serve metric and archival

purposes, I made decimated versions (downscaling geometry and texture) for Unity from 3-6 million faces to 300,000.

After the models were completed, the next step was to integrate them into the Copan VR. I decided to bring the models, i.e., digital assets, directly into Unity in order to evaluate the program's capacity to host them to explore the concept of object identity. This evaluation necessitates a deep understanding of the underlying principles of the MayaCityBuilder Project.

Chapter 4. Fundamental Principles

4.1. GIS

For the past twenty years, Geographic Information Systems (GIS) has been essential in archaeology for a myriad of purposes including data management, spatial analysis, and more recently reconstructing and visualizing archaeological spaces in 3D (von Schwerin 2013, 2016; Richards Rissetto 2013, 2014, 2017; Dell'Unto 2016; Buckland 2018). It is now a fundamental tool and often lays the foundation for studying and engaging in digital archaeology and Digital Humanities (Dell'Unto, 2016; Richards-Rissetto 2017).

In my research, GIS is the foundation of the data lattice built to investigate object identity in relation to spatial context, which provides users with a "touchstone" of reality in a virtual world to better immerse them in an archaeological context. The primary spatial data (Fig. 4.1) comes from the MayaArch3D project and constitutes LiDAR data captured in 2013-- accurate to 0.5m (von Schwerin, 2016)—and GIS data derived from the LiDAR data and earlier pedestrian survey maps (Fash and Long 1983).
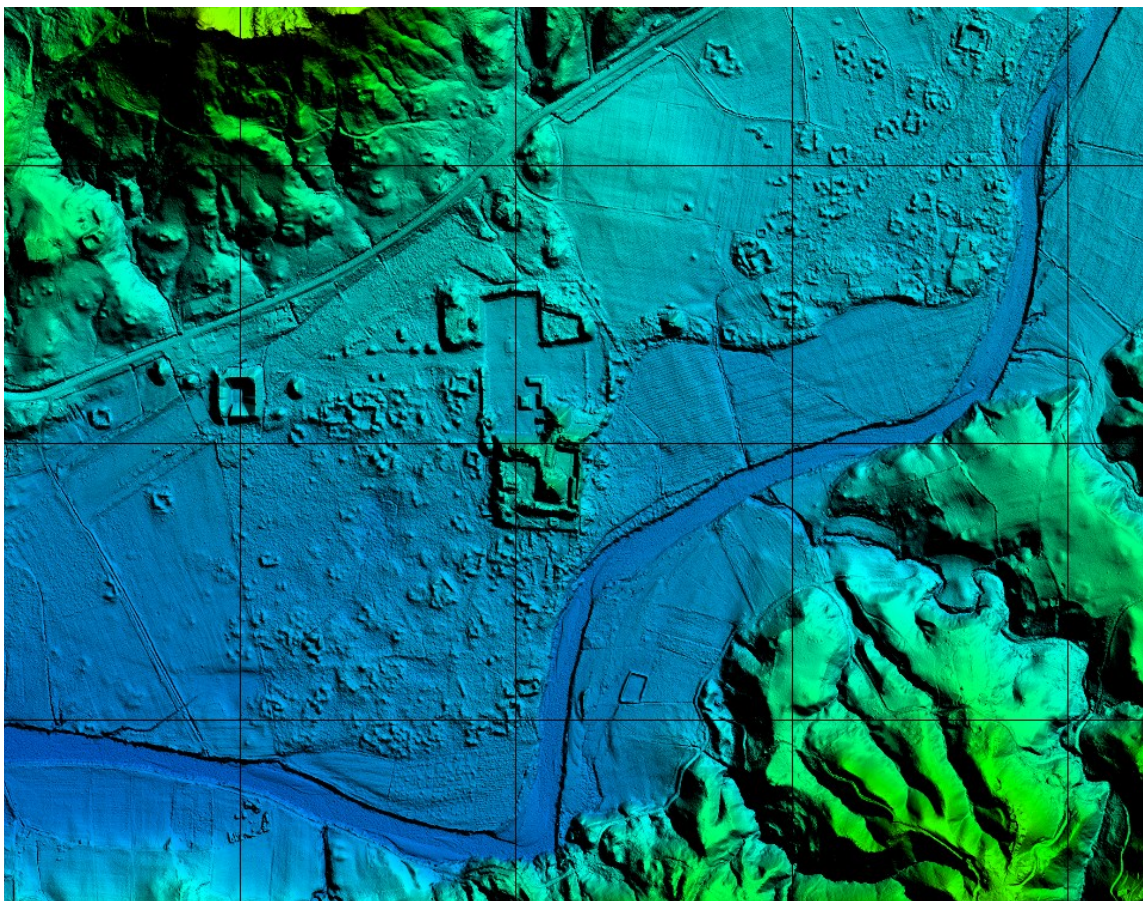
Fig 4.1. Digital Elevation Model (DEM) of the Copan principal group. (courtesy of MayaArch3D)

Figure 4.1 illustrates the DEM (Digital Elevation Model) derived from the original 3D LiDAR points that removes vegetation and yet maintains archaeological features (von Schwerin, 2016). Even though LiDAR data provides such a detailed topography for reconstructing ground data, it does not come without the obvious caveat of only being able to map the modern surface. While this is problematic when trying to recreate an ancient landscape, it is beneficial for allowing us to construct an archaeological interpretation of the landscape. The LiDAR provides a base map of an archaeological surface from which we can create interpreted landscapes that serve as analytical and interpretive tools for archaeological in both creation, and subsequent

exploration (Forte 2016). While the Copan VR encompasses 24 square kilometers surrounding the city's main-civic ceremonial center, my research focuses on the East Court of the Acropolis—a small part of the larger landscape. However, situating objects, buildings, and architectural complexes in their broader spatial context (e.g., landscape) is vastly important because it contextualizes smaller spaces, such as the East Court, helping to generate a more authentic sense of place for an active user in the simulation (Forte 2010). I propose that, in spite of its limitations, situating objects in their larger spatial context goes beyond simply contextualizing spaces it also works vice versa. When individual objects become part of their "original" spatial context and in particular part of an immersive and interactive experience, these objects afford different and new interpretations that archaeologists can use to understand and perceive relationships in more intuitive ways, contextualizing a cyber-archaeological approach (Forte 2015; Forte 2016).
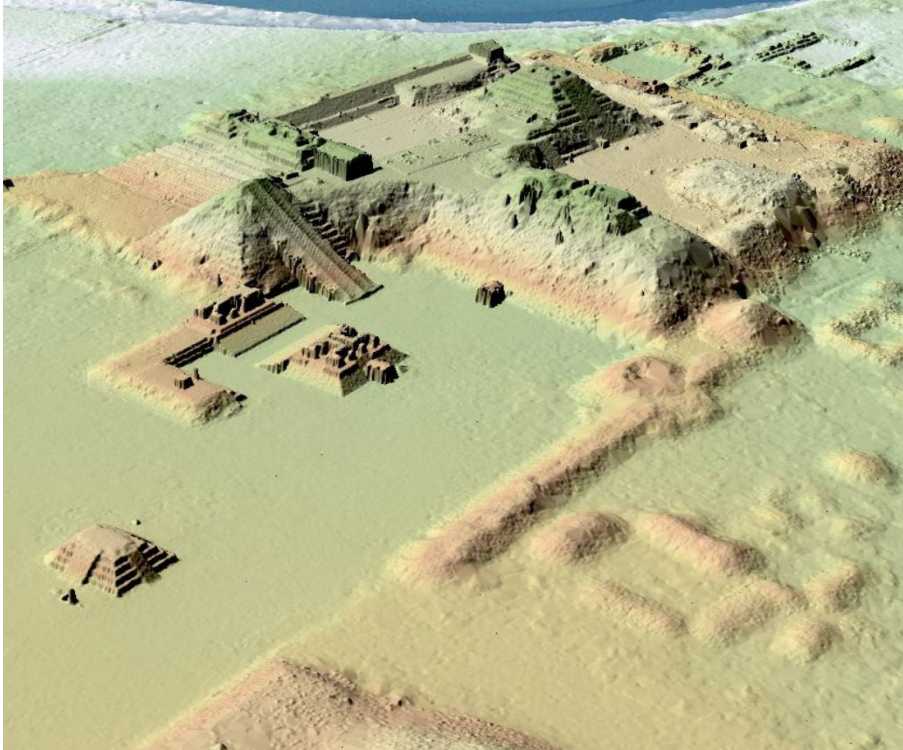
Fig 4.2. DTM with vegetation removed (courtesy of MayaArch3D)

4.2 Unity

The georeferenced 3D model of Copan created from the LiDAR and GIS data
(Fig. 4.2) serves as the footprint for the virtual world (Agugiaro et al 2011; Richards-
Rissetto et al 2012; Richards-Rissetto et al 2013; von Schwerin et al 2013). Unity is a 3D
game engine for designing, testing, and launching virtual environments primarily for the
creation of video games, as well as other Audio Video ventures. Archaeologists often use
Unity because the basic license is free, it is relatively easy to use, and features drag and
drop mechanics for to important GIS-derived data to generate virtual environments (Fig.
4.2 & 4.3).

Fig 4.3. Copan VR environment rendered in Unity derived from LiDAR and GIS data (MayaCityBuilder)

The MayaCityBuilder Project has developed three workflows to import georeferenced data and 3D models into Unity (Richards-Rissetto et al. 2017). Regardless of the method, the process employs a polygon shapefile that contains model footprint locations converted to a COLLADA file, and a terrain file based on LiDAR data converted to a heightmap (Fig. 4.1). These files are imported into Unity to create a 3D model of Copan's terrain aligned with georeferenced archaeological structures. The 3D environment rendered in Unity is partly reality and partly realism. By this, I mean that the virtual environment is constructed using data of extant archaeological

artifacts and features (reality) as well as using 3D models constructed from archaeological interpretation (realism). The practical upshot of integrating archaeological 3D data into a virtual environment comprising a broader spatial context is that each object is no longer disconnected and "free-floating" like they are in single object viewers such as Sketchfab. The remotely sensed models bring reality to the simulated environment and the virtual space gives each "object" its spatial identity and context so they can be more than free-floating objects in a single object viewer or an archived file. Additionally, the virtual environment, i.e. simulated space or physical surroundings for individual objects, gain contextual information from the integrated remotely sensed objects.
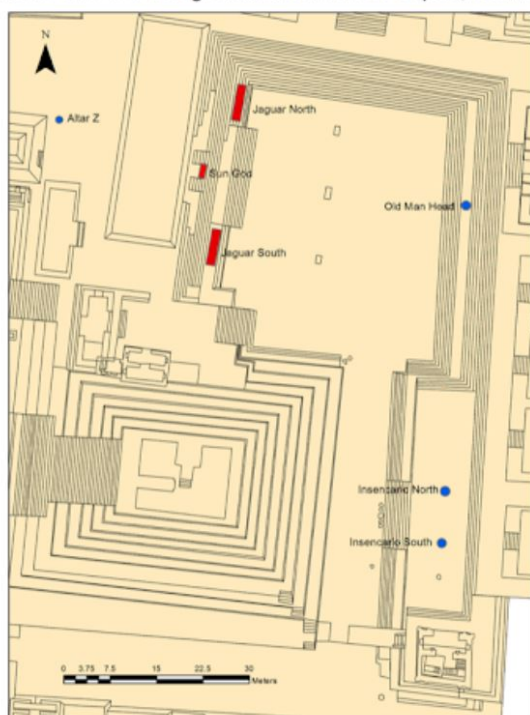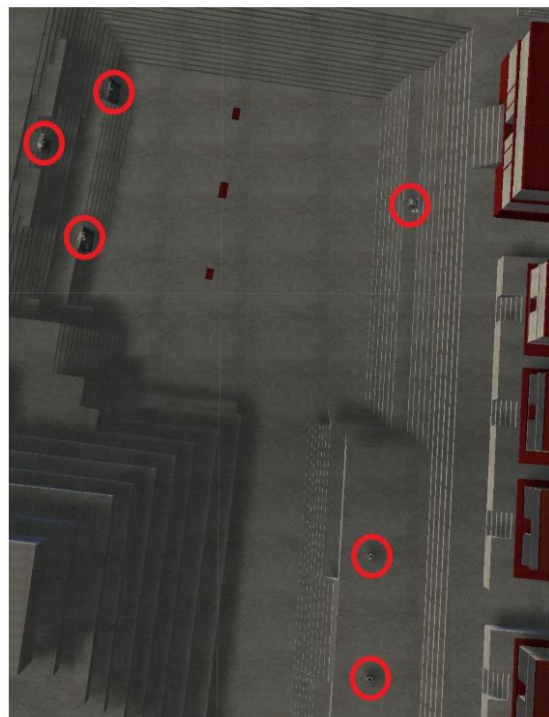
Fig 4.4. Matching images of the GIS map with footprints and the finished VR landscape

Returning to realism vs. reality and the relationship with object identity, I contend that the GIS data gives the VR spatial reference to "insert" reality-based objects to contextualize them not only in geographic space, but more importantly for this research, on the basis of perceived space (Fig. 4.4). Object identity can bring a broader understanding of the objects in simulated space by asking the user to understand their spatial context not through object metadata but by experiencing their place in the environment. Here the realism of the virtual space and the virtual "things" put in it is a, albeit interpreted, reflection of the reality of the physical things and the landscape to which they are tied.

Chapter 5. Exploring Object Identity

Using the Unity program, I explore how using in the 3D models generated from the field data (i.e., photogrammetric models) an embodied space like the Copan VR simulation how users could create object identity. Here the concepts of realism and reality are critical. Notably, realism, is simulated and abstracted but relies on "real" data or reality to enhance it to. Reality is the real-world data used to construct and contextualize the simulated environment. In combination, the virtual space with its integrated remotely sensed objects are embodied by the immersive movement users.

5.1. Moving models to Unity

To work towards this vision of perceiving the relationships and presence of objects through object identity and spatial context, individual models need to be integrated into larger spatial context so they can begin to display the relationships and simulated contexts they have with the environment and the other embedded objects.

Given that there were no existing workflows that did not require any additional software or programs to move the models directly from Agisoft to Unity, one objective of my research was to develop a straightforward and "standardized" approach that other archaeologists and cultural resource managers could adopt to their own projects. In order to achieve this objective, I tested three file types that are compatible, i.e. interoperable, between Agisoft and Unity, and widely used by archaeologists.

They are: .fbx .dae and .obj. The file type .obj or Wavefront OBJ is a, now, open source "Geometry Definition File" that was developed for animation studios to hold only geometric data about a 3D object. It usually generates a companion "material" file or .mtl that can include mapping data for different textures. COLLADA (collaborative design activity) files or .dae are open source and functionally similar to .obj for my purposes, but they are notably different in that the structure for COLLADA is intended to transport 3D data and all its attributes between programs rather than just define the dimensions of the data. Because of this feature, .dae files move the object and all of its metadata from the program that it originated, losslessly. Finally, .fbx (FilmBox) files are a proprietary format owned by Autodesk but originally designed to move 3D data from motion capture devices between projects. While the format is free to use, the software and license are closed, and functionally .fbx integrates data very similarly to .dae so the file carries all of the metadata generated during the model's creation. Generally the upshot of .fbx, though similar to .dae, is it is viewed as much more stable and supportable format. These three file types are considered working standards in many programs for moving or defining 3D model data, but each offers a different level of integration for legacy data and metadata.

In my tests, I found that the .fbx, and .dae formats exported from Agisoft resulted in a Unity editor crash when importing the files from Agisoft. After carrying out some research on the file types, examining the loaded files in the scene before a crash, and reading some of the crash reports, I determined that this was because these two file types included *all* the metadata from Agisoft. This data was, in my case, incompatible with Unity's design. In .fbx and .dae each photo from processing and its metadata was also loaded into the active scene. It became clear that the simulation would not run if I used any format that brought the metadata generated by Agisoft into the scene due to the program attempting to load 100-200 photos, their mapped locations, and technical specs (aperture settings, light readings, focal length etc.) in addition to, an already complex geometric shape and texture file. In this case .obj was the only file that would work because it simply exports geometry and texture maps resulting in a much lighter load for Unity's engine to render and display. Using just the .obj, the model mesh and geometry is simply dropped into the Unity asset folder and the texture, as a .jpg image, is applied in the scene without the assistance of the .mtl, because I generated only a single texture for any of the models. However, if someone needed to import and map multiple textures to a single 3D model, a simple work around for Unity not accepting .mtl files would be using a .fbx converter to simply convert the .obj (which does not contain any metadata) with its texture to .fbx and use the .fbx format in unity, which works because it carries only the geometry and texture; thus, functioning like an obj.

While .obj is a perfectly suitable file type for simply moving 3D objects from program to program, it is not possible with this approach to move much metadata with the models; instead as the approach currently stands the metadata must be added

manually to Unity. The largest drawback of importing the models using this approach is the lack of scale and orientation data applied in Unity. Since Agisoft can use an object scale, and even GPS coordinates to orient objects it is possible to export this data but seemingly impractical to implement it in Unity due to the issues using .fbx or .dae. Instead, the coordinates for the object footprints had to be entered manually for each model, slowing down the process. In addition, without object scale (i.e. object measurements made using photogrammetry and natively applied to the geometry) from Agisoft, I needed to develop a work around to reapply or find the correct scale for the Unity coordinate plane.

After researching measuring tool plug-ins (additional downloadable software that run in Unity's development tool), I found that none of the free pieces of software actually worked with the version (2017.3.1) of Unity I was using. This was an initial challenge to overcome, but it also conveyed the problem with using an additional piece of software like a plug-in. There was simply no guarantee that a plug-in solution would continue working indefinitely as newer versions of the engine are implemented. Instead of using plug-ins, I employed a "default cube" to manually scale the object using the scale applied to the Unity scene by the GIS data; a solution that would remain "intact", offering better sustainability for the method.

Given that the models cannot easily bring an interpretable scale data into Unity from Agisoft, the models needed to be scaled to the simulated environment, and to do this they needed a visible measuring tool present in the scene (and in original photogrammetric data acquisition) (Fig. 5.1). All of the models captured for this project included some kind of measuring tool or "scale bar" that was visible on the ground or on

the turntable during the photographic stage of model generation. In short, this was to ensure the models could be scaled relative to the scale bars visible in any program, in the event that the scale applied by Agisoft did not carry over properly. Using this approach, I was able to scale each object integrated into Unity using the scale bar visible in the finished photogrammetric models.

Fig 5.1. Measuring device required in scene in order to scale in Unity

Using the default cube 3D asset, which Unity always represents by 1x1x1—the portion of the object that displays the measurement tool is aligned with Unity's default cube. In cases where the scale for an object is smaller than 1 meter (meters represents the scale of the imported GIS Copan data that constitutes the VR environment), the scale factor can be adjusted so the cube maintains the correct measurements at a smaller scale such as centimeters or any fraction of a meter.
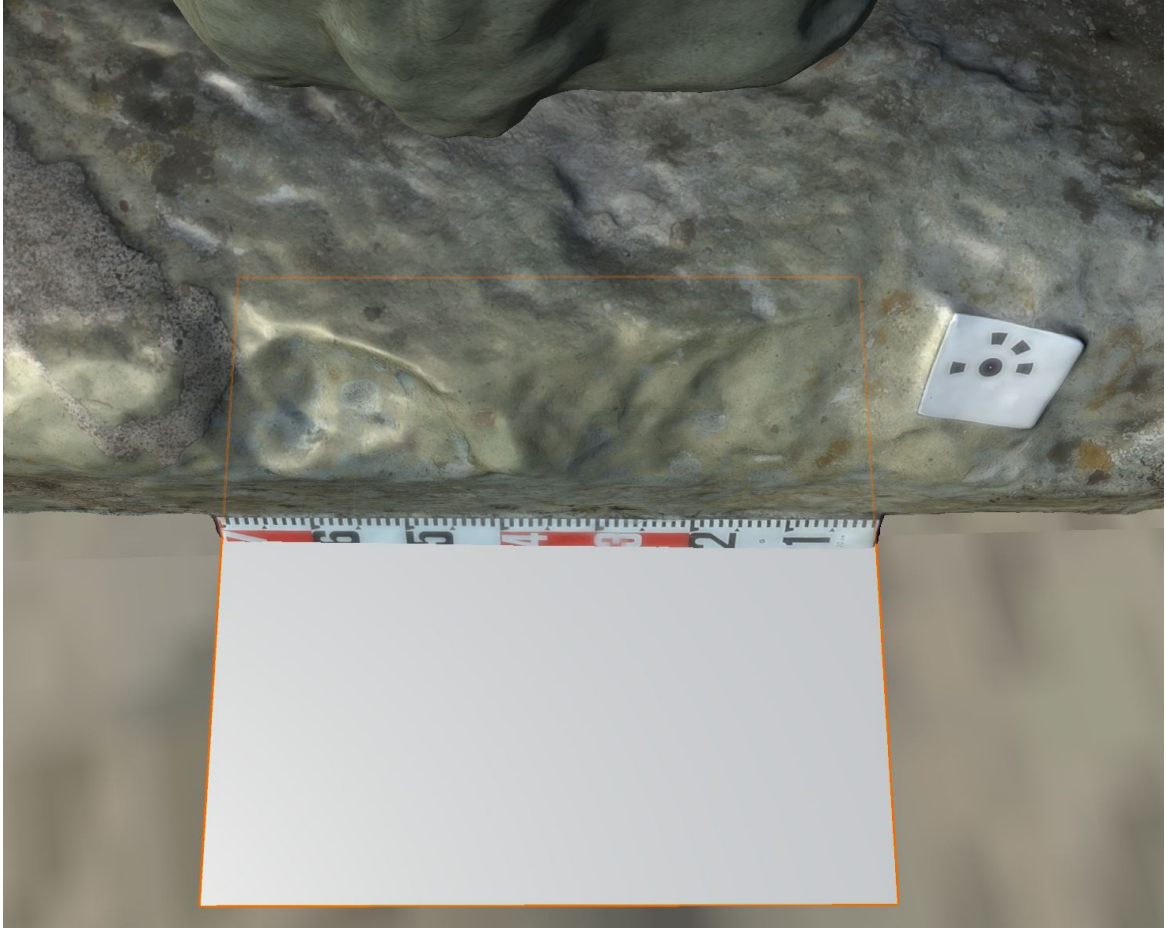
Fig 5.2. Default cube calibrated for the DEM matched to the measuring device from a model- in this case .7m is the adjusted default size.

After the cube's horizontal length and the length of the model's scale bar match (Fig. 5.2), the digital object in Unity represents the object's approximate size in Agisoft. Once matched, the scale coordinates are recorded, and the scale bar can be removed from the object. While this process works to assign scale to individual objects imported into an already existing scene in Unity, it is still a temporary solution for assigning object size in the VR, and I am researching and testing a more streamlined and exact method so that photogrammetric models can be seamlessly moved into VR environments (Fig. 5.3; 5.4; 5.5; 5.6).
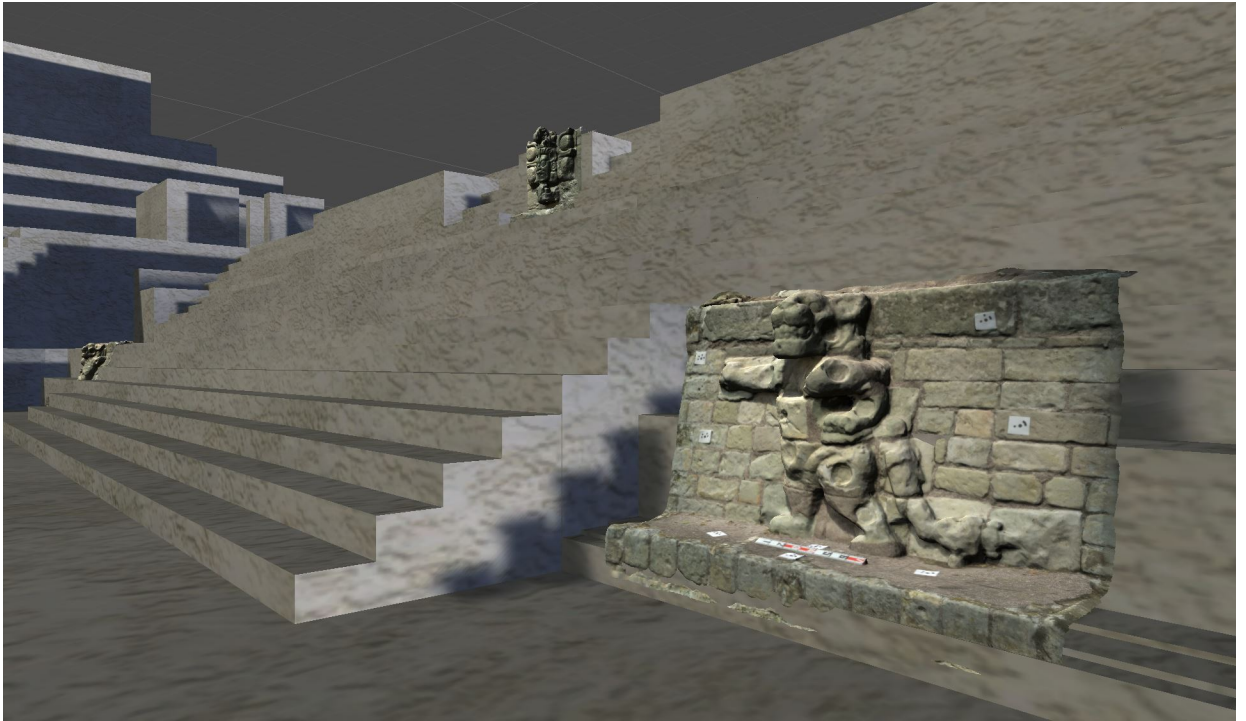
Fig 5.3. Models migrated into Unity and scaled for the environment (Right Jaguar).

Fig 5.4. Models migrated into Unity and scaled for the environment (left Jaguar).

Fig 5.5. Models migrated into Unity and scaled for the environment (Sun god or Venus mask).

Fig 5.6. Models migrated into Unity and scaled for the environment (East Court Incensarios).

5.2. Object Identity and the Experience of Observation

Using VR as a medium comes with certain affordances that shape user experience about the things and environments with which they are interacting. For example, I content that a user who is able to freely move about a 3D environment and interact with the "things" in it has a different experience from users who can only rotate a single object 360 degrees within a neutral space devoid of original spatial or cultural context. Both platforms lead to different experiences, not better or worse, but affording different opportunities for engagement. In archaeology, VR environments embedded with in-situ photogrammetric models additionally contextualize the 3D space and get closer to embodying both object interaction and a sense of place.

To explore this idea, I turn now to the case study and the ancient Maya. For the ancient Maya, the attribute of sight was a powerful physical phenomenon; in fact, it was the sense through which the other senses (sound, touch, smell, and taste) were channeled (Houston 2013). The gaze was not only an aspect of vision but powerful, intentional, and imbued with physicality (Fig. 5.7). In Mayan thought, while the eye is receiving images and information, it is also protruding into reality and affecting the places where its gaze rests (Hanks 1990; Houston 2013). Ancient texts show examples of people and animals with protruding eyes (Fig. 5.8, 5.9) signifying the "procreative" quality of their vision while possibly referring to a distance between what is being looked at and the viewer (Houston 2013). Additionally, certain creator deities and supernatural beings at one time had the ability of omniscience and through their sight were able to peer beyond the land, fearing this power and its potential consequences; they willfully clouded their vision (Christenson 2000; Houston 2013).
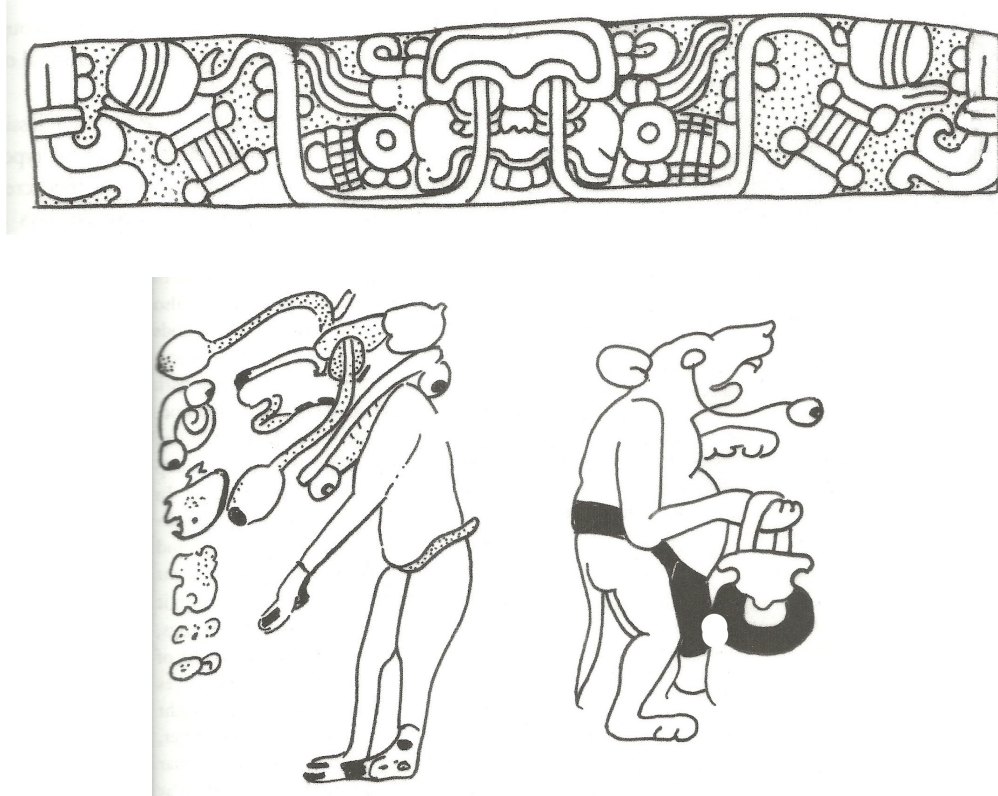
Fig 5.7, 5.8, & 5.9. Extruded eyeballs in Mayan art: "Sayil, a supernatural being" (top), "named deer spirit" (left), and "mammal with vessel" (right). Modified from Houston, 2013.

In virtual spaces, observers enact vision in a similar way, the "interaction" between users and objects is initially visual. When actively looking at objects or space in VR, there is a perceived distance between you and the physical subject of your gaze; in contrast, when viewing 3D objects out of context with a backdrop of neutral space a sense of distance is lost. This difference occurs, in part because, to "assign" object identity requires viewers to "pro-creatively" use their senses to imbue the things in their vision with meaning, and thus the act of movement and interaction alongside vision is the primary method of learning about the simulated context of the objects and environment. At the same time, the observer has the ability to "uncloud" their vision and when focusing on the sensed data see reality that is a part of and "beyond" the simulated space.

Enacting this concept in a Maya context is perhaps highly appropriate and contextually useful given the Maya idea of sight and how it interacts with the physical world; bringing us closer to an understanding of how they might have perceived these objects and spaces, or at least providing present-day experiences closer to the past.

In Maya architecture and civic organization, the placement and design of structures was intended to shape the experience of the people within it (Mongelluzzo, 2013; Richards-Rissetto 2010). Often the arrangement of architecture served to enforce power dynamics among the populace, where the stone would speak to the senses, conveying who was welcome or who was not, and how one should perceive the space in which they were standing (Mongelluzzo, 2013). In the case of the East Court at Copan, scholars contend that the west staircase was a destination point for a perambulation that represented a confined descent into the underworld (Baudez 2015; von Schwerin 2011). Spectators in the East Court would have been looking west toward the setting sun which is depicted as the Old Sun on the center relief and the entrance to the underworld, guarded by two jaguars becomes narrower as it progresses denoting it as a path for the privileged only (Baudez 2015). This progression leads the actors down into the courtyard where they are met with three slabs sculpted to display roaring jaguars flanked by shields, imagery of war and sacrifice, and the process through which the old sun is strengthened and can be born again (Baudez 2015).

This example shows that the Maya used the structure of their ceremonial places to denote kinds of power. Here onlookers are reminded of the privileged understanding of the cosmology and how the seclusion of this space denotes privacy and privilege. Maya hierarchy was punctuated by vertical distance, up and further away denoted power, and

so viewers on the floor of the court would need to look up and presumably further away to see the procession carried out, reinforcing a viewer's place in the cosmology and potentially society (Mongelluzzo 2013). Sight played an important role in Maya thought and was clearly regulated and coerced by visual representations of power structures evident in the structural design of both civic and ceremonial spaces.

5.3. Object Identity in Models and Landscapes

3D digital models, in the case of artifacts, often seem to reflect the disconnection that their real-life counterparts experience once excavated, cataloged, and stored (Pietroni 2016). Digital "things" that exist in the traditional or the default digital space inherently lack any relationship to other things or ideas that real objects might possess as a means of identity. Noting Prechtel (2016), 3D digital models used for visualization gain justification and purpose only when they can be perceived in three dimensions, thus 3D projections onto a two-dimensional surface that is not embodied presents a problematic mode of existence for 3D artifacts.

It is important to note that although modelling does capture an essential visual essence, it does not produce the same physical presence of the original (Jefferey 2015). Digital models have different and unique attributes from physical objects. They carry measurable geometric data instead of having a touchable surface, they have polygon counts and texture atlases that users are unable to feel and experience through touch, and yet users must perceive them through these attributes for them to exist and have meaning (Agugiaro et al. 2011; Jeffery 2015).

Using new technologies, we can mitigate or even alleviate this situation. Numerous programs allow for the perception of this new data type on any device from phone screens to VR goggles, or from web-based viewing to desktop programs. However, the traditional interaction afforded by the popular single object viewers (e.g. Sketchfab, Google Poly, Microsoft 3D Viewer) (Fig. 5.10) is perhaps not sufficient, given the potential for embodied object interaction in a three-dimensional space, where the space is embodied by the user.
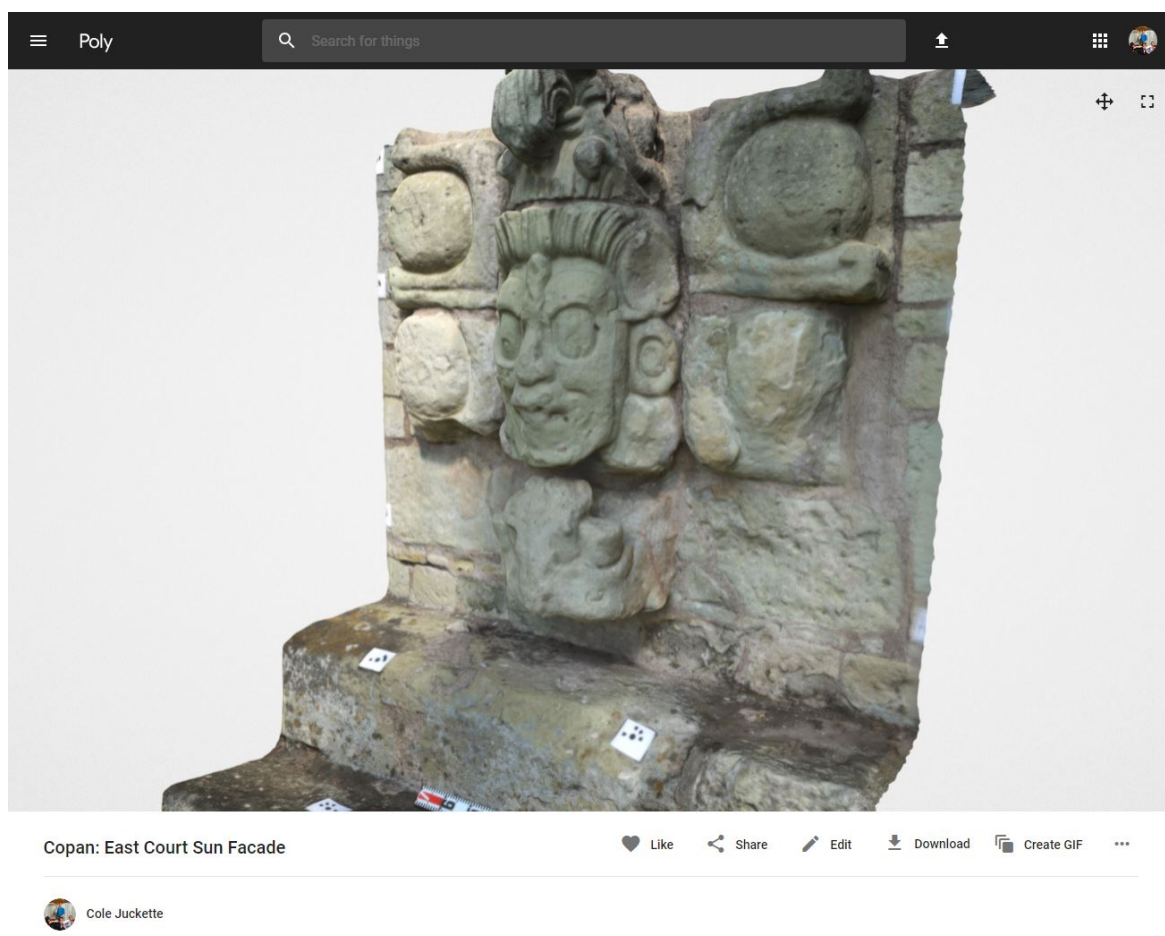

Fig 5.10. Screenshot of the author's Poly page, showing a "single object viewer"

When these 3D models are embedded in a virtual space and perceived or embodied in 3D, they gain a naturally observable spatial context, and through this context, object relationships with the space and between each other can be explored. Differently from the "virtual" environment before, described by Forte (2010; 2016) as the predecessor to "cyber" archaeological spaces, where the experience was primarily topographical, bringing photorealistic models into the environment allows users to experience both "micro" and "macro" levels of detail. Put another way, the relationship between realism and reality can now be explored in the VR landscape. Users can pause to examine a particular object and the highly detailed inscriptions on its surface, while still stepping back and gaining a sense of place from the larger environment, which is enriched by the presence of objects within it. The flow of data is bidirectional, as the environment or the modeled topography itself is an interpretable object that receives contextual data from everything in it and provides data back to those objects. The act of experiencing the simulated environment evokes a sensory experience that can be analyzed, altered, and understood, providing for the creation of new knowledge (Dell'Unto 2016; Forte 2010; Forte 2016; Pietroni 2016; Prechtel 2016). (See https://www.youtube.com/watch?v=XEXZJHNpn4c for a video of the Copan VR with integrated Models)

Using the Copan VR with incorporated 3D models, we can potentially use object identity to explore and explain the relationship between past power dynamics and that objects and buildings that reinforced or encouraged them. Using the east court as an example, we can use immersive visualization through different positioning to help understand how the view and interaction of different classes would have informed a

person's experience during a ceremonial activity. The placement of an actor portraying

the setting sun descending into the underworld (floor of the east court) would be as

different, from the placement of an onlooker positioned on the eastern floor of the court,

as it would be from the position of an elite above the floor near the structures that

comprised the upper eastern bank of the court. Each of these vantages would likely

comprise a different experience of the ceremony, and the imagery depicted on the reliefs

would be brought into different levels of focus for spectators and participants. The visual

narratives played out during a ceremony can be explored in a VR space and could

possibly inform archaeological analysis of these processions.

Chapter 6. Virtual Space

6.1. VR as a Structure for a "Living" Database

By placing 3D models of individual objects into an immersive VR landscape, an

interactive data lattice can be constructed, empowered and informed by the things

contained within it and their spatial context. Such contextualization is vital to exploring

embodiment through, for example, spatial position (a basic connection to the landscape),

chronology (its place in time, perhaps shown visually over a variety of dates and periods

of history), environment (the natural connections a thing makes to everything around it),

narrative (the exploration of activity, identity and movement), and the users own

perception (Forte 2010; Forte 2016; Tilley 2008; Tilley 2016).

In essence, this simulation represents a "living" database capable of both storing

the data in it and presenting it in a unique interactive way, created from the virtual

program. In this case, the data is experiential, relying on perceptually driven analysis,

where the data and metadata are taken from paper or single object 3D viewers and ingested into a "pseudo-real" space that users can experience via embodiment. Practically, such a VR approach is perhaps not intended to possess the utility of an archival database but rather provides a platform for conducting a more physical or embodied act of querying and creating an experience from user (inter)action. This unique way of visualizing or storing data represents a step toward enhancing object identity and data reuse, and a step toward providing a more embodied experience in the laboratory where realism and reality can be evaluated and balanced based on a user's needs.

6.2. Recycling data

Often in digital projects, after archaeologists generate remotely sensed objects or create aa VR environment, digital assets are displayed in analog publication only, as demonstration of an idea or interpretation. While this is a perfectly acceptable tool for answering questions in the field, I contend that the usefulness of these virtual objects is not fully realized outside of a 3D immersive and embodied environment. Removing 3D assets from the studies of impact that utilize them to answer questions, also potentially removes some context from the files themselves. Digital assets not perceived or visualized lose some of their purpose in a digital setting (Prechtel 2016). Therefore, setting up a platform that strategically uses them as the means of exploration greatly benefits their usefulness after creation. Exploring object identity and lived, or used spaces, using virtual reality opens the door to asset reuse by providing a platform for qualitative (re)discovery.

6.3. The Phenomenology of a Virtual Space

Phenomenology, as explained by Tilley, is partially the practice of using one's body and immersion (through embodiment) to study "things, places, and landscapes", and is realized throughout landscape archaeology as a vital research method for understanding the archaeological past (Tilley 2004). In this project, it is vital to conceive of users as more than stationary viewers, but as dynamic participants engaged with their surroundings and thus able to be embodied in the virtual landscape. VR, when designed with this goal in mind, has the potential to make heritage visualizations and analysis experiential rather than just observable fitting an appropriation of Tilley's landscape phenomenology (Fig. 6.1 see, https://www.youtube.com/watch?v=B9U3y0CbVh0 for a video of Copan VR that features object interaction).

Fig 6.1. Ceramic Incensario lid placed inside the model of structure 18.

Copan VR does not yet meet Tilley's vision for enacting a phenomenology of landscape, as it is still disconnected from a truly physical space, lacking the multisensory input and response of reality, it is "disconnected" by being primarily experienced through a pair of screens and almost entirely visual (Tilley 2008; Tilley 2016). However, VR does allow for 3D models to be placed in a pseudo-physical space where their spatial connections and experiential relationships can be explored, rather than as immaterial objects in a hard drive or single object viewer. Users have the capability of both interacting with the objects and the contextualized space while also gaining the ability to explore the interaction between the objects and the space providing more opportunities for study and learning (Forte 2016). This approach, while not present in reality still affords a qualitative insight to the interactions expressible in the space in question (Forte 2016).

6.4. Static and Flowing Virtual Space

3D objects can also be visualized in VR without "original" spatial context. For example, by designing a neutral building interior and framing each object with polygons one can make a "virtual museum" (Fig. 6.2). This museum contains   individual objects from the virtual landscape but is disconnected from it, and while plaques or maps can provide information (as text) about real-world physical connections, the objects do not possess the same kind of relationship to their contextual space as in the Copan VR; instead, users perceive them as out of place and in this case "disconnected".
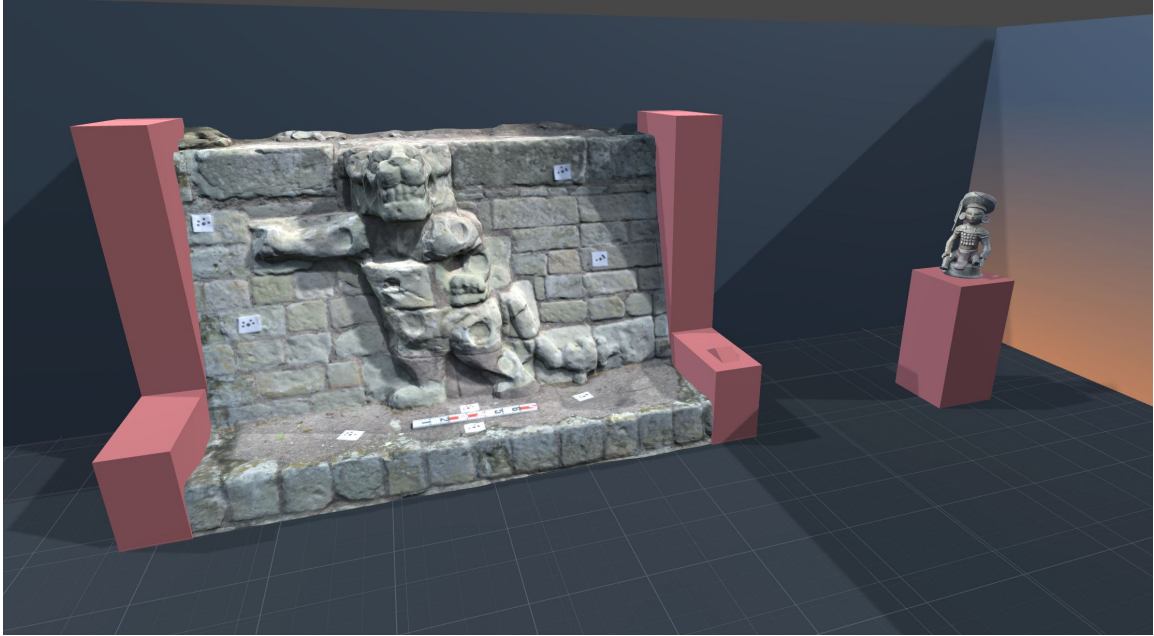
Fig 6.2. Screenshot of a corner in the Virtual Copan Museum.

The primary difference between the two approaches is essentially a difference between what I refer to as observable context and an implied or explained context. While an implied context is clearly usable and sufficient for basic understanding of an object and its attributes, a more complete understanding that includes an understanding of the relationships that it has with its context is achievable only through a more complete observable context that relies on the user as a dynamic actor in the space.

A space, such as the "virtual museum", that uses the implied context is an inherently static virtual place that simply houses models and the participant is only an observer. The objects and the data surrounding them are immutable and the contextual space between them is contorted to fit the space they occupy. Exploration of the relationships between the objects and the environment becomes difficult in such empty or neutral spaces; however, integrating them into a contextualized space representing their

potential past surroundings, creates potential for new knowledge from digitally projected

experiences. Conceptually these two scenarios represent the difference Forte (2016)

describes between the virtual and cyber archaeological approaches, where the former

lacks the necessary component of interaction that defines a useful qualitative approach to

virtual space as a platform for embodiment. The Copan VR represents a virtual

landscape where the objects in it inform on themselves and each other, while allowing for

interaction between the user and the objects in an immersive setting where the objects

gain a sense of place related to their context.

6.5 The Austerity of Models and Simulated Space

While working with remotely sensed models of objects within a contextualized

virtual space, provides alternative experiences of immersion, there are certain

shortcomings that need to be addressed. First, the problem of simulating context about

objects with little or no provenience is apparent when trying to determine how best to

place them in the virtual world. While research how to display these models and realize

uses for them analytically, it is difficult to explore them beyond their aesthetic presence

in the program without knowing more about their original provenience (in some cases) or

how past peoples used them. However, this issue also offers possibilities for   future

experimentation on how object identity could aid in finding an artifact's point of origin,

by examining the detailed relationships it has with other objects of its kind in the virtual

simulation.

Second, a disconnection exists between modern users and the cultural context of

past people, such as the ancient Maya, who used these objects and spaces. There is

simply no way, as of yet, to approximate the kind of experiences and knowledge of the

people of Copan, whose lives were structured by these objects and spaces. While we walk

through Copan VR, we are free to roam and see every part of the simulated environment

that we want, which would likely not have been the case for different classes of Copan's

people. Now that a simulation exists, it is possible to in future work to design immersive

experiences that try to approximate this kind of dynamic, but these concepts are still

being explored and studied. A potential case could use the Copan's East Court to

examine imagery presented on different structures, their narrative, and how access to

spaces shaped experiences to denote power relations.

Lastly, it is important to examine the underlying non-conformity of presenting 3D

models in a simulated space. The models incorporated are photorealistic pieces from a

modern context in Copan and do not reflect the "modeled" realism of the other parts of

the 3D environment, which reflect a different time frame for the city's existence as well

as a different level of detail in their appearance. Presenting them side by side can give the

viewer a jarring response. Seeing the computer-generated textures of the environment

interrupted by a sudden cacophony of high visual detail is certainly not the best way to

experience or explore a 3D environment Further, such simulations can distort the

chronology of the 3D environment by using objects from a modern context in a

simulation that is meant to approximate an ancient one.

Combining remotely sensed objects within simulated past spaces, however,

provides opportunities to explore the utility of augmenting the models and using their

geometric structure to varying degrees. For instance, I could alter the jaguar models in a

software such as Blender so that they reflect a more accurate approximation of their color

and completeness during the East Courts period of use, i.e. seeking realism to create a sense of place. In contrast, using only the simulated structures with applications in AR (or Augmented Reality) allows users to experience completed structures and spaces from a specified period atop existing architecture, while still allowing for the exploration and use of object identity.

7. Conclusion

Object identity, in an abstract sense, represents the ever-engaged potential for 3D models to gain not only a sense of place but a presence of being when experienced in a virtual environment. If we think about the way we treat physical artifacts in the field and how recent breakthroughs with embodied archaeology and post-processual techniques have resulted in new knowledge gained through archaeology, we should treat the virtual copies of the "things" we study with the same care and interpretive frame as material culture. Now more than ever the ability to immerse oneself in a virtual archaeological tool is achievable with few constraints, and this thesis and project is like a stepping stone representing the potential for further investigation and development.

Object Identity helps to support contentions that is essential for archaeologists to evaluate the interpretive frame of mind when entering a virtual world and how the reality of the sensed world can collide with the realism of our archaeological interpretations. In sum, I contend that uncertainty (realism) in simulated virtual space is necessary as well as, remotely sensed (or otherwise) data (reality) augments archaeological inquiry. Spatial context brings identity to the objects populated within it, but it is also vital to see that contextual model as an object of equal interpretive value or the bi-directional nature

of dataflow in this concept will be lost and the value of "real" data might be distorted as being greater that the interpreted data.

In the future, I would like to further explore the potential of the frameworks explored in this thesis, such as object identity. Data reuse is already an important aspect and strength of this project but if combined with the virtual environment in MayaCityBuilder as a means of creating embodied "living" databases that function on an archival level as well as analytical, the potential for advancement in cultural heritage studies could be striking. In addition, the immersion for the Copan VR and additional data from the MayaCityBuilder and MayaArch3D Projects should be incorporated, most notably the work by Graham Goodwin (2018) to spatially model audio models in the civic space of Copan.

Finally, while this thesis emphasizes qualitative data feedback from users, the potential to collect quantitative data about the experience is not yet realized. As mentioned by Forte (2016), the interaction with a virtual space takes place most notably, and most usefully on a cognitive level. Using this notion as a guide, it can be said that a quantitative approach would require interaction with the user on the same cognitive level. Potentially using EEG neuroimaging, we could examine the brain's reaction to perceiving space in VR and compare neural reactions to real spaces, thus attempting to find a way to measure the immersive-ness of a program or finding patterns in how the brain reacts to object interactions in VR vs. real life.

Works cited

Agugiaro, G., Remondino, F., Girardi, G., von SCHWERIN, J., Richards-Rissetto, H., & de Amicis, R. (2011). Queryarch3D: Querying and visualising 3D models of a Maya archaeological site in a Web-based interface. *Geoinformatics FCE CTU*, *6*, 10-17.

Baudez, C. F. (2015). *Maya sculpture of Copan: The iconography*. University of Oklahoma Press.

Barceló, J. A., Forte, M., & Sanders, D. H. (Eds.). (2000). *Virtual reality in archaeology*. Oxford: Archaeopress.

Bell, E. E., Canuto, M. A., & Sharer, R. J. (Eds.). (2004). *Understanding Early Classic Copan*. UPenn Museum of Archaeology.

Bruner, J. S. (1962). The conditions of creativity. In *Contemporary Approaches to Creative Thinking, 1958, University of Colorado, CO, US; This paper was presented at the aforementioned symposium.*. Atherton Press.

Buckland, P. I., Dell'Unto, N., & Pálsson, G. (2018). To tree, or not to tree? On the Empirical Basis for Having Past Landscapes to Experience. *DHQ: Digital Humanities Quarterly*, *12*(3).

Champion, E. (2010). Playing with the Past. In *Playing with the Past* (pp. 129-155). Springer, London.

Champion, E., Bishop, I., & Dave, B. (2012). The Palenque project: evaluating interaction in an online virtual archaeology site. *Virtual reality*, *16*(2), 121-139.

Champion, E. (2016). *Critical Gaming: interactive history and virtual heritage*. Routledge.

Chessa, M., Maiello, G., Borsari, A., & Bex, P. J. (2019). The perceptual quality of the oculus rift for immersive virtual reality. *Human–computer interaction*, *34*(1), 51-82.

Christenson, A. J. (Ed.). (2000). *Popol Vuh: The Mythic Sections, Tales of First Beginnings from the Ancient K'iche'-Maya*. Foundation for Ancient Research and Mormon Studies at Brigham Young University.

Csordas, T. J. (1990). Embodiment as a Paradigm for Anthropology. *Ethos*, *18*(1), 5-47.

Dell'Unto, N., Leander, A. M., Dellepiane, M., Callieri, M., Ferdani, D., & Lindgren, S. (2013, October). Digital reconstruction and visualization in archaeology: Case-study drawn from the work of the Swedish Pompeii Project. In *2013 Digital Heritage International Congress (DigitalHeritage)* (Vol. 1, pp. 621-628). IEEE.

Dell'Unto, N. (2016). Using 3d GIS platforms to analyse and interpret the past. In *Digital Methods and Remote Sensing in Archaeology* (pp. 305-322). Springer, Cham.

Demetrescu, E., Ferdani, D., Dell'Unto, N., Touati, A. M. L., & Lindgren, S. (2016). Reconstructing the original splendour of the House of Caecilius Iucundus. A complete methodology for virtual archaeology aimed at digital exhibition. *SCIRES-IT-SCIentific RESearch and Information Technology*, *6*(1), 51-66.

Desai, P. R., Desai, P. N., Ajmera, K. D., & Mehta, K. (2014). A review paper on oculus rift-a virtual reality headset. *arXiv preprint arXiv:1408.1173*.

Dylla, K., Frischer, B., Müller, P., Ulmer, A., & Haegler, S. (2008). Rome reborn 2.0: A case study of virtual city reconstruction using procedural modeling techniques. *Computer Graphics World*, *16*(6), 62-66.

Fash, W. L. (2000). *Scribes, warriors, and kings: the city of Copán and the Ancient Maya*. London: Thames and Hudson.

Forte, M., & Siliotti, A. (1997). Virtual archaeology. *New York: Harry N. Abrams*.

Forte, M. (Ed.). (2010). *Cyber-archaeology*. Oxford: Archaeopress.

Forte, M. (2015). Cyberarchaeology: a Post-Virtual Perspective. *Humanities and the Digital. A Visioning Statement. MIT Press. Boston*.

Forte, M. (2016). Cyber archaeology: 3D sensing and digital embodiment. In *Digital Methods and Remote Sensing in Archaeology* (pp. 271-289). Springer, Cham.

Frischer, B., Abernathy, D., Guidi, G., Myers, J., Thibodeau, C., Salvemini, A., ... & Minor, B. (2008, August). Rome reborn. In *ACM SIGGRAPH 2008 new tech demos* (p. 34). ACM.

Garstki, K. (2017). Virtual representation: the production of 3D digital artifacts. *Journal of Archaeological Method and Theory*, *24*(3), 726-750.

Gibbs Jr, R. W. (2005). *Embodiment and cognitive science*. Cambridge University Press.

Gillings, M. (1999). Engaging place: a framework for the integration and realisation of virtual-reality approaches in archaeology. *BAR International Series*, *750*, 247-254.

Goodwin, G. (2018). Modeling Sound in Ancient Maya Cities: Moving Towards a Synesthetic Experience using GIS & 3D Simulation.

Hanks, W. F. (1990). *Referential practice: Language and lived space among the Maya*. University of Chicago Press.

Houston, S., Stuart, D., & Taube, K. (2013). *The memory of bones: body, being, and experience among the Classic Maya*. University of Texas Press.

Jeffrey, S. (2015). Challenging heritage visualisation: beauty, aura and democratisation. *Open Archaeology*, *1*(1).

Kantner, J. (2000). Realism vs. reality: creating virtual reconstructions of prehistoric architecture. *BAR International Series*, *843*, 47-52.

Karras, G. E., Patias, P., & Petsa, E. (1996). Digital monoplotting and photo-unwrapping of developable surfaces in architectural photogrammetry. *International Archives of photogrammetry and Remote Sensing*, *31*, 290-294.

Koutsoudis, A., Vidmar, B., Ioannakis, G., Arnaoutoglou, F., Pavlidis, G., & Chamzas, C. (2014). Multi-image 3D reconstruction data evaluation. *Journal of Cultural Heritage*, *15*(1), 73-79.

Limp, W. F. (2016). Measuring the Face of the Past and Facing the Measurement. In *Digital Methods and Remote Sensing in Archaeology* (pp. 349-369). Springer, Cham.

Miller, P., & Richards, J. (1995). The good, the bad, and the downright misleading: archaeological adoption of computer visualisation. *BAR INTERNATIONAL SERIES*, *600*, 19-19.

Millhauser, J. K., & Morehart, C. T. (2016). The ambivalence of maps: A historical perspective on sensing and representing space in mesoamerica. In *Digital Methods and Remote Sensing in Archaeology* (pp. 247-268). Springer, Cham.

Mongelluzzo, R. (2013). Maya palaces as experiences: ancient Maya royal architecture and its influence on sensory perception. *Making Senses of the Past: Toward a Sensory Archaeology*, (40), 90.

B. Olson, 2016. "The Things We Can Do With Pictures," in *Mobilizing the Past for a Digital Future*, eds. E. Averett, J. Gordon, D. Counts, pp. 237–50.

Opitz, R., & Herrmann, J. (2018). Recent trends and long-standing problems in archaeological remote sensing. *Journal of Computer Applications in Archaeology*, *1*(1), 19-41.

Pattee, A. (2016). Photogrammetric Procedure for Modeling Castles and Ceramics.

Pietroni, E. (2016). From remote to embodied sensing: new perspectives for virtual museums and archaeological landscape communication. In *Digital Methods and Remote Sensing in Archaeology* (pp. 437-474). Springer, Cham.

Plets, G., Gheyle, W., Verhoeven, G., De Reu, J., Bourgeois, J., Verhegge, J., & Stichelbaut, B. (2012). Three-dimensional recording of archaeological remains in the Altai Mountains. *Antiquity*, *86*(333), 884-897.

Prechtel, N., & Münster, S. (2016). Cultural heritage in a spatial context–towards an integrative, interoperable, and participatory data and information management. In *3D Research Challenges in Cultural Heritage II* (pp. 272-288). Springer, Cham.

Pujol, L. (2004). Archaeology, museums and virtual reality. *Digithum*, *6*, 1-9.

Rabinowitz, A. (2015). The work of archaeology in the age of digital surrogacy. *Visions of substance: 3D imaging in Mediterranean archaeology*, 27-42.

Rands, R. L., Bishop, R. L., & Harbottle, G. (1978). *Thematic and compositional variation in palenque-region incensarios*(No. BNL-26128; CONF-7806150-1). Southern Illinois Univ., Carbondale (USA); Brookhaven National Lab., Upton, NY (USA).

Reilly, P. (1990, March). Towards a virtual archaeology. In *Computer Applications in Archaeology* (pp. 133-139). Oxford: British Archaeological Reports.

Richards-Rissetto, H., Remondino, F., Agugiaro, G., von Schwerin, J., Robertsson, J., & Girardi, G. (2012, September). Kinect and 3D GIS in archaeology. In *2012 18th International Conference on Virtual Systems and Multimedia* (pp. 331-337). IEEE.

Richards-Rissetto, H., Robertsson, J., Remondino, F., Agugiaro, G., von Schwerin, J., & Galibri, G. (2013). Geospatial virtual heritage: an interactive, gesture-based 3D GIS to engage the public with ancient Maya archaeology. *Proceedings of Computer Applications and Quantitative Methods in Archaeology, Southampton, United Kingdom, March*, *2629*.

Richards-Rissetto, H., & Landau, K. (2014). Movement as a means of social (re) production: using GIS to measure social integration across urban landscapes. *Journal of Archaeological Science*, *41*, 365-375.

Richards-Rissetto, H., & Plessing, R. (2015, September). Procedural modeling for ancient Maya cityscapes initial methodological challenges and solutions. In *2015 Digital Heritage* (Vol. 2, pp. 85-88). IEEE.

Richards-Rissetto, H. (2017). What can GIS+ 3D mean for landscape archaeology?. *Journal of Archaeological Science*, *84*, 10-21.

Richards-Rissetto, H. (2017). An iterative 3D GIS analysis of the role of visibility in ancient Maya landscapes: A case study from Copan, Honduras. *Digital Scholarship in the Humanities*, *32*(suppl_2), ii195-ii212.

Richards-Rissetto, H., & von Schwerin, J. (2017). A catch 22 of 3D data sustainability: Lessons in 3D archaeological data management & accessibility. *Digital applications in archaeology and cultural heritage*, *6*, 38-48.

H. Richards-Rissetto, Z. Day, S. Bolan and I. Beddes, "Not all data are born digital: workflows to facilitate data integration and rapid visualization of 3D landscapes," 46th Computer Applications in Archaeology, Tubingen, Germany. March 2018 (https://cdrhsites.unl.edu/keeping-data-alive/workflows_2.html).

Sapirstein, P. (2016). Accurate measurement with photogrammetry at large sites. *Journal of Archaeological Science*, *66*, 137-145.

Schott, J. R. (2007). *Remote sensing: the image chain approach*. Oxford University Press on Demand.

von Schwerin, J., Auer, M., Billen, N., Loos, L., Richards-Rissetto, H., Reindel, M., Zipf, A., Remondino, F., Fernández-Palacios, B.J. (2015): A 4DWebGIS for the Documentation and Analysis of Complex Archaeological Sites [Abstract]. In: 43rd Computer Applications and Quantitative Methods in Archaeology Annual Conference Book of Abstracts (CAA 2015). Siena, Italy.

von Schwerin, J., Richards-Rissetto, H., Remondino, F., Agugiaro, G., & Girardi, G. (2013). The MayaArch3D project: A 3D WebGIS for analyzing ancient architecture and landscapes. *Literary and Linguistic Computing*, *28*(4), 736-753.

von Schwerin, J., Richards-Rissetto, H., Remondino, F., Spera, M. G., Auer, M., Billen, N., ... & Reindel, M. (2016). Airborne LiDAR acquisition, post-processing and accuracy-checking for a 3D WebGIS of Copan, Honduras. *Journal of Archaeological Science: Reports*, *5*, 85-104.

Sharer, R. J., & Traxler, L. P. (2006). The ancient maya. *Journal of Latin American Anthropology*, *11*(1), 220-222.

Tilley, C. (2004). *The materiality of stone: explorations in landscape phenomenology*. Berg publishers.

Tilley, C. (2008). Phenomenological approaches to landscape archaeology. *Handbook of landscape archaeology*, 271-276.

Tilley, C. (2016). *Interpreting Landscapes: Geologies, Topographies, Identities; Explorations in Landscape Phenomenology 3*. Routledge.

Using Virtual Reality and Photogrammetry to Enrich 3D Object Identity

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Abstract—**The creation of digital 3D models for cultural heritage is commonplace. With the advent of efficient and cost effective technologies archaeologists are making a plethora of digital assets. This paper evaluates the identity of 3D digital assets and explores how to enhance or expand that identity by integrating photogrammetric models into VR. We propose that when a digital object acquires spatial context from its virtual surroundings, it gains an identity in relation to that virtual space, the same way that embedding the object with metadata gives it a specific identity through its relationship to other information. We explore this concept by integrating reality-based photogrammetric models with hypothetical 3D reconstructions in VR to bring together "realism" and "reality" to help users form a spatial identity for the objects they are viewing and pursue a more interactive experience with both the embedded models and pursue new lines of archaeological inquiry.**

Keywords—virtual reality, GIS, photogrammetry, landscape archaeology, embodiment

I. Introduction

Digital technologies enable archaeologists to more quickly and easily convert physical "things" into digital "things". Technologies such as laser scanning and photogrammetry rapidly acquire high-resolution 3D data that is post-processed into various products and formats [1]. While hardware and software increasingly allow us to work with larger 3D datasets, a challenge we still face is that often 3D data remain as isolated objects, viewed individually in 3D viewers such as Sketchfab or 3DHOP with minimal metadata and paradata. The downside is that the potential of 3D data are not fully realized—these data are rarely reused in other visualizations and even more rarely for subsequent (i.e., beyond original purpose) scholarly research. To facilitate the re-use of 3D data we contend archaeologists must re-evaluate, or move beyond, an object-centric approach. While such a shift has many facets, we focus on a workflow to integrate photogrammetrically-derived 3D objects into 3D virtual reality scenes. Underlying this research is the debate surrounding "realism" vs. "reality". Do we use hypothetical reconstructions to present a vision of the past that gives a sense of ancient life (realism) or do we visualize strictly what we can reconstruct from archaeological data (reality)? While opponents of realism contend that hypothetical reconstructions give a false impression of certainty, proponents believe that hypothetical reconstructions convey a reality that helps engage the public and assists scholarly research [2,3,4]. In this project, we seek to bring together these "two sides" using a VR environment to facilitate 3D data re-use not only for visualization purposes but for new scholarly research involving embodiment [5,6]. We seek to

find compromise and balance between 'realism" and "reality" by integrating a highly authentic platform design (based on georeferencing) that also allows users a sense of perception and space [7].

A. MayaCityBuilder

This research is part of the MayaCityBuilder project, which uses Geographic Information Systems (GIS) and 3D visualization to study social interaction in Ancient Maya cities [8,9,10]. To work towards this goal, the project focuses on developing transmutable design and workflows for making spatial simulations in VR based on GIS and other geospatial data that also serve as a toolset for other projects [11] (Fig. 1).

The case study is the ancient city of Copan located at the southeast periphery of the ancient Maya world. Building on geospatial data from the MayaArch3D Project [12,13], we are developing a VR environment of mid-eighth to early-ninth century Copan. The VR integrates 3D models from Computer Aided Design (CAD), procedural modeling, laser scanning, and photogrammetry to contextualize artifacts and structures within a larger spatial context.

Fig. 1. Copan VR environment (Unity-based)

B. Research Goals

In this paper, we focus on integrating high-resolution photogrammetric models into an existing VR environment developed using 3D reconstructions derived from GIS data and CAD models (3D Studio Max, SketchUp) using the game engine Unity [14,15,16] There are three components:

- Create geometrically complete photorealistic models of artifacts and architectural sculpture
- Integrate these photogrammetric models into the Copan VR
- Evaluate the VR environment as an interactive tool that allows users to test 3D reconstructions by bringing together individual 3D objects into a larger spatial context

II. PHOTOGRAMMETRIC METHODS

Photogrammetry, or image-based modeling, is now common in archaeology. Generally speaking, the photogrammetric process involves three stages: object selection, data acquisition, and data post-processing (modeling).

A. Object Selection

In June 2017, we ran a workshop to teach terrestrial photogrammetry to Anthropology students at the Universidad Nacional Autónoma de Honduras (UNAH) at Copan. As part of this workshop, we coordinated with the Honduran Institute of Anthropology and History (IHAH) to identify high-priority models to assist in conservation efforts. These models represent the individual 3D objects integrated into the Copan VR and include: two "Dancing Jaguar" architectural reliefs (Fig. 2) and a relief of the Mayan Sun God positioned over the main stair, which are situated on the walls and staircase of the western portion of the East Court of the Acropolis at Copan.

In addition to these three objects, two stone incensarios and one architectural block of a Bacab that currently rests on the eastern stairs of the court were captured. In the lab at the Regional Center for Archaeological Investigations (CRIA) we acquired data for several intact or reconstructed ceramic objects. Finally, we successfully modeled a jade figurine using an experimental low-light photography technique that maximizes surface details and minimizes glare [17].
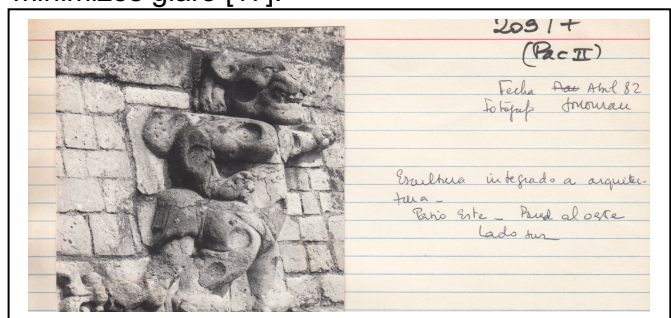

Fig. 2. Catalog card for Dancing Jaguar No.2.

B. Data Acquisition

We chose photogrammetry—an image-based approach—as the method of 3D capture because it is cost effective and affords high-resolution 3D models [18,19]. We used a Nikon D5500 DSLR camera with 24.2 megapixels for capturing field

data. While we encountered certain challenges working outdoors at the archaeological site such as intense sunlight and unpredictable rain resulting in objects with diverse illumination, we overcame such problems by adjusting basic camera settings like ISO, aperture, and shutter speed for each object session depending on what conditions were available. [19]. For objects captured indoors under "controlled" settings, we used light boxes and portable LED light rigs. The average number of photos for these objects ranges from 100-250 based on object size, shape (geometric complexity), and quality desired because we found that with the available equipment using more photographs for certain objects, yielded sharper textures.

C. Data Post-processing

We employed Agisoft's PhotoScan Pro to generate the 3D models. Scale was applied in Agisoft either by using the software's recognized markers to input distances across a plane or by placing a measuring tool (e.g., ruler) on or near the object while it is being photographed and manually inputting the distance (Fig. 3). We test the measurements on each object to ensure they are at least within 1mm accuracy and if necessary each photo is examined and photos with excessively high pixel error values (i.e. greater than 1 pixel) are removed. Given that models are intended for VR and the challenging environmental circumstances, we balanced our efforts to achieve geometric accuracy with acquiring high-quality textures in a limited time frame.
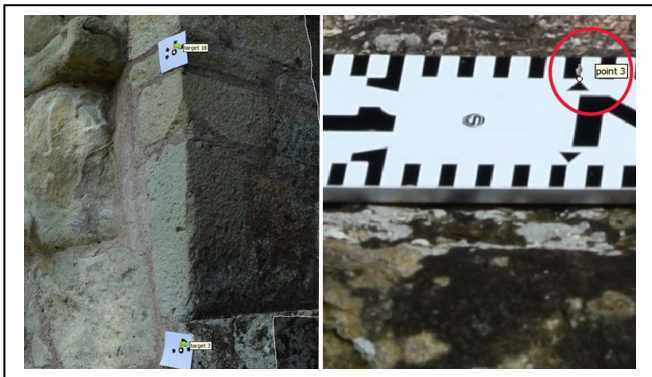

Fig. 3. Calibrated markers (left); scene scale (right) for measurements.

Lastly, we export the models into the .obj format (for importing to Unity), .ply (for importing to Meshlab), and 3D .pdf (for easy distribution to Honduran project members and others, who only have access to Adobe software) (Fig. 4).

Fig. 4. Finished Dancing Jaguar model

III. VR Integration

A. Using GIS to Give Models Spatial Context

Given that a main goal of this research is to find compromise and balance between "realism" and "reality", we employ GIS data to provide spatial reference to the VR environment. The process involves: (1) exporting a polygon shapefile of structure footprints from GIS to a collada file and (2) converting the Digital Elevation Model (DEM) to a heightmap for import into Unity. These two files provide terrain, structure location (in relation to terrain), and scale in the VR. In the Copan VR these structure footprints are populated with 3D models generated from various sources including extruded GIS footprints based on a height attribute, SketchUp models (exported to collada), and 3D Studio Max files to create the Copan VR (Fig. 1). This 3D environment is what provides spatial context to the photogrammetric models.
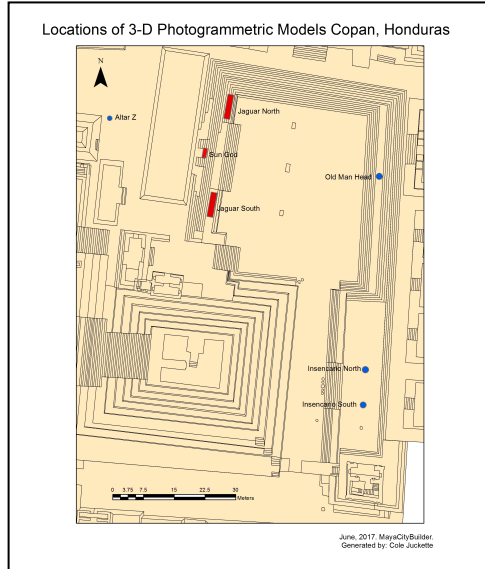
Fig. 5. GIS map of object locations in East Court, Copan.

Fig. 5 illustrates the locations of six of the photogrammetric models from the project—all of which were previously present in the GIS. These locations serve as anchors within the VR lattice to place the photogrammetric models; in other words, they give a visible spatial context to these originally "free-floating" or isolated objects (for example, as typically seen on a platform such as Sketchfab).

B. Integrating Photogrammetric Models into VR

Our objective was to develop a workflow to easily and efficiently import and integrate the photogrammetric models into the VR without requiring additional proprietary software, in other words directly from Agisoft to Unity. To achieve this objective, we performed tests on three 3D model file types—.fbx, .obj, and .dae—to determine which file type "carries" the most information with it, particularly in regard to orientation and scale. When exported from Agisoft .fbx and .dae files store the pathways to each aligned photo in an Agisoft project. Therefore, when, for example, we imported the Dancing Jaguar, Unity attempted to simultaneously visualize over 200 photos in addition to an entire textured 3D object, causing the program to crash. A

solution for severing the connection between the files types and their component photos in Unity alone is potentially possible but has not been attempted as of yet. Therefore, we turned to the .obj file type, which is a common file used in digital scholarship and is a widely accepted format for both desktop and web based platforms. The downside to using OBJ's is that they do not carry the same amount of orientation and reference data into Unity because they use an associated .mtl file to store this information, and Unity cannot import a .mtl. Thus, the location, orientation, and scale of OBJ models uploaded must be manually adjusted in the program. While this manual approach is only a short-term solution, the OBJ allows us to integrate the photogrammetric models into the VR without causing problems with our program.

Using the Unity coordinate plane and either a "distance tool" or a "default cube", we then align and scale the models so they properly anchor to the GIS footprint locations. At this point, the photogrammetric models have proper spatial reference in the Copan VR allowing users to interact with these archaeological artifacts in their simulated context rather than as isolated objects (Fig. 6).
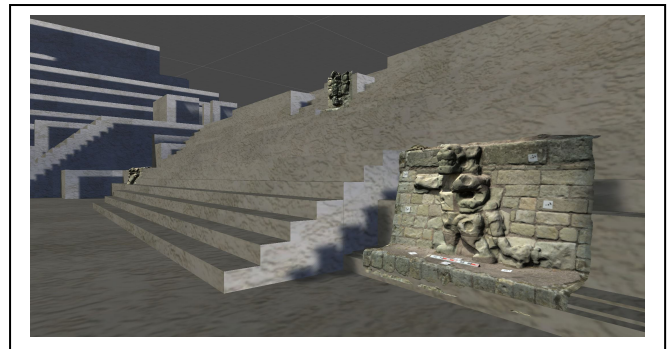

Fig. 6. Integrated structural models in the East Court.

IV. Object Identity: Virtual Spatial Paradigms

3D digital models, like the physical objects they represent, are, often without context, inherently "disconnected" things that lack the necessary relationships to other things and ideas to give them an interpretable identity. It is also true that, though modelling can capture the visual essence of a physical object there is still no aspect of a digital

model that develops a physical presence the same as the original [20]. Digital models have different and unique attributes from physical objects. They carry measurable geometric data instead of having a touchable surface, they have polygon counts and texture atlases that are unable to be felt and experienced through touch, and they must be tied to these data (attributes) in order to exist and have meaning [20,21]. Drawing from the work of Tilley we can understand the place and importance of embodiment and concepts like phenomenology in archaeological study, mainly the ability to study "things, places, and landscapes" by immersing oneself and their body in it [22]. In digital heritage we aim to see users as more than viewers, but as participants engaged with their surroundings, using VR to make the heritage more than merely observable but truly experiential. Furthermore, given that we are digitizing heritage, we need to give digital assets the attributes necessary to allow users to experience or embody them as we do physical and tangible heritage. As it relates to phenomenology, VR cannot yet encompass Tilley's vision as it is still disconnected from a true physical multisensory experience of presence; that is, inherently disconnected by being viewed through a series of screens and VR is still a primarily visual experience [23]. Conceptually however, VR allows us to move 3D assets out of a collection or library of purely immaterial objects and into a pseudo-physical space where they gain spatial significance and experiential interaction becomes possible. For example, fig. 7 illustrates gesture-based immersive interaction using a Leap Motion with Oculus Rift headset allowing a user to "hold" a torch to while walking through an ancient Maya temple. Noting Prechtel [7], 3D digital models used for visualization gain justification and purpose only when they can be perceived in three dimensions. Using new technologies we can move the data off of paper, so to speak, and really interact with it. However, while interacting with single, isolated objects has great utility, we also need to move beyond "free floating" objects. Virtual reality affords more experiential interaction than 3D single object viewers.

Fig. 7. Using the Leap Motion device for object interaction.

In particular, by integrating photogrammetric models (or other reality-based 3D models of extant artifacts, sculpture, or structures) within VR, these 3D objects gain a relationship with their environment through an observable spatial context. Users can focus on object details such as carved iconography (typically missing in the rest of the VR environment) and yet are still free to step back and experience a sense of place enriched by the embedded 3D object within its larger context. In this way, the identities of both the object and the VR environment (i.e., surrounding buildings, plazas, landscapes, etc.) become enriched being perceived as sensory metadata and allowing for the creation of new knowledge [7].

FUTURE DIRECTIONS

The next steps in this project are twofold: (1) automate the workflow and (2) embed metadata into the 3D photogrammetric models that transfers directly into the larger virtual environment and vice versa. We plan to customize script using C# to automate the workflow for integrating photogrammetric models into Unity to not only streamline the process, but to avoid potential problems of accuracy in manual model placement, orientation, and scale. In this approach, the photogrammetric models need to "bring" with them a readable version of the script that codes object orientation and scale based on the Unity scale units. While the MayaCityBuilder Project has written C# code to automatically populate building footprints based on an id in Unity—the process to code footprints in Unity is still manual [11]. Moreover, the challenge remains to modify the script to automatically orient and scale the models to the footprints.

In archaeology, we typically employ an object-centric approach that carries metadata with 3D digital objects [24]; however, when embedded within a VR environment, these 3D models do not acquire new metadata from their virtual spatial surroundings, nor does the metadata of the 3D objects become part of the VR metadata—the model remains independent in the Assets folder. Instead, we propose a bi-directional approach in which metadata (and paradata) flows from the object to the scene and back to the embedded objects. Such an approach will enrich the inherent identity of 3D

objects and enhance their usability, going beyond their involvement in the virtual environment and providing a contextual roadmap for end users to deploy in analysis and re-use.

REFERENCES

[1] F. Remondino and S. Campana (editors), "3D recording and modelling in archaeology and cultural heritage - theory and best practices". Oxford, England: Archaeopress BAR, 2014.

[2] J. Kantner, "Realism vs. reality: creating virtual reconstructions of prehistoric architecture" in Virtual Reality in Archaeology, J.A. Barcelo, M. Forte, and D. Sanders, Eds. Oxford, England: Archaeopress BAR, 2000, pp. 47-52

[3] A. Bentkowska-Kafel, H. Denard and D. Baker (editors), "Paradata and transparency in virtual heritage". Farnharm, UK: Ashgate Pub. 2012.

[4] M. Forte, "Cyber archaeology: 3D sensing and digital embodiment" in Quantitative Methods in the Humanities and Social Sciences, M. Forte and S. Campana, Eds. Springer, Cham. 2016, pp. 271-289.

[5] M. Forte and E. Bonini, "Embodiment and enaction: a theoretical overview for cybercommunities, in Heritage in the digital era M.Ioannides, A.Addison, A. Georgopoulos, L.Kalisperis, A.Brown, D.Pitzalis, Eds., Multi-Science Publishing Co. 2010, pp. 45-56.

[6] N. Prechtel, and S. Munster, "Cultural heritage in a spatial context—towards an integrative, interoperable, and participatory data and information management". In 3D Research Challenges in Cultural Heritage II, pp. 272-288. Springer, Cham, 2016.

[7] H. Richards-Rissetto, "An iterative 3DGIS analysis of the role of visibility in ancient Maya landscapes: a case study from Copan, Honduras," Digital Scholarship in the Humanities, 32(2): ii195–ii212, 2017.

[8] H. Richards-Rissetto and K. Landau, "Movement as a means of social re(production): using GIS to measure social integration in urban landscapes," Journal of Archaeological Science 41: 365-375. 2014.

[9] H. Richards-Rissetto, "What can GIS + 3D mean for landscape archaeology?" Journal ofArchaeological Science 84: 10-21. 2017.

[10] H. Richards-Rissetto, Z. Day, S. Bolan and I. Beddes, "Not all data are born digital: workflows to facilitate data integration and rapid visualization of 3D landscapes," 46th Computer Applications in Archaeology, Tubingen, Germany. March 2018.

[11] J. von Schwerin, H. Richards-Rissetto, F. Remondino, and G. Agugiaro, "The MayaArch3D Project: A 3D WebGIS for analyzing ancient Maya architecture and landscapes at Copan, Honduras,"Literary and Linguistic Computing 28(4):736-753.2013.

[12] von Schwerin, J., H. Richards-Rissetto, F. Remondino, M. Grazia Spera, M. Auer, N. Billen, L. Loos, and M. Reindel, "Airborne LiDAR acquisition, post-processing and accuracy-checking for a 3D WebGIS of Copan, Honduras." Journal of Archaeological Science Reports 5: 85-104.2016.

[13] M. Lyons, "A 3D reconstruction of Structure 10L-18 in Copán, Honduras: data structuring for transparency" (MA thesis). Department of Cultural Anthropology of the Americas, University of Bonn. 2016.

[14] H. Richards-Rissetto, "From mounds to maps to models: visualizing ancient architecture across landscapes," Digital Heritage International Congress, Volume 2: 519-522. IEEE Conference Publications. 2013.

[15] J. von Schwerin, "The sacred mountain in social context. Symbolism and history in Maya Architecture: Temple 22 at Copan, Honduras," Ancient Mesoamerica 22(2): 271-300. 2011.

[16] A. Pattee, "Photogrammetric procedure for modeling castles and ceramics". archiv.ub.uni-heidelberg.de, 2016.

[17] P. Sapirstein, "Photogrammetry as a tool for architectural analysis: the digital architecture project at Olympia." In Archaeological Research in the Digital Age: Proceedings of the 1st Conference on Computer Applications and Quantitative Methods in Archaeology, Greek Chapter. Rethymno, Crete, March 6–8 2014, pp. 129-39. 2015.

[18] A. Koutsoudis, B. Vidmar, G. Ioannakis, F. Arnaoutoglou, G. Pavlidis, and C. Chamzas, "Multi-image 3D reconstruction data evaluation." Journal of Cultural Heritage 15, no. 1 (2014): 73-79.

[19] K. Garstki, "Virtual representation: the production of 3D digital artifacts". Journal of Archaeological Method and Theory 24, no. 3 (2017): 726-750.

[20] S. Jeffrey, "Challenging heritage visualisation: beauty, aura and democratisation". Open Archaeology 1, no. 1 (2015).

[21] G. Agugiaro, F. Remondino, G. Girardi, J. von Schwerin, H. Richards-Rissetto, and R. de Amicis, "QueryArch3D: querying and Vvsualizing 3D Models of a Maya archaeological site in a webbased interface." Geoinformatics FCE CTU Journal, vol. 6: 10-17, Prague, Czech 2011.

[22] C. Tilley, The Materiality of Stone: Explorations in Landscape Phenomenology. Oxford: Berg, 2004.

[23] Tilley, Christopher. "Phenomenological approaches to landscape archaeology." *Handbook of landscape archaeology*(2008): 271-276

[24] G. Agugiaro, F. Remondino, G. Girardi, J. von Schwerin, H. Richards-Rissetto, and R. de Amicis, "QueryArch3D: querying and Vvsualizing 3D Models of a Maya archaeological site in a webbased interface." Geoinformatics FCE CTU Journal, vol. 6, pp. 10-17, Prague, Czech Republic.2011.

APPENDIX B: 2017 FIELD INFORME

Proyecto MayaCityBuilder: Informe de Campo Junio 5-Junio 23, 2017

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Objetivos:

Para este corto periodo (3 semanas), establecimos dos objetivos.
(1) El primer objetivo consistía en enseñar el proceso de fotogrametria de artefactos y esculturas a estudiantes del Departamento de Antropología (licenciatura en arqueología) de UNAH.
(2) El segundo objetivo consistió en la creación de modelos 3D que fueran relevantes para IHAH.

Antecedentes

Objetivos a largo plazo del Proyecto MayaCityBuilder

El Proyecto MayaCityBuilder emplea el Sistema de Información Geográfica (GIS en inglés), así como visualización tridimensional 3D para estudiar la interacción social en los antiguos asentamientos urbanos del periodo Maya. Nos basamos en el trabajo previo hecho por PAC I (OPIV), el Proyecto MayaArch3D, y en dos trabajos de campo breves en 2015 y en 2016. En 2015 trabajamos en CRIA, en las Ruinas de Copán durante 3 semanas (ver Informe Preliminar 2015). In 2016, continuamos recogiendo información sobre las cerámicas PAC I de Copán junto al empleo de GIS de la región para identificar SuOPs (Sub Operaciones) con alta probabilidad de contener fragmentos de cerámica que pudieran ser utilizados para ajustar la cronología del Clasicismo Tardío – el período de tiempo objeto de estudio en esta investigación (ver Informe Preliminar2016).

Los objetivos, sin embargo, fueron algo diferentes en 2017. Nuestros dos objetivos principales fueron: (1) enseñar a estudiantes de UNAH en el uso de la fotogrametría para crear modelos de artefactos y escultura en 3D y (2) la creación modelos 3D de alta relevancia para el Instituto

Hondureño de Antropología e Historia (IHAH). Algunos de los modelos 3D se integrarían en el entorno virtual 3D que el proyecto está creando para Copán.

Objetivo no1: Enseñanza de Fotogrametría a los estudiantes hondureños

La fotogrametría es un método que usa fotografías en 2D para crear modelos de objetos en 3D.

Es el método usado en Arqueología que ha experimentado un crecimiento mayor en años recientes debido al desarrollo de métodos semi-automáticos. La fotogrametría se usa para recoger datos para la creación de modelos 3D de edificios, paisajes (UAV), artefactos, así como para la captura estratográfica y para trazar un perfil de la excavación. Se trata de una tecnología no invasiva, de bajo coste, y portátil, permitiendo conseguir modelos con precisión próxima al de unos pocos micrones, haciendo de la misma el método de aproximación ideal para arqueólogos. Es por estas razones que UNL colaboró con UNAH para enseñar a estudiantes hondureños de Arqueología la técnica de la fotogrametría.

Dos grupos de estudiantes (3 en cada uno de ellos) formados por Dr. Richards-Rissetto y dos estudiantes de maestría (MA en inglés) de UNL—un grupo cada semana. Los objetivos que nos propusimos enseñarles fueron:
Objetivo no1- conceptos claves de fotogrametría

Objetivo no2- cómo obtener las fotos deseadas basadas en la iluminación, el material a estudiar, el tamaño del objeto, etc.

Objetivo no3- cómo procesar las fotos para la creación de modelos 3D usando el software Agisoft Photoscan (el de mayor difusión entre los arqueólogos y de coste relativamente bajo)

Objetivo no4- cómo exportar modelos 3D para usar en otro software como MeshLab o con presencia en Internet, por ejemplo, utilizando Sketchfab

Dado el corto período de tiempo de que disponíamos (1 semana para cada grupo), nos centramos en objetos independientes y en esculturas arquitectónicas. No practicamos la adquisición y el procesamiento posterior de fotografías para grandes estructuras o excavaciones; sin embargo, discutimos sobre estos dos usos y suministramos información sobre las diferencias clave entre los métodos. Capturamos fotos de objetos en el Parque Arqueológico de Copán y en el Centro Regional de Investigaciones Arqueológicas (CRIA).

Objetivo no 1: enseñar los conceptos clave de la fotogrametría

Primero enseñamos a los estudiantes algunos conceptos básicos de la fotogrametría: qué es, cómo funciona ... Por ejemplo:

La fotogrametría es la ciencia de hacer mediciones a partir de fotografías para crear, por ejemplo, mapas y dibujos, medidas y/o modelos 3D de un objeto o escenario del mundo real.

Existen diferentes métodos de fotogrametría: de corto alcance y terrestres y aéreos (por ejemplo, UAV, avión, etc.) y diferentes métodos que requieren diferentes aproximaciones. Enseñamos a los estudiantes fotogrametría terrestre de corto alcance utilizando Structure from Motion (SfM), una técnica fotogramétrica utilizada para crear modelos 3D y ortoimágenes a partir de una serie de fotografías superpuestas (Figura 1).
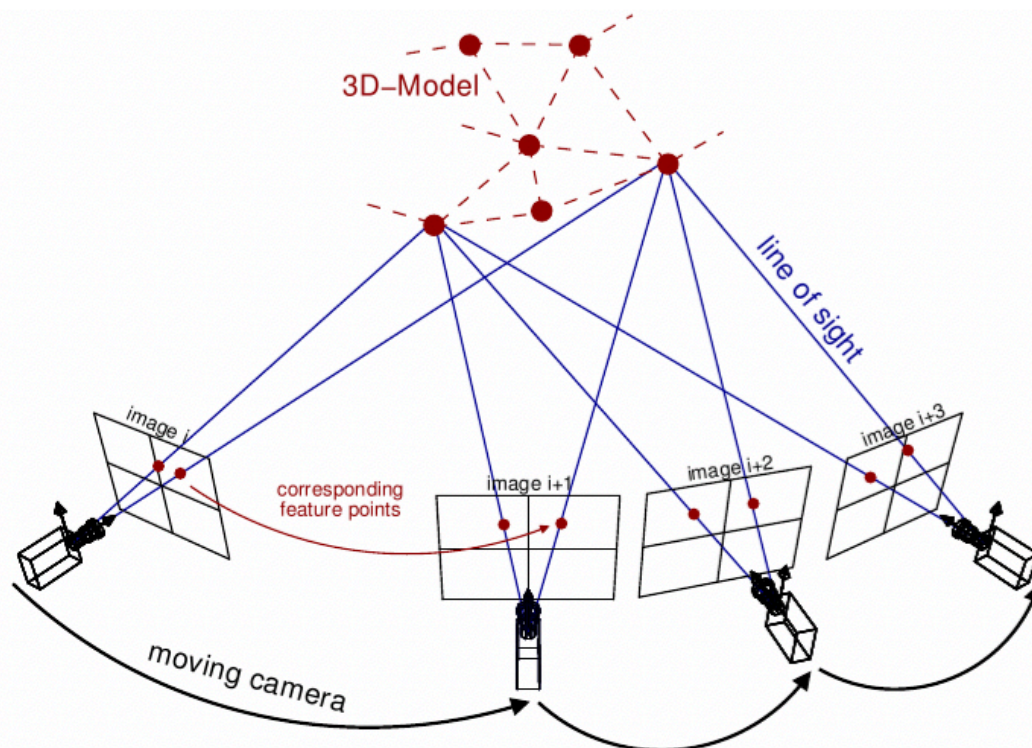

Figura 1: Ilustración de la Estructura de Movimiento (SfM en inglés) (de la Biblioteca Theia Vision)

Objetivo no 2: cómo adquirir fotografías adecuadas según el objeto y el entorno.

Primero explicamos algunos conceptos clave de la fotografía, en particular los tres ajustes que son más críticos para tomar buenas fotografías para fotogrametría: apertura, velocidad de obturación e ISO. A continuación, ilustramos cómo tomar fotografías adecuadas de un objeto sin el empleo de objetivos (en este caso, en la semana 1 practicamos con una escultura del dios del maíz y en la semana 2 con un altar en la plataforma de danza entre las Cortes de Acrópolis Este y Oeste) haciendo hincapié en lo siguiente: requerimiento de una superposición mínima 70% (máx = 90%) para cada foto, encuadre de todo el objeto en cada foto, mantenimiento del objeto en el centro de la foto, ausencia de movimiento en el fondo de las fotos a ser posible (aunque no es algo esencial), toma de fotos consistentes alrededor del objeto en una dirección, y toma de fotos a diferentes niveles aproximadamente cada 30 grados y superior dependiendo

del objeto (generalmente se requieren de 3 a 5 niveles para objetos pequeños y medianos) (Figura 2).

Figura 2: Estudiantes de UNAH practican la toma de fotos con la escultura del Dios del Maíz en el Museo de Escultura de Copán

Para comenzar nuestro trabajo seleccionamos el Museo de Escultura y el Parque Arqueológico de Copán porque la iluminación era bastante constante y los objetos eran fácilmente accesibles. Después de una demostración, los estudiantes practicaron la toma de un conjunto de fotos ellos mismos. Luego, nos mudamos a CRIA para enseñarles a los estudiantes cómo adquirir fotos para objetos relativamente pequeños que se pueden colocar en una mesa giratoria. En este enfoque, no caminamos alrededor de un objeto que toma fotos, sino que colocamos la cámara en un trípode (con ubicación fija) y giramos la mesa de giro en pequeños incrementos de distancia para capturar al menos el 70% de superposición para cada foto. Se aplica el mismo concepto de toma de fotos en distintos niveles que difieren en ángulos de 30 grados cada uno. Sin embargo, las condiciones de iluminación fueron más difíciles en CRIA debido a las ventanas y/o luces fluorescentes; por lo tanto, mejoramos las condiciones de iluminación utilizando cajas de luz y luz indirecta (Figura 3). Además, introdujimos el concepto

de empleo de objetivos para mejorar los resultados de la alineación de la cámara y, por consiguiente, la precisión general del modelo final (Figura 4).
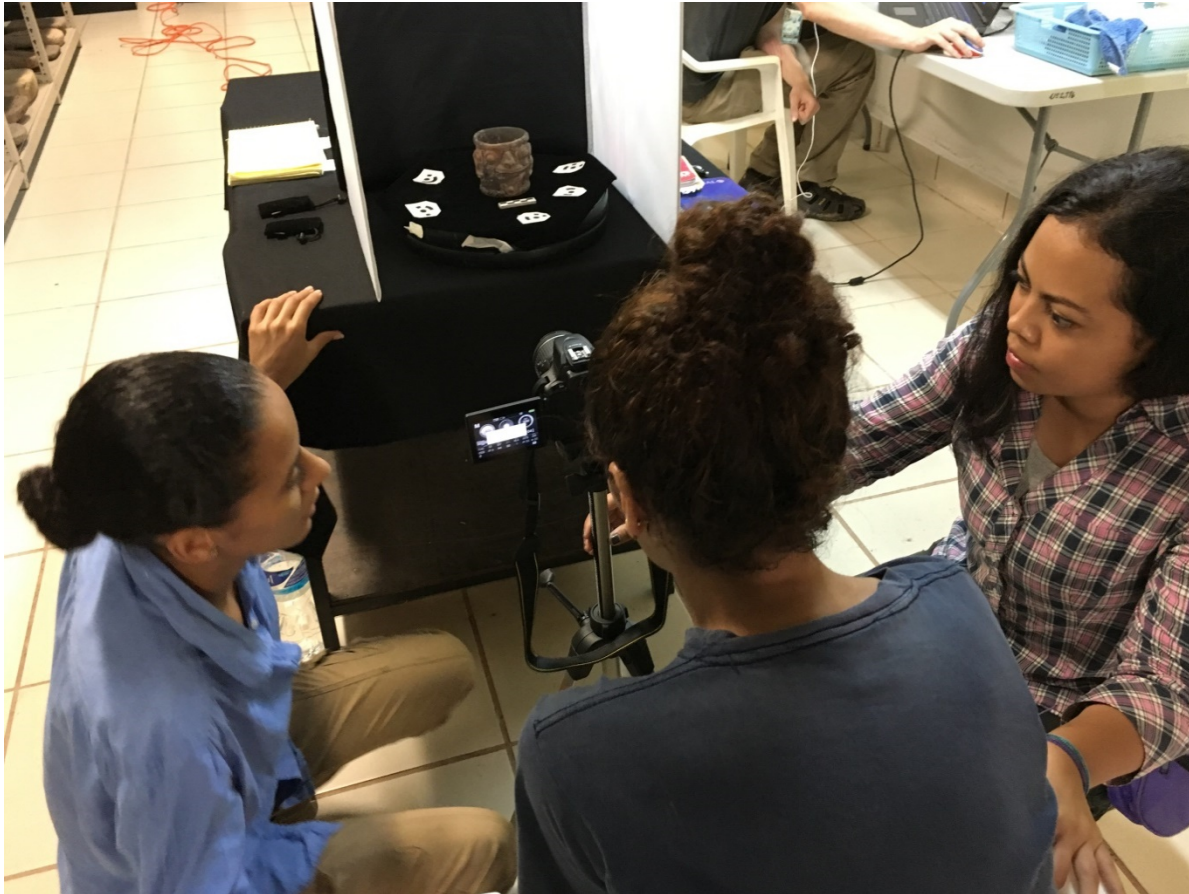

Figura 3: Ilustración del uso de las cajas de luces y de luz indirecta para obtener fotos de artefactos de tamaño pequeño

**Figura 4: Ilustración del uso de objetivos y de la mesa giratoria para artefactos pequeños**

Objetivo no3: cómo procesar las fotos para crear modelos en 3D usando el software Agisoft Photoscan.

Después de que los estudiantes tomaran el primer conjunto de fotografías, les presentamos Agisoft Photoscan, el software fotogramétrico que se utiliza para procesar las fotografías y generar un modelo 3D. Les explicamos el flujo de trabajo básico (los pasos básicos) en el proceso: agregar fotos, alinear fotos, crear una nube densa, crear una malla y crear una textura junto con los parámetros típicos utilizados para los tipos de objetos que estaban modelando.

A continuación, les enseñamos cómo procesar fotos que incluyeran objetivos y una escala. Esto suponía dos pasos adicionales. Los objetivos deben procesarse antes de la alineación y la escala se crea antes de generar una nube densa. Para permitir la práctica, así como una experiencia más cercana a la práctica, los estudiantes llevaron a cabo todo el proceso en Agisoft nuevamente para el análisis de un objeto nuevo, pero esta vez introdujimos más complejidad al proceso (pasos) debido a los objetivos buscados y a la escala a utilizar.

Muchos objetos necesitan tener dos juegos completos de fotografías (fragmentos) para capturar todo el objeto. Por ejemplo, un jarrón de cerámica (si no es demasiado delicado) debe fotografiarse en posición vertical y luego al revés para obtener fotos de la base. Los estudiantes practicaron tomar fotografías de tales objetos y luego les enseñamos cómo procesar estos dos conjuntos de fotos, llamados fragmentos (en Agisoft) e importar máscaras; por tanto, de nuevo introdujimos un nivel más de complejidad. La figura 5 enumera estos pasos.

Figura 5: Flujo de trabajo en Agisoft; los paréntesis representan pasos opcionales basados en la adquisición (Juckette 2017).
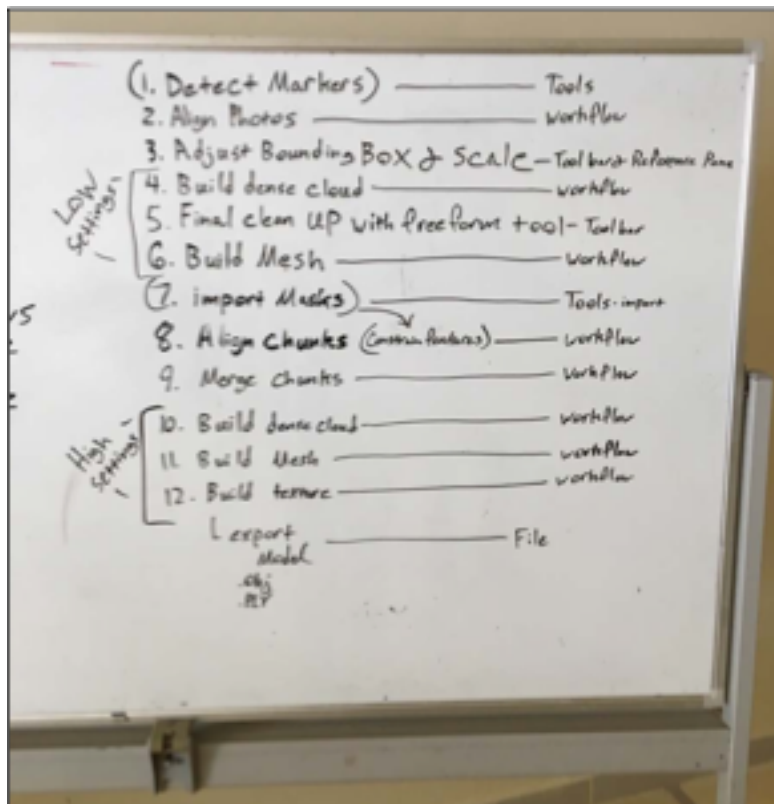

Los estudiantes practicaron este proceso en varios modelos, desde la adquisición de fotos hasta el procesamiento en Agisoft para permitirles una experiencia con la mayor práctica posible durante una semana.

Objectivo no4: cómo exportar modelos 3D
Finalmente, les mostramos cómo exportar modelos 3D para Agisoft. Enfatizamos dos tipos de archivos: OBJ y PLY. OBJ se usa a menudo para subir a SketchFab (https://sketchfab.com/ - servidor gratuito en línea utilizado a menudo por arqueólogos cuando se requiere un procesamiento posterior adicional o un análisis del modelo 3D. Por ejemplo, presentamos a los estudiantes a MeshLab http://www.meshlab.net/)— software gratuito de código abierto para procesar y editar mallas triangulares 3D. Meshlab ofrece un conjunto de herramientas para editar, limpiar, inspeccionar, representar, texturizar y convertir mallas o redes. También ofrece herramientas para la medición y el análisis como la visualización de la curvatura.

Figura 6: Escala de radiante de una pieza de banco (CPN 999) para ilustrar las características generadas utilizando MeshLab
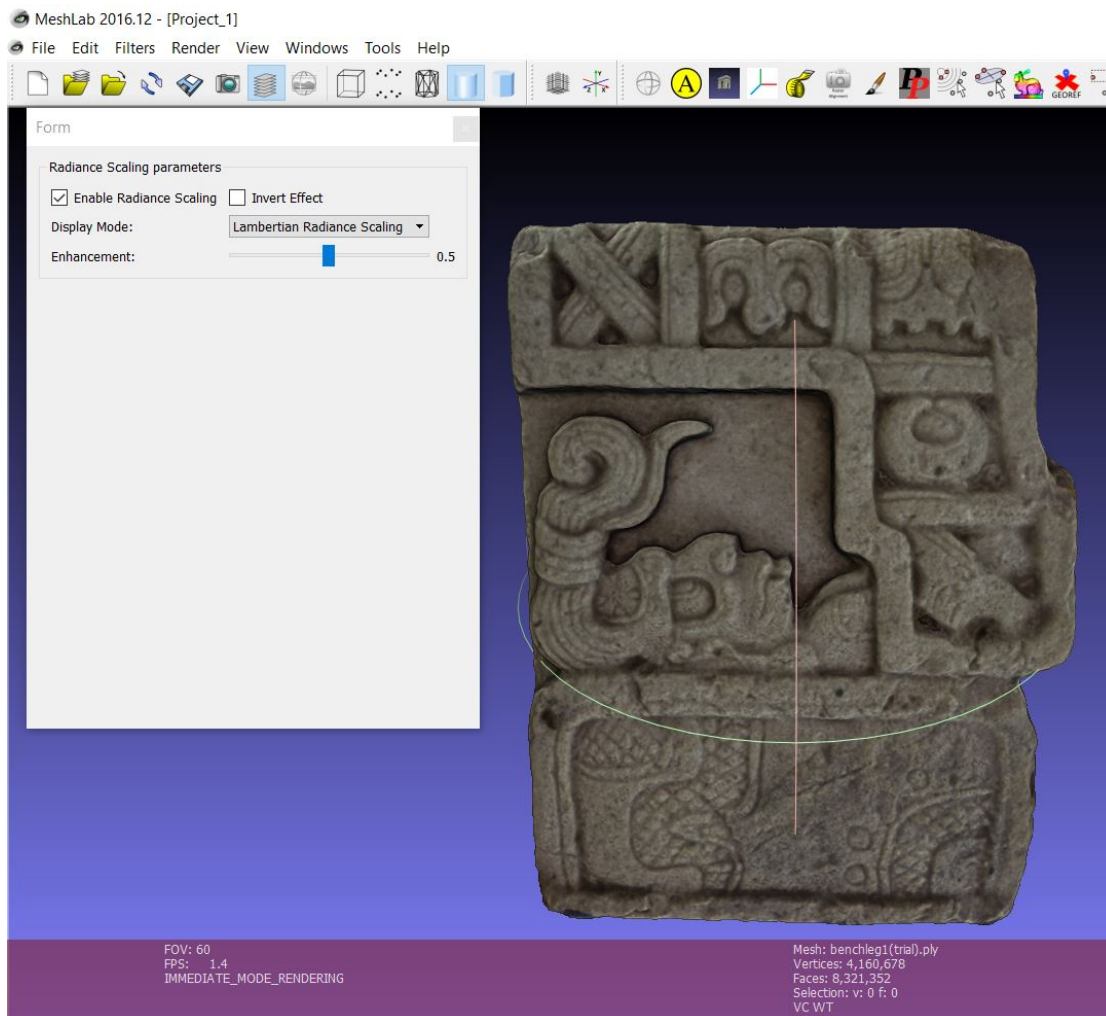

Por ejemplo, la Figura 6 ilustra la escala de radiante de una pieza de banco (CPN 999) almacenada en CRIA. Los modelos 3D también se pueden convertir a PDF 3D para permitir un acceso mayor utilizando Adobe Reader (gratis).

Objetivo no 2: Creación de modelos 3D para IHA

Los modelos 3D digitales proporcionan datos x, y y z sobre artefactos arqueológicos y sus características. Utilizando fotogrametría, los datos 2D se recopilan y procesan para crear y 3D los datos. Este proceso captura un objeto en su estado actual permitiendo un modelado basado en la realidad. Estos modelos 3D que se generan sirven de ayudar a los administradores del patrimonio cultural y a los arqueólogos en la toma de decisiones con fines de preservación, conservación e investigación. Los datos digitales se proporcionan como un registro del estado

de un artefacto en un momento específico en el tiempo y los modelos 3D se pueden procesar en una fase posterior con el empleo de un software como MeshLab para iluminar detalles que no son visibles a simple vista y que permitan mediciones más precisas (Figura 7).

Figura 7: Modelo de 3D CPN-C-1487 importado a MeshLab (.ply) que ilustra esta herramienta de medición
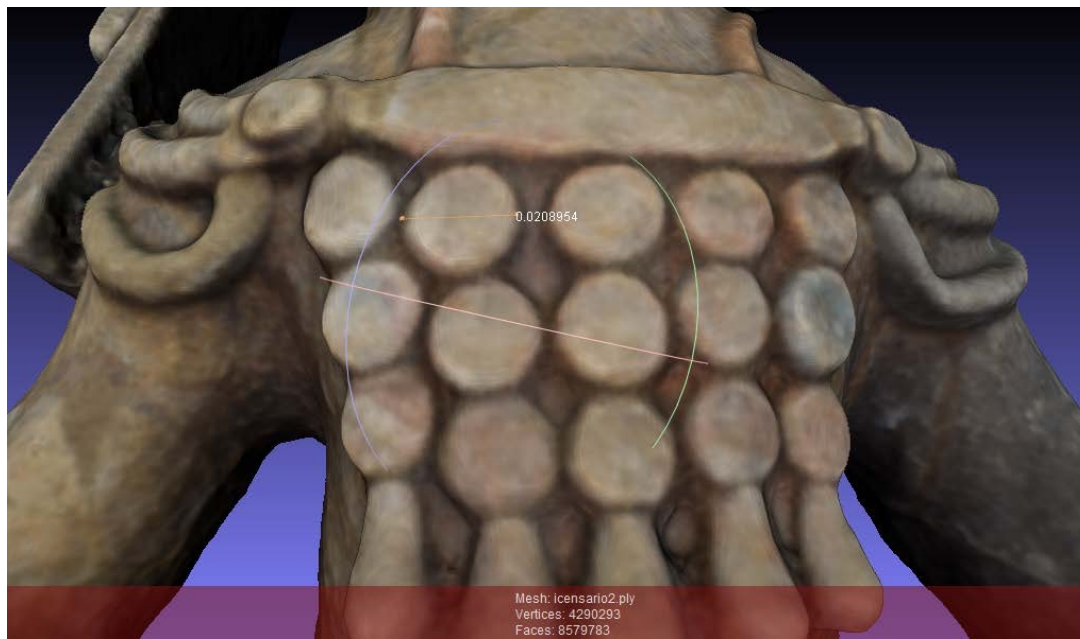
Para apoyar los esfuerzos de digitalización y conservación para IHAH, consultamos con Arq. Héctor Eliud Guerra, Subdirector del Parque Arqueológico de Copán, y Norman Martínez, Gerente de CRIA, para identificar objetos de alta prioridad para generar modelos 3D. Basado en sus comentarios y en nuestros intereses de investigación para el entorno de realidad virtual, adquirimos fotos de los siguientes artefactos y piezas de escultura. Consultamos con Reina Flores de la Biblioteca CRIA para determinar los números de CPN y obtener información básica sobre los objetos, cuando estén disponibles. [Escaneamos estos documentos para incluirlos en la versión digital del informe.] Hemos depositado los modelos 3D completos del banco de

trabajo no 1 (CPN 999), Jaguar Norte, Jaguar Sur, Incensario (CPN- 1487) y el Dios Sol (Máscara de Venus) con Norman Martínez y Arq. Héctor Eliud Guerra. Enviaremos por FTP los otros modelos 3D y las fotos asociadas a los mismos después de su procesamiento posterior en UNL

Parque Aqueológico de Copán

IHAH solicitó un modelo 3D de las dos Esculturas de Jaguar (Jaguares del Sur y del Norte) en West Wall en East Court para ayudar en los esfuerzos de restauración. Las dos esculturas de Jaguar son esculturas de alto relieve en la Estructura 24 ("La Escalera del Jaguar") en el lado oeste de East Court. , Acrópolis. Las dos esculturas flanquean el tramo de escaleras más bajo (16,5 m de ancho) contra la pared inclinada de la primera terraza de la estructura (Baudez

1994). Los jaguares están en posturas dinámicas reflejadas y a menudo se les conoce como los "jaguares danzantes".

Escultura de Jaguar no 1 (Sur), East Court: IHAH solicitó un modelo 3D de la Escultura de Jaguar del Sur en el Muro Oeste del Patio Este, Acrópolis para ayudar en los esfuerzos de restauración. En nuestro primer intento, tomamos fotos con el techo protector; sin embargo, no pudimos conseguir los ángulos necesarios; por consiguiente, obtuvimos permiso para desplazar temporalmente el techo. Reina localizó cuatro tarjetas fotográficas para la Escultura de Jaguar del Sur (Figuras 8-11) que escaneamos para una comparación visual con las fotos actuales (2017) (Figura 12).
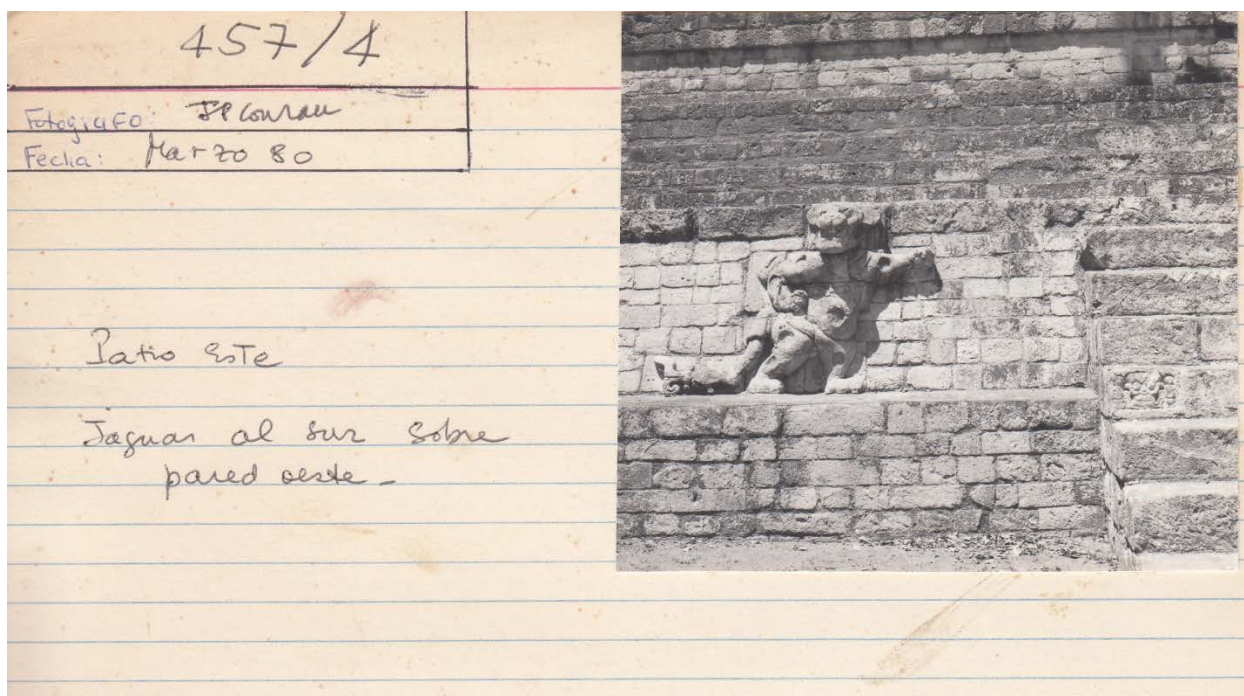
Figura 8: Tarjeta foto de Jaguar Sur tomada en marzo de 1980, Biblioteca, CRIA
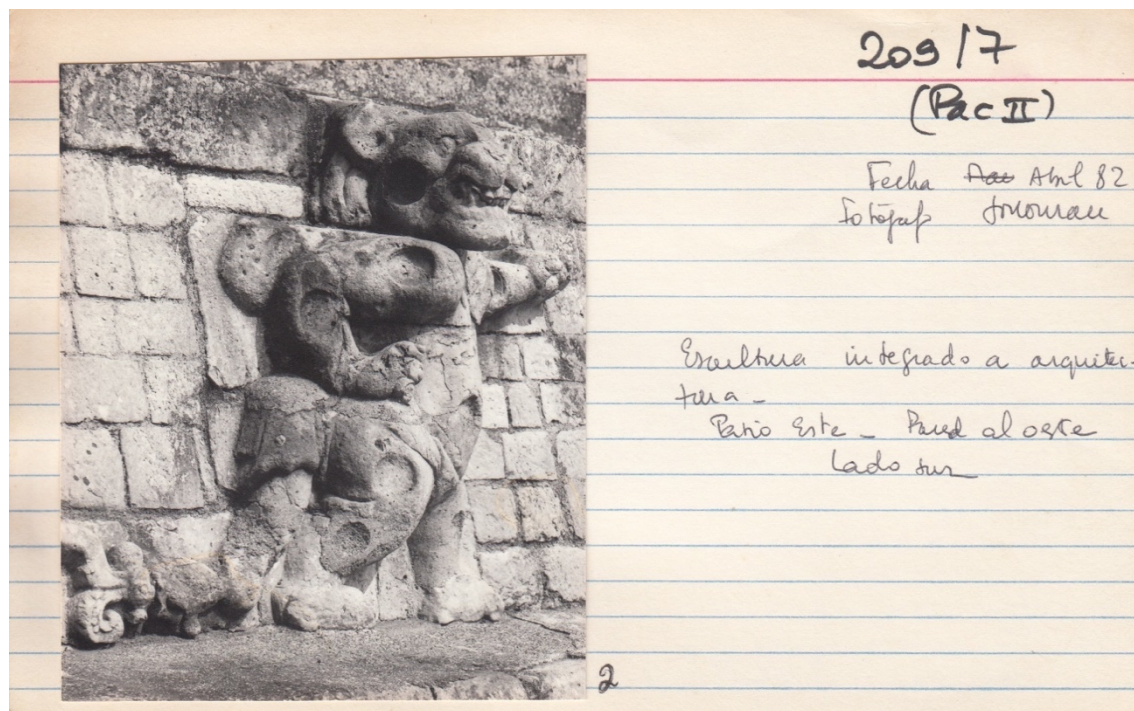
Figura 9: Tarjeta foto de Jaguar Sur tomada en abril de 1982, Biblioteca, CRIA
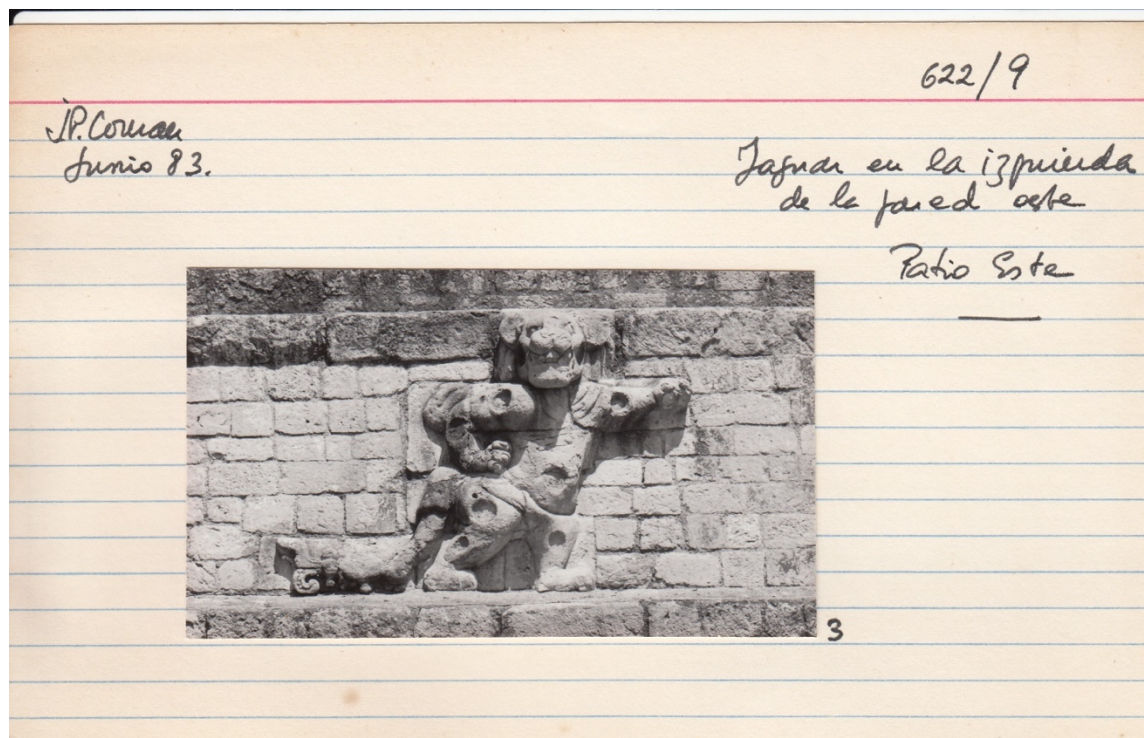

Figura 10: Tarjeta foto de Jaguar Sur tomada en junio de 1983, Biblioteca, CRIA
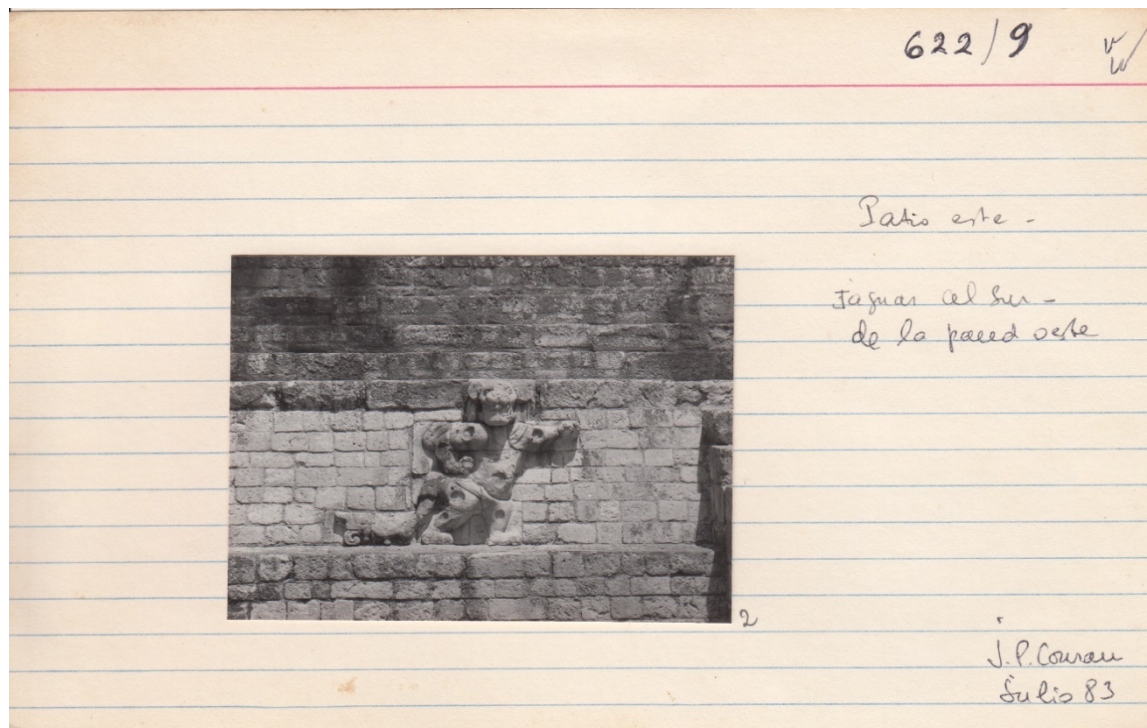
Figura 11: Tarjeta foto de Jaguar Sur tomada en julio de 1983, Biblioteca, CRIA

Figura 12: Fotos de Jaguar Sur, Lado Occidental del Patio Este, Acropolis (Tomadas en junio de 2017)

Escultura de Jaguar (Norte) no 2, Patio Este: IHAH solicitó un modelo en 3D de la escultura Jaguar Norte en el Muro Occidental del Patio Este, Acrópolis para ayudar en los esfuerzos de

restauración. También recibimos permiso para desplazar temporalmente el techo para adquirir las fotos necesarias. Como ilustran las fotos, el Jaguar norte está más deteriorado que la escultura del Jaguar sur. Reina localizó una tarjeta fotográfica para la Escultura de Jaguar Norte (Figura 13) que escaneamos para una comparación visual con las fotos actuales (2017) (Figura 14). La Figura 15 ilustra el modelo 3D con objetivos generados en Agisoft.

Figura 13: Tarjeta foto de Jaguar Norte tomada en noviembre de 1977, Biblioteca, CRIA

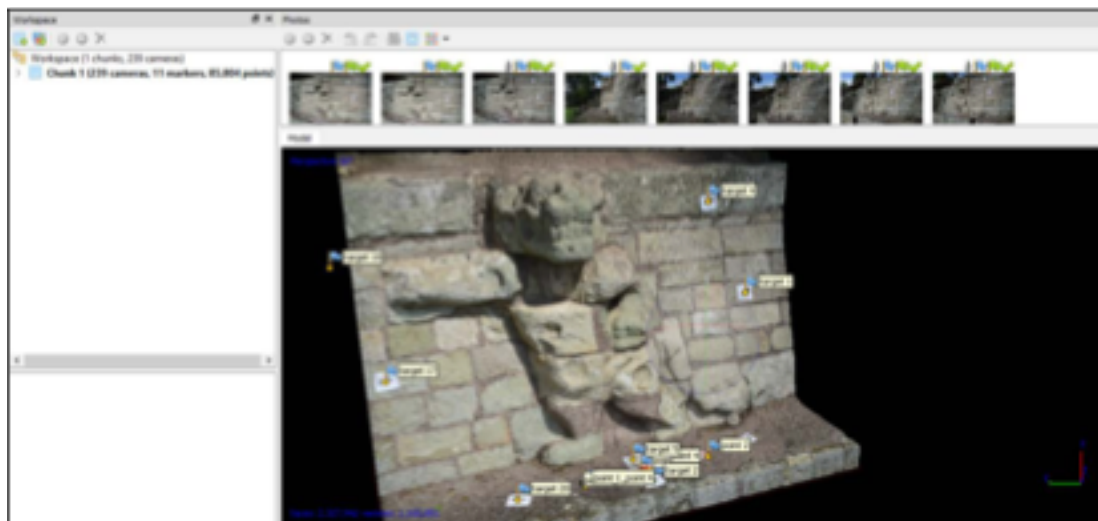**Figura 14: Tarjeta foto de Jaguar Norte, Muro Oeste del Patio Este, Acropolis (Tomada en junio de 2017)**
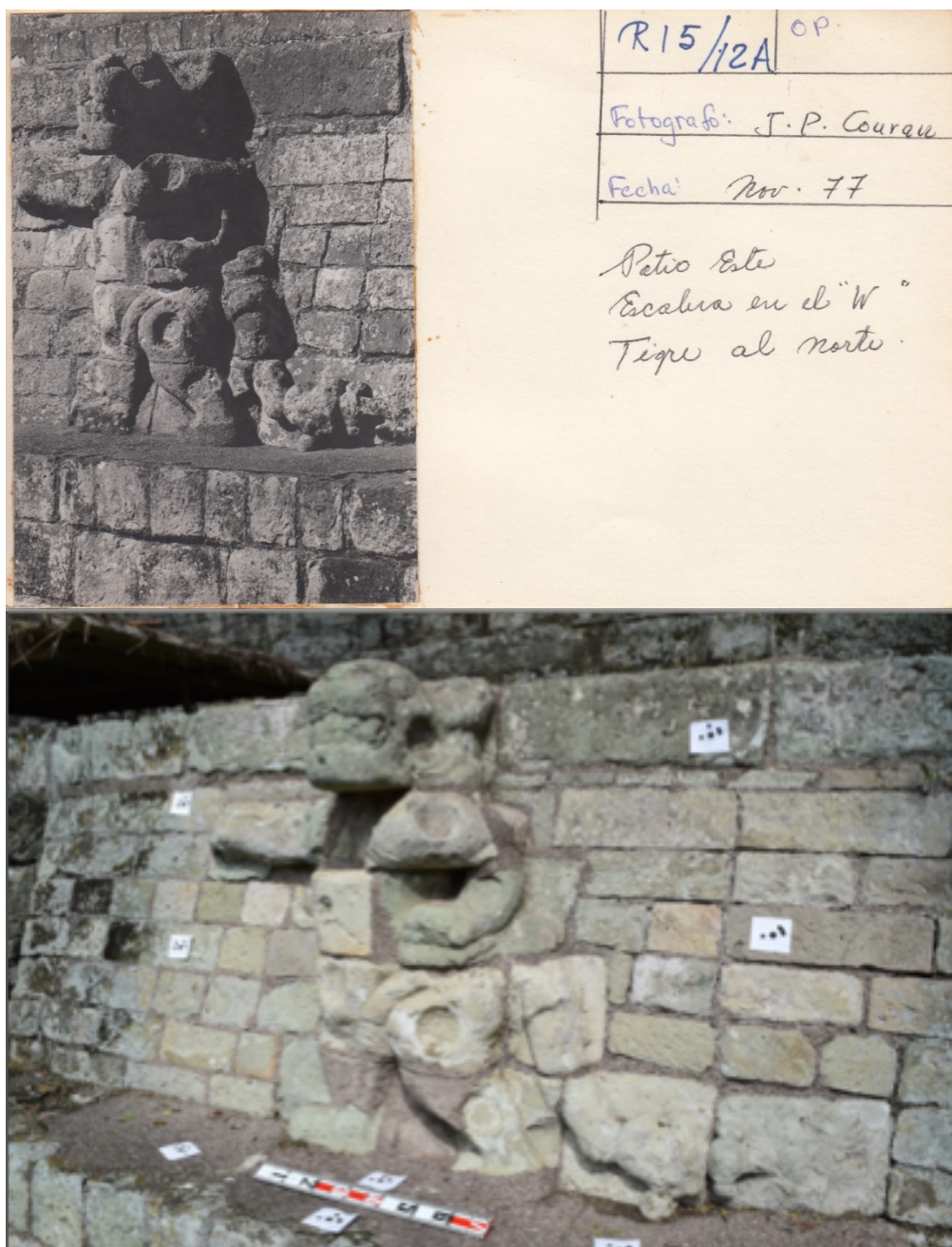
Figura 15: 3D Modelo con pbjetivos de Jaguar Norte (Agisoft Photoscan), Muro Oeste del Patio Este, Acropolis

Dios del Sol (máscara de Venus) Muro Oeste del Patio Este, Acrópolis
El Dios del Sol (o máscara de Venus) es la pieza central del Muro Oeste del Patio Este y aparece entre el tercer tramo de escaleras que conduce a la Plataforma de Danza. Varias cuadras conforman la escultura y la escultura ha sido interpretada para representar la puesta de sol al oeste (Baudez 1994). Reina localizó tres tarjetas fotográficas para el Dios Sol (Máscara Venus) en la biblioteca (Figuras 16-18).

Figura 16: Foto 3D del Dios del Sol (máscara de Venus), Muro Oeste del Patio Este, Acrópolis (Tomada en noviembre de 1977)
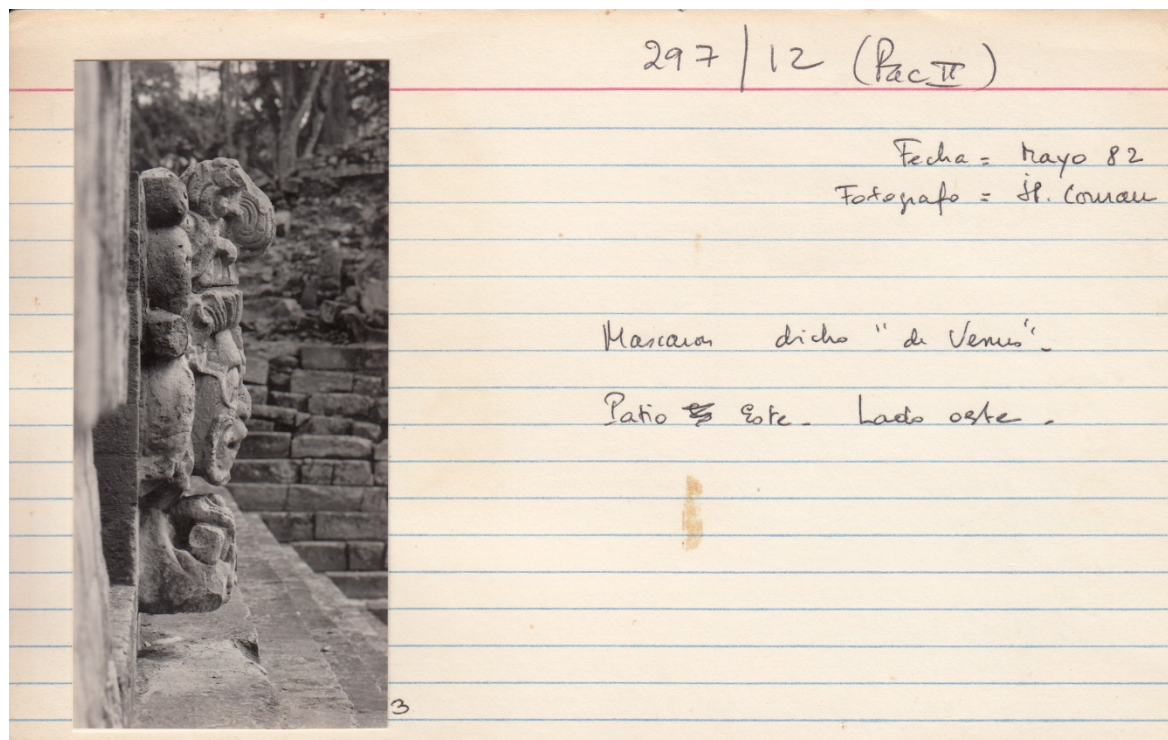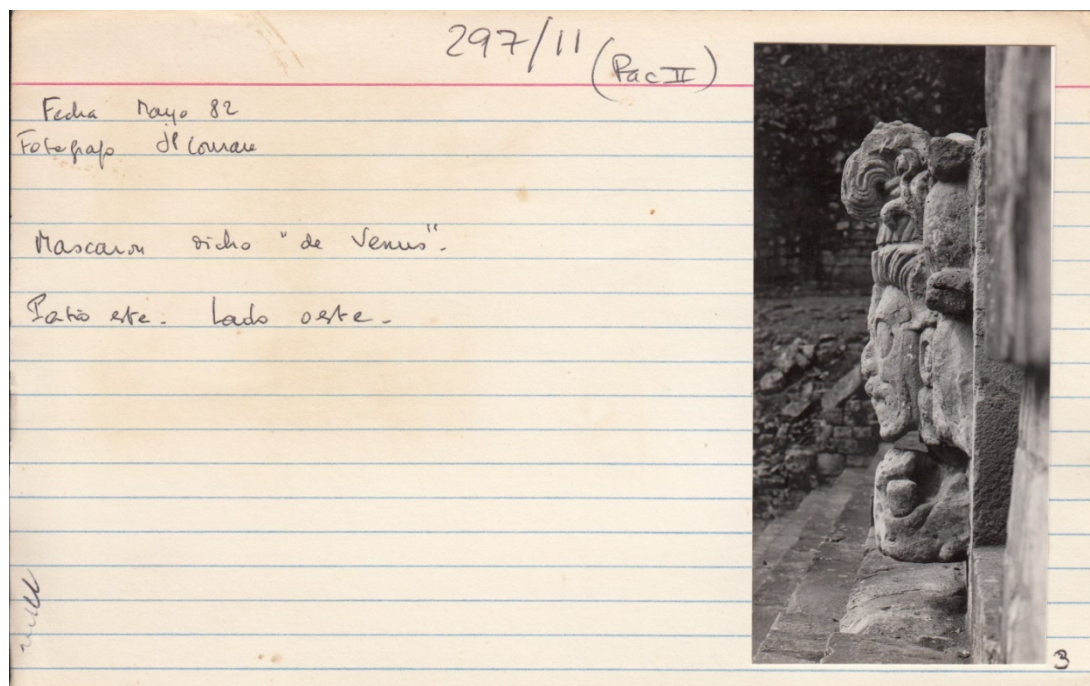
Figura 17: Foto dirección norte del Dios del Sol (máscara de Venus), Muro Oeste del Patio Este, Acrópolis (Tomada en mayo de 1982)

Figura 18: Foto dirección sur del Dios del Sol (mascara de Venus), Muro Oeste del Patio Este, Acrópolis (Tomada en mayo de 1982)

La Figura 19 muestra fotos del estado actual de la escultura del Dios Sol en el Patio Este. Las Figuras 20-22 ilustran el modelo 3D generado del Dios del Sol usando Agisoft.

Figura 19: Fotos del Dios del Sol (máscara de Venus), Muro Oeste del Patio Este, Acrópolis (Tomada en junio de 2017)

Figura 20: 3D modelo oscurecido del Dios del Sol (máscara de Venus), Muro Oeste del Patio Este, Acrópolis, (junio de 2017)
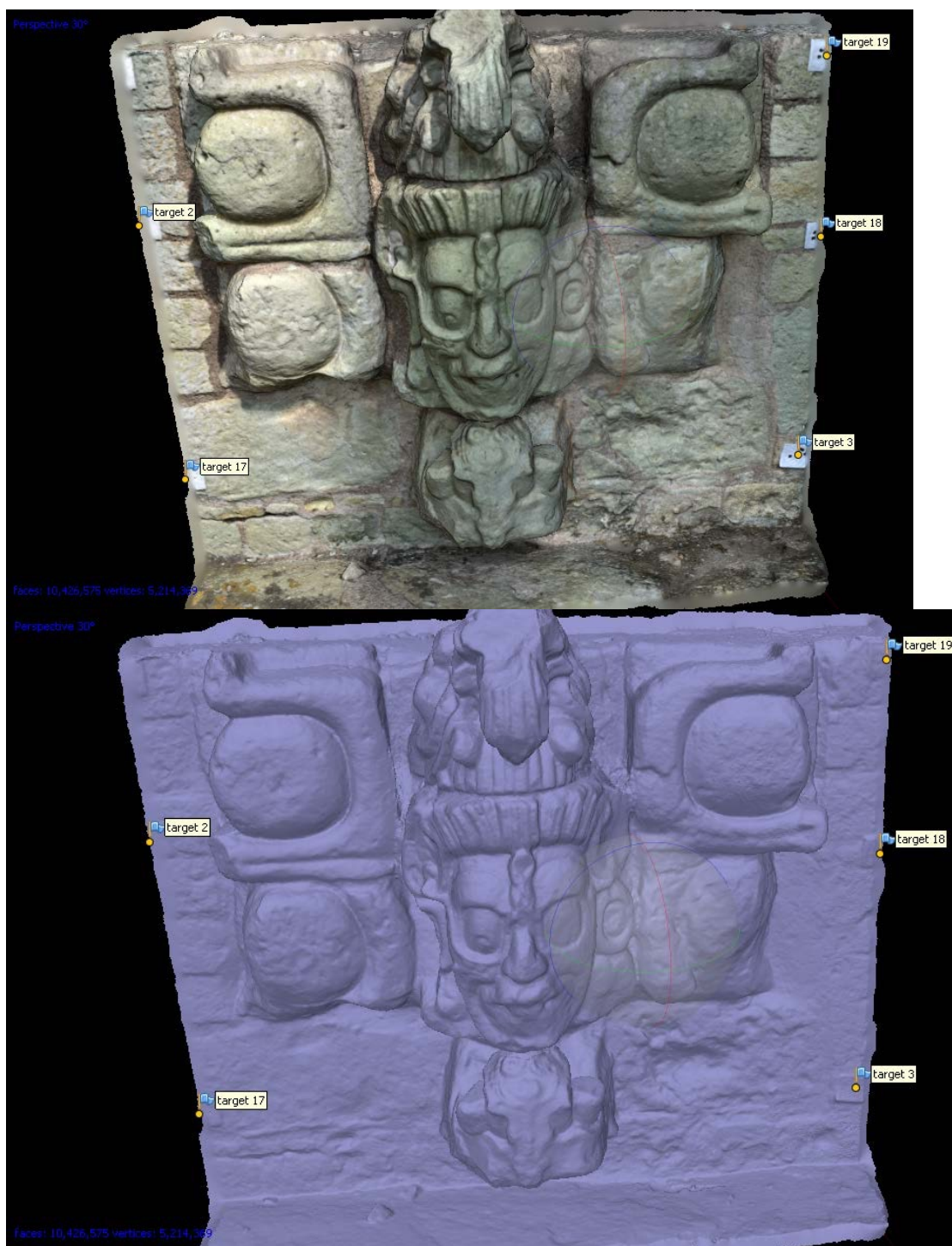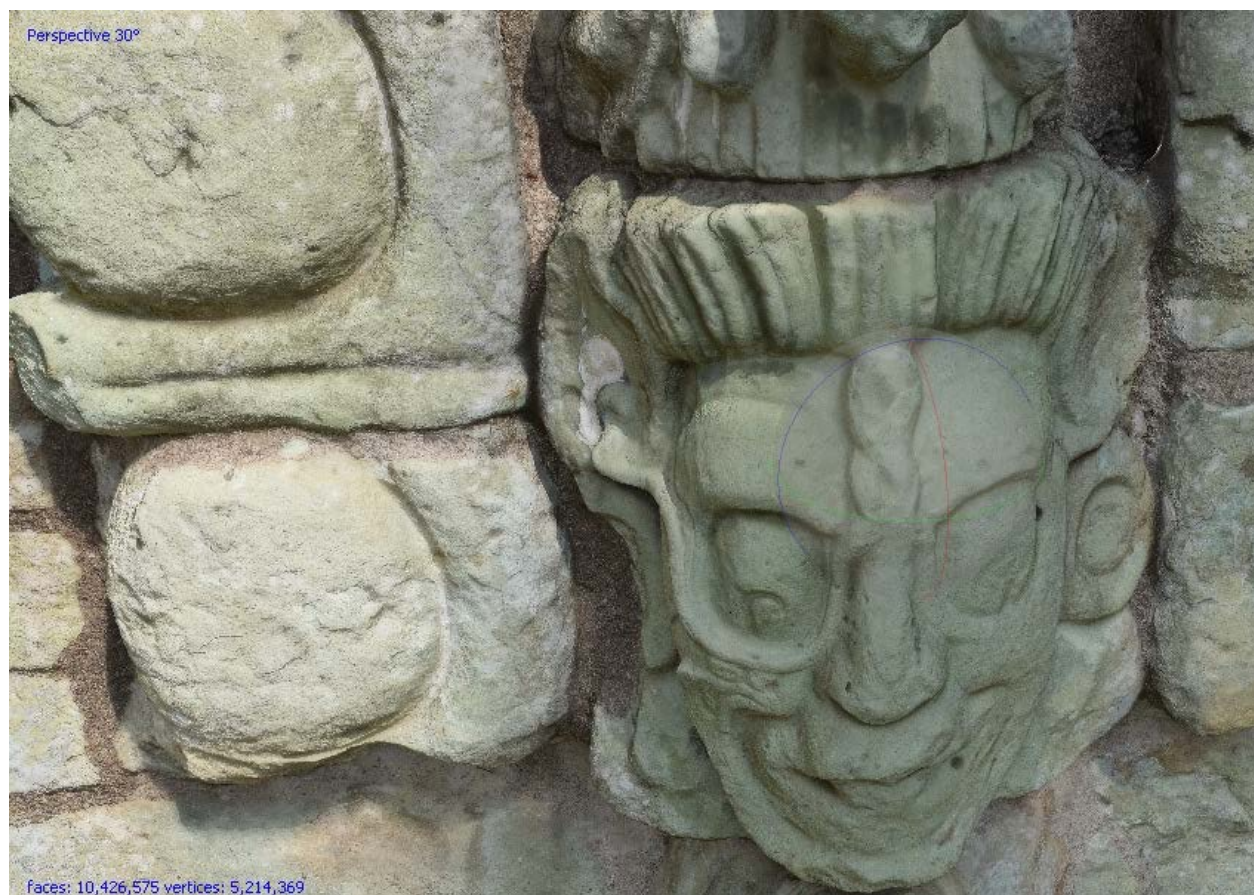
Figura 21: 3D de modelo sólido del Dios del Sol (máscara de Venus), Muro Oeste del Patio Este, Acrópolis, (junio de 2017)
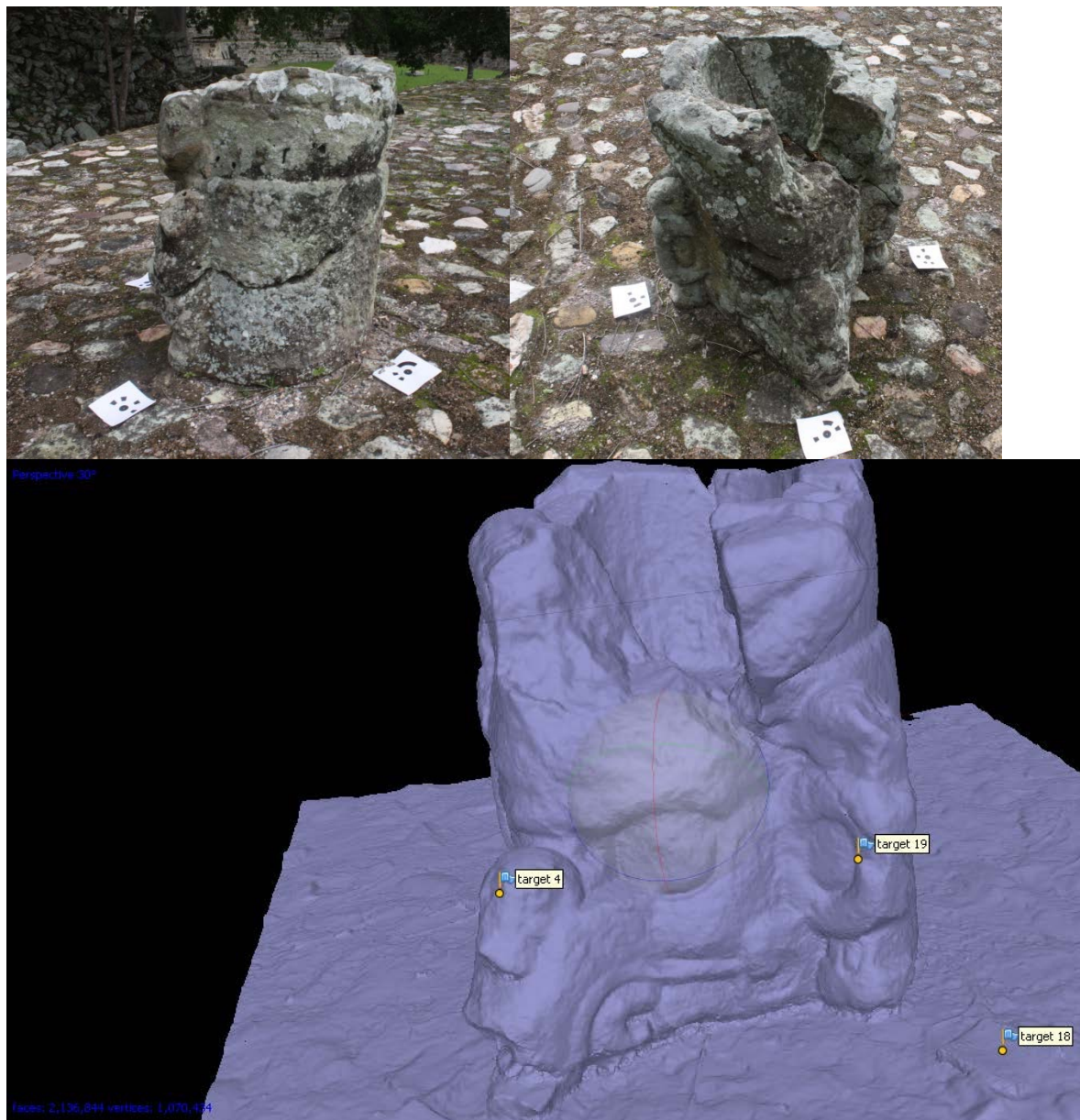
Figura 22: 3D modelo de textura del Dios del Sol (máscara de Venus), Muro Oeste del Patio Este, Acrópolis, (junio de 2017)

Incensario no 1, Patio Este, (circa Templo 18): CPN Desconocido

Figura 23: Incensario no 1, Patio Este, sobre la plataforma norte del Templo 18

Figura 24: 3D modelo sólido de Incensario no 1, Patio Este, sobre la plataforma norte del Templo 18

Incensario no 2, Patio Este, (circa Templo 18): CPN Desconocido

Figura 25: Incensario no 1, Patio Este, sobre la plataforma norte del Templo 18

Figura 26: 3D modelo sólido de Incensario no 2, Patio Este, sobre la plataforma norte del Templo 18

Pauahtun (Cabeza de Hombre Viejo), Patio Este (Lado Este)

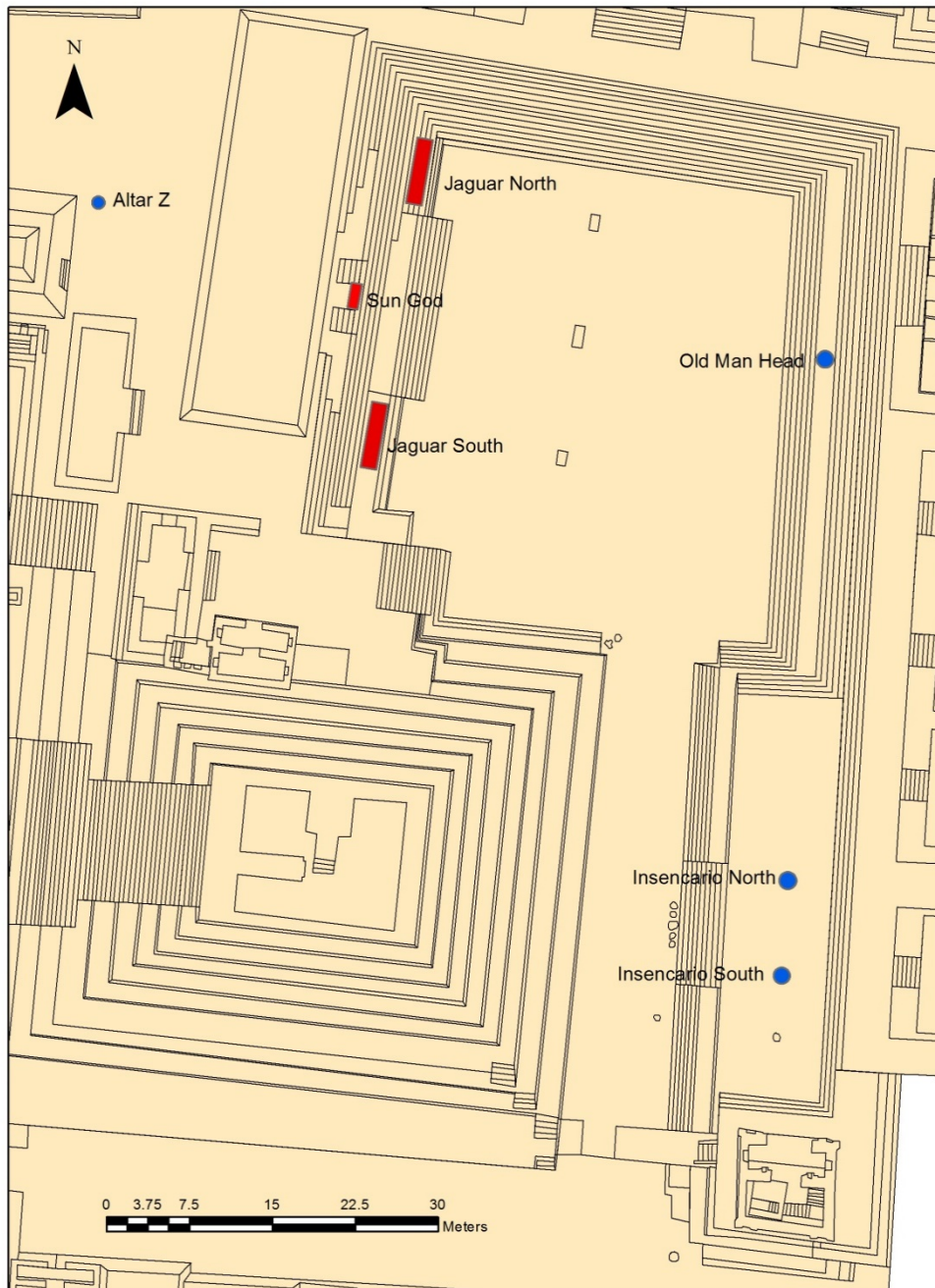**Figura 27: Pauahtun Cabeza de Hombre Viejo), Patio Este, sobre la plataforma del lado este Altar Z**,
Lado Oeste de la Plataforma Jaguar, Acropolis—practica de objeto con estudiantes

Figura 28: Altar Z, Oeste de Jaguar Plataforma de Danza

Localizaciones Fotogramétricas de Modelos 3D Copán, Honduras

Locations of 3-D Photogrammetric Models Copan, Honduras

June, 2017. MayaCityBuilder.
Generated by: Cole Juckette

Figura 29: Mapa de localización de esculturas/artefactos de modelos 3D que generamos

CRIA Incensario INV-1487

CPN-C-1487, OP-37-5-109, Tunel-4-rasgo 95 (Figuras 30-32)
Este incensario fue excavado en 1989 en los túneles de Estructura de Chorca de Str. 10L-26.

Figura 30: Fotos con objetivos con Incensario (CPN -C-1487), Copán, Honduras

Figura 31: 3D Modelo oscurecido de Incensario (CPN -C-1487), Copán, Honduras
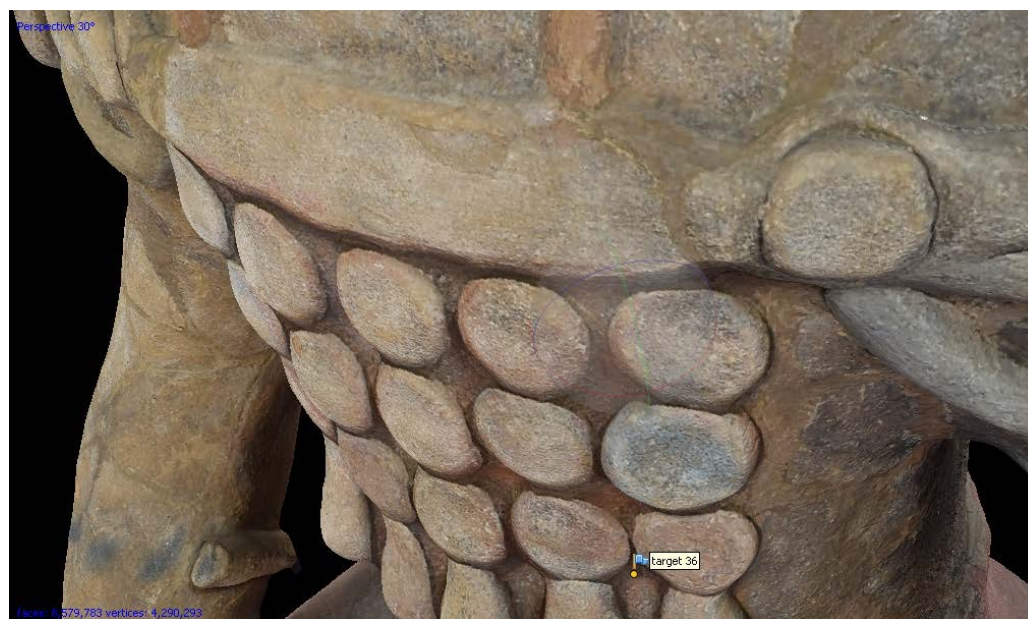
Figura 32: Textura 3D Modelo of Incensario (CPN -C-1487), Copán, Honduras

Estatuilla Silbato INV-1692

CPN-C-1692, OP 48/13/170, Str. 10L-86

Esta estatuilla es un silbato encontrado en el Entierro no 1 en la Sala no1 (debajo del banco en la esquina NE) Str. 10L-86 por la Universidad de Tulane en 1994.

Figura 33: Foto de Silbato con objetivos (CPN-C-1692), Copán, Honduras

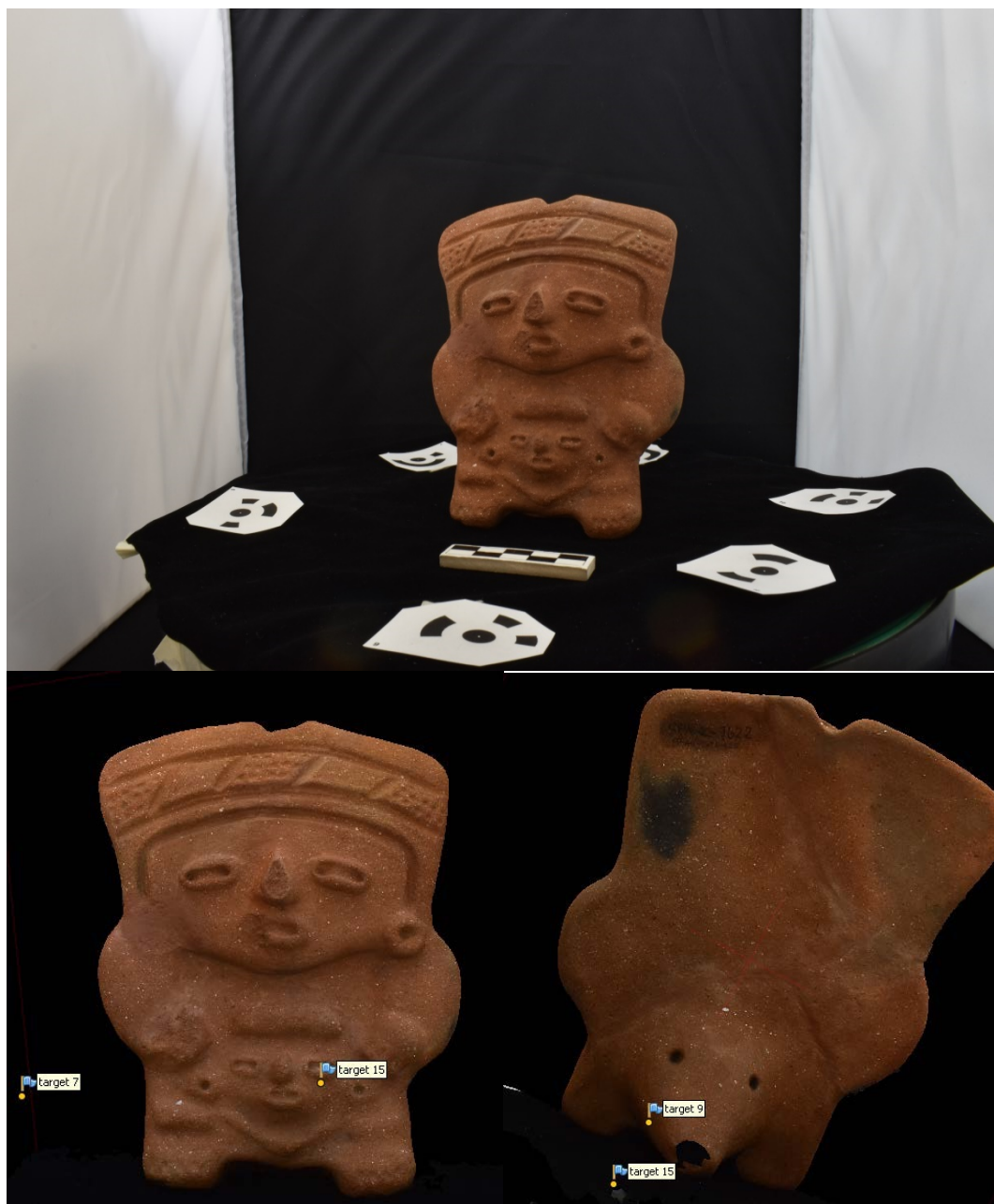**Figura 34: Textured 3D Model of Whistle (CPN-C-1692), Copán, Honduras (left: front; right: back)**

Small Jar: Vasija 3 (de 5), INV-732

CPN-C-1451, OP IV/99/185, 487, Sep. IV-17 Pac I, Viel y Cheek 1983, p.567, 571, fig. 5-6d

No pudimos encontrar ningún tipo de información sobre este artefacto en la biblioteca. Este es el artefacto que los estudiantes hicieron ellos mismos como practica "final."

Figura 35: Fotos con objetivos de Jarra Pequeña (CPN-C-1451)

Banqueta con glifos: CPN 999 1-4 (4 piezas)

Esta banqueta con glifos es del Grupo 9K-47 y se encuentra en cuatro piezas almacenadas en el almacén CRIA. El banco se rompe por la mitad (2 piezas) y tiene dos soportes. Norman Martínez preguntó si podíamos hacer modelos en 3D de las cuatro piezas para ayudarles a comprender mejor cómo podrían haber encajado las piezas originalmente. En el pasado, la pieza había sido expuesta en el Museo en Tegucigalpa, Honduras. No encontramos más información sobre esta pieza en la biblioteca CRIA.

Figura 36: Fotos con objetivos de la banqueta no 1 (CPN 999-1); delante (arriba), detrás (abajo)

Figura 37: Fotos con objetivos de la banqueta no 2 (CPN 999-1); delante (arriba), detrás (abajo)

Figura 38: Fotos con objetivos de la banqueta no 3 (CPN 999-1); delante (arriba), detrás (abajo)

Figura 39: Fotos con objetivos de la banqueta no 4 (CPN 999-1); delante (arriba), detrás (abajo)
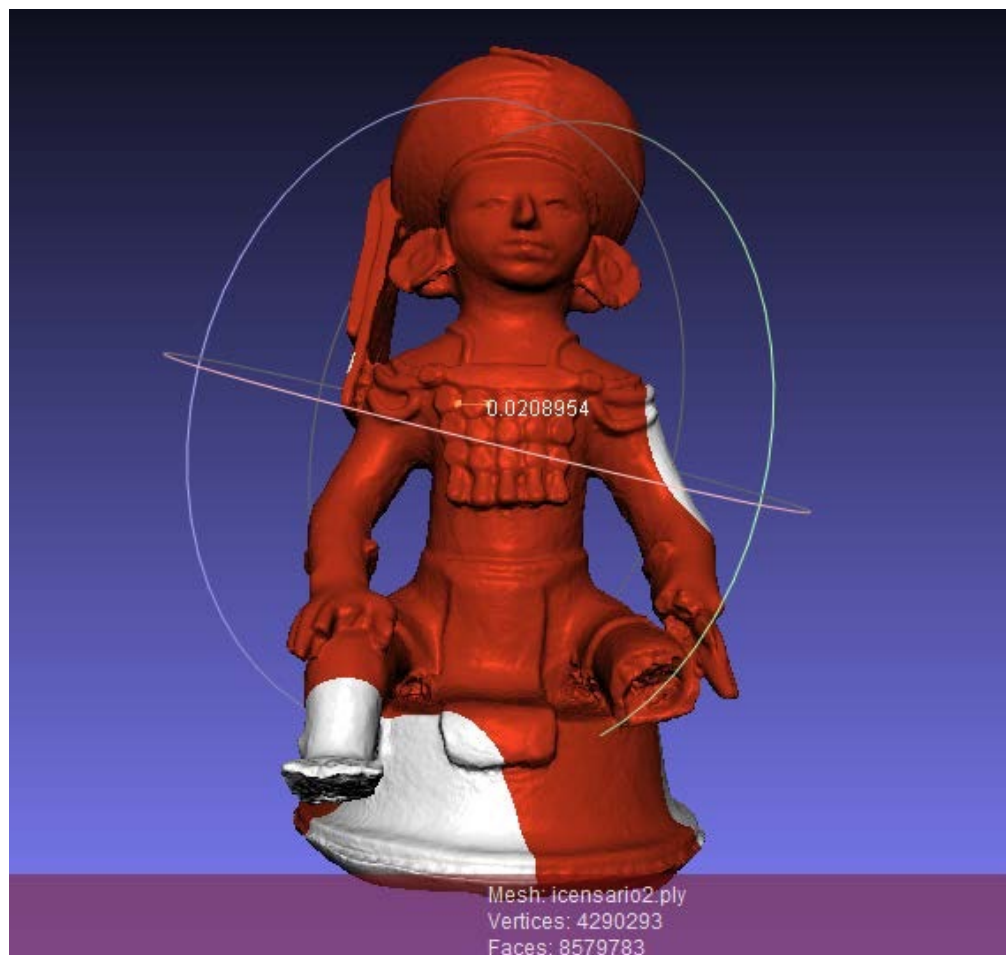
Figura 40: Modelo 3D de CPN-C-1487 importado de MeshLab (.ply) Ilustra diferencias en materiales del incensario

APPENDIX C: 2018 FIELD INFORME

Proyecto MayaCityBuilder: Informe de Campo 07 de junio – 04 de 22 junio, 2018

Investigadores:

Dr. Heather Richards-Rissetto, Antropología, Universidad de Nebraska-Lincoln (EE.UU.) Cole Juckette, M.A. Estudiante, Antropología, Universidad de Nebraska-Lincoln (EE.UU.)

Estudiantes y Facultad de UNAH:

- Husni Abdala Ruiz Nuñez, Antropología, UNAH
- Hansel Rosales, Antropología, UNAH
- André Sebastian Reye, Antropología, UNAH
- Nohemy Rivera, Profesor Auxiliar, Universidad Nacional Autónoma de Honduras, Facultad

  de Ciencias Espaciales, UNAH

- Kevin Gerardo Irias, Universidad Nacional Autónoma de Honduras, Facultad de Ciencias

  Espaciales, UNAH

- Harvin Antonio Díaz, Universidad Nacional Autónoma de Honduras, Facultad de Ciencias

  Espaciales, UNAH

- Cesar Israel Rodríguez, Universidad Nacional Autónoma de Honduras, Facultad de Ciencias

  Espaciales, UNAH

- Marco Antonio Pineda, Universidad Nacional Autónoma de Honduras, Facultad de Ciencias

  Espaciales, UNAH

- Jessica Gabriela Villatoro, Universidad Nacional Autónoma de Honduras, Facultad de

  Ciencias Espaciales, UNAH

- Vilma Lorena Ochoa, Universidad Nacional Autónoma de Honduras, Facultad de Ciencias

  Espaciales, UNAH

Personal de IHAH

- Hector Eliud Guerra Aldana, IHAH
- Otros personal de IHAH

Objetivos:

Para este corto periodo (2 semanas), establecimos tres objetivos.
(1) El primer objetivo consistía en enseñar el proceso de fotogrametria de artefactos y

esculturas a estudiantes del Departamento de Antropología (licenciatura en arqueología) y Ciencias Espaciales de UNAH y el personal de IHAH.

2. (2) El segundo objetivo consistió en la creación de modelos 3D que fueran relevantes para IHAH y continuar realizar investigaciónes de archivo en la biblioteca del CRIA y escanear materiales sobre 8 artifactos que creamos modelos en 3D en 2017.
3. (3) El tercer objetivo es publicar un articulo para la 3rd International Digital Heritage Congress del 26-30 de octubre 2018 en San Francisco, USA (http://www.digitalheritage2018.org/) con coautores Hector Eliud Guerra Aldana y Norman Martinez de IHAH. (Apéndice B).

1

Antecedentes

Objetivos a largo plazo del Proyecto MayaCityBuilder

El Proyecto MayaCityBuilder emplea el Sistema de Información Geográfica (GIS en inglés), así como visualización tridimensional 3D para estudiar la interacción social en los antiguos asentamientos urbanos del periodo Maya. Nos basamos en el trabajo previo hecho por PAC I (OPIV), el Proyecto MayaArch3D, y en dos trabajos de campo breves en 2015 y en 2016. En 2015 trabajamos en CRIA, en las Ruinas de Copán durante 3 semanas (ver Informe Preliminar 2015). In 2016, continuamos recogiendo información sobre las cerámicas PAC I de Copán junto al empleo de GIS de la región para identificar SuOPs (Sub Operaciones) con alta probabilidad de contener fragmentos de cerámica que pudieran ser utilizados para ajustar la cronología del Clasicismo Tardío – el período de tiempo objeto de estudio en esta investigación (ver Informe Preliminar2016).

Los objetivos, sin embargo, fueron algo diferentes en 2017. Nuestros dos objetivos principales fueron: (1) enseñar a estudiantes de UNAH en el uso de la fotogrametría para crear modelos de artefactos y escultura en 3D y (2) la creación modelos 3D de alta relevancia para el Instituto

Hondureño de Antropología e Historia (IHAH). Algunos de los modelos 3D se integrarían en el entorno virtual 3D que el proyecto está creando para Copán. **En 2018**, nuestros objetivos eran casi los mismos.

Objetivo no1: Enseñanza de Fotogrametría a los estudiantes hondureños

La fotogrametría es un método que usa fotografías en 2D para crear modelos de objetos en 3D. Es el método usado en Arqueología que ha experimentado un crecimiento mayor en años recientes debido al desarrollo de métodos semi-automáticos. La fotogrametría se usa para recoger datos para la creación de modelos 3D de edificios, paisajes (UAV), artefactos, así como para la captura estratográfica y para trazar un perfil de la excavación. Se trata de una tecnología no invasiva, de bajo coste, y portátil, permitiendo conseguir modelos con precisión próxima al de unos pocos micrones, haciendo de la misma el método de aproximación ideal para arqueólogos. Es por estas razones que UNL colaboró con UNAH para enseñar a estudiantes hondureños de Arqueología la técnica de la fotogrametría.

Un grupo de estudiantes (3 de Antropología), algún personal de IHAH (de CRIA) y estudiantes y facultad de Ciencias Espaciales de IHAH—formados por Dr. Richards-Rissetto y un estudiante de maestría (MA en inglés) de UNL—asistieron la práctica por dos días en la primera semana. Nosotros dimos la práctica en el parque arqueológico de Copan. Para los otros tres días ensenamos los tres estudiantes de Antropología en el museo de escultura y CRIA. En la segunda semana los estudiantes utilizando la información de la práctica incluyendo el tutorial (Apéndice A) para construir un modelo 3D con poco ayuda (Figura 1).

Los objetivos que nos propusimos enseñarles fueron: **Objetivo no1**- conceptos claves de fotogrametría

Objetivo no2- cómo obtener las fotos deseadas basadas en la iluminación, el material a estudiar, el tamaño del objeto, etc.

Objetivo no3- cómo procesar las fotos para la creación de modelos 3D usando el software Agisoft Photoscan (el de mayor difusión entre los arqueólogos y de coste relativamente bajo)

Objetivo no4- cómo exportar modelos 3D para usar en otro software como MeshLab o con presencia en Internet, por ejemplo, utilizando Sketchfab o en un 3DPDF.
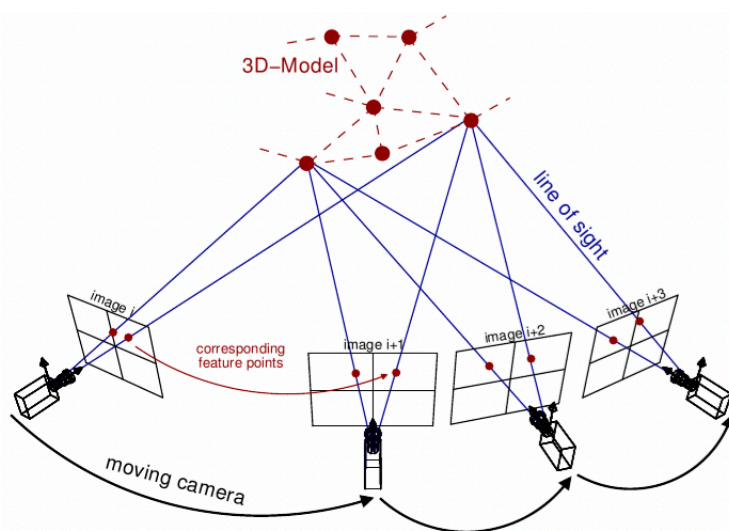
Dado el corto período de tiempo de que disponíamos (1 semana para cada grupo), nos centramos en objetos independientes y en esculturas arquitectónicas. No practicamos la adquisición y el procesamiento posterior de fotografías para grandes estructuras o excavaciones; sin embargo, discutimos sobre estos dos usos y suministramos información sobre las diferencias clave entre los métodos. Capturamos fotos de objetos en el Parque Arqueológico de Copán y en el Centro Regional de Investigaciones Arqueológicas (CRIA).

Objetivo no 1: enseñar los conceptos clave de la fotogrametría

Primero enseñamos a los estudiantes algunos conceptos básicos de la fotogrametría: qué es, cómo funciona ... Por ejemplo:

La fotogrametría es la ciencia de hacer mediciones a partir de fotografías para crear, por ejemplo, mapas y dibujos, medidas y/o modelos 3D de un objeto o escenario del mundo real. Existen diferentes métodos de fotogrametría: de corto alcance y terrestres y aéreos (por ejemplo, UAV, avión, etc.) y diferentes métodos que requieren diferentes aproximaciones. Enseñamos a los estudiantes fotogrametría terrestre de corto alcance utilizando Structure from Motion (SfM), una técnica fotogramétrica utilizada para crear modelos 3D y ortoimágenes a partir de una serie de fotografías superpuestas (Figura 1).

Figura 1: Ilustración de la Estructura de Movimiento (SfM en inglés) (de la Biblioteca Theia Vision)

3

Objetivo no 2: cómo adquirir fotografías adecuadas según el objeto y el entorno.

Primero explicamos algunos conceptos clave de la fotografía, en particular los tres ajustes que son más críticos para tomar buenas fotografías para fotogrametría: apertura, velocidad de obturación e ISO. A continuación, ilustramos cómo tomar fotografías adecuadas de un objeto sin el empleo de objetivos (en este caso, en la semana 1 practicamos con objetos en el museo de escultura haciendo hincapié en lo siguiente: requerimiento de una superposición mínima 70% (máx = 90%) para cada foto, encuadre de todo el objeto en cada foto, mantenimiento del objeto en el centro de la foto, ausencia de movimiento en el fondo de las fotos a ser posible (aunque no es algo esencial), toma de fotos consistentes alrededor del objeto en una dirección, y toma de fotos a diferentes niveles aproximadamente cada 30 grados y superior dependiendo del objeto (generalmente se requieren de 3 a 5 niveles para objetos pequeños y medianos) (Figura 2).

Figura 2: Estudiante de UNAH practica la toma de fotos con la escultura del Dios del Maíz en el Museo de Escultura de Copán

Para comenzar nuestro trabajo seleccionamos el Museo de Escultura y el Parque Arqueológico de Copán porque la iluminación era bastante constante y los objetos eran fácilmente accesibles. Después de una demostración, los estudiantes practicaron la toma de un conjunto de fotos ellos mismos. Luego, nos mudamos a CRIA para enseñarles a los estudiantes cómo adquirir fotos para objetos relativamente pequeños que se pueden colocar en una mesa giratoria. En este enfoque, no caminamos alrededor de un objeto que toma fotos, sino que colocamos la cámara en un trípode (con ubicación fija) y giramos la mesa de giro en pequeños incrementos de distancia para capturar al menos el 70% de superposición para cada foto. Se aplica el mismo concepto de toma de fotos en distintos niveles que difieren en ángulos de 30 grados cada uno. Sin embargo, las condiciones de iluminación fueron más difíciles en CRIA debido a las ventanas y/o luces fluorescentes; por lo tanto, mejoramos las condiciones de iluminación utilizando cajas de luz y luz indirecta (Figura 3). Además, introdujimos el concepto

de empleo de objetivos para mejorar los resultados de la alineación de la cámara y, por consiguiente, la precisión general del modelo final (Figura 4).

Figura 3: Ilustración del uso de las cajas de luces y de luz indirecta para obtener fotos de artefactos de tamaño pequeño

Figura 4: Ilustración del objeto de investigaciones de los estudiantes y de la mesa giratoria para artefactos pequeños

5

Objetivo no3: cómo procesar las fotos para crear modelos en 3D usando el software Agisoft Photoscan.

Después de que los estudiantes tomaran el primer conjunto de fotografías, les presentamos Agisoft Photoscan, el software fotogramétrico que se utiliza para procesar las fotografías y generar un modelo 3D. Les explicamos el flujo de trabajo básico (los pasos básicos) en el proceso: agregar fotos, alinear fotos, crear una nube densa, crear una malla y crear una textura junto con los parámetros típicos utilizados para los tipos de objetos que estaban modelando.

A continuación, les enseñamos cómo procesar fotos que incluyeran objetivos y una escala. Esto suponía dos pasos adicionales. Los objetivos deben procesarse antes de la alineación y la escala se crea antes de generar una nube densa. Para permitir la práctica, así como una experiencia más cercana a la práctica, los estudiantes llevaron a cabo todo el proceso en Agisoft nuevamente para el análisis de un objeto nuevo, pero esta vez introdujimos más complejidad al proceso (pasos) debido a los objetivos buscados y a la escala a utilizar.

Muchos objetos necesitan tener dos juegos completos de fotografías (fragmentos) para capturar todo el objeto. Por ejemplo, un jarrón de cerámica (si no es demasiado delicado) debe fotografiarse en posición vertical y luego al revés para obtener fotos de la base. Los estudiantes practicaron tomar fotografías de tales objetos y luego les enseñamos cómo procesar estos dos conjuntos de fotos, llamados fragmentos (en Agisoft) e importar máscaras; por tanto, de nuevo introdujimos un nivel más de complejidad. Vea el apéndice A para el tutorial creamos con el proceso en Agisoft (por ahora es en inglés porque el software es en inglés).

Los estudiantes y facultad de UNAH y el personal de INAH practicaron este proceso en varios modelos, desde la adquisición de fotos hasta el procesamiento en Agisoft para permitirles una experiencia con la mayor práctica posible durante una semana (Figuras 5-7).

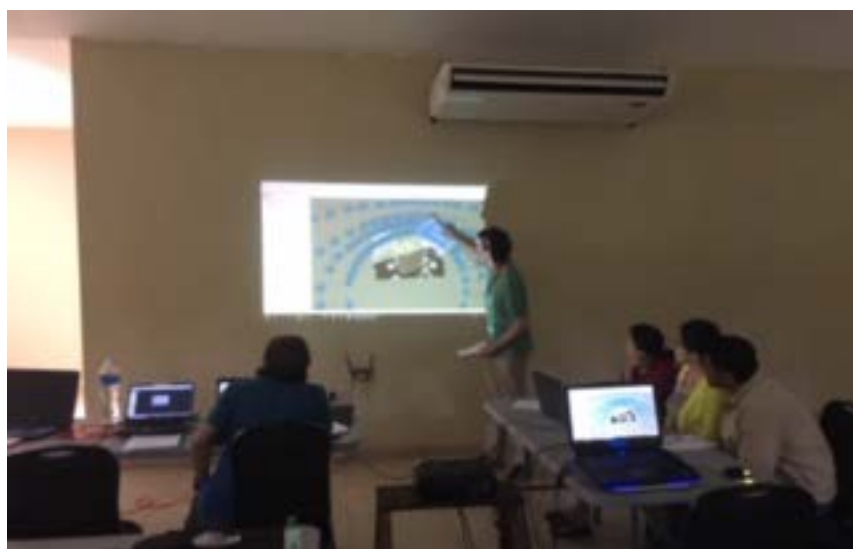**Figura 5: La práctica de fotogrametría en el parque arqueológico de Copan**

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Figura 6: La práctica de fotogrametría en el parque arqueológico de Copan

Abajo están imagines de los resultados de los estudiantes antropología para la construcción de un modelo 3D de un vaso trípode (Figuras 8- 10).

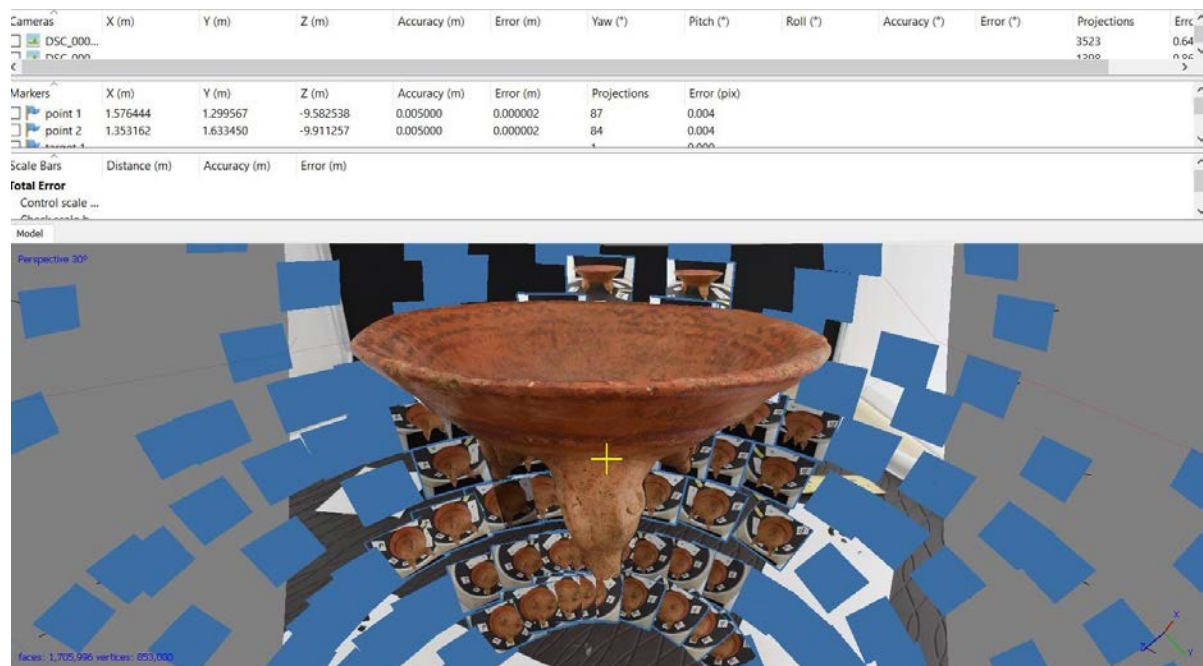**Figura 7: Los estudiantes aprendiendo el procesamiento posterior de fotografías en CRIA**

7

Cameras	X (m)	Y (m)	Z (m)	Accuracy (m)	Error (m)	Yaw (°)	Pitch (°)	Roll (°)	Accuracy (°)	Error (°)	Projections	Erro
DSC_000...											3523	0.64
DSC_000											1208	0.96

Markers	X (m)	Y (m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
point 1	1.576444	1.299567	-9.582538	0.005000	0.000002	87	0.004
point 2	1.353162	1.633450	-9.911257	0.005000	0.000002	84	0.004
target 1						1	0.000

Scale Bars	Distance (m)	Accuracy (m)	Error (m)

Total Error
  Control scale ...
  Check scale b...

Model

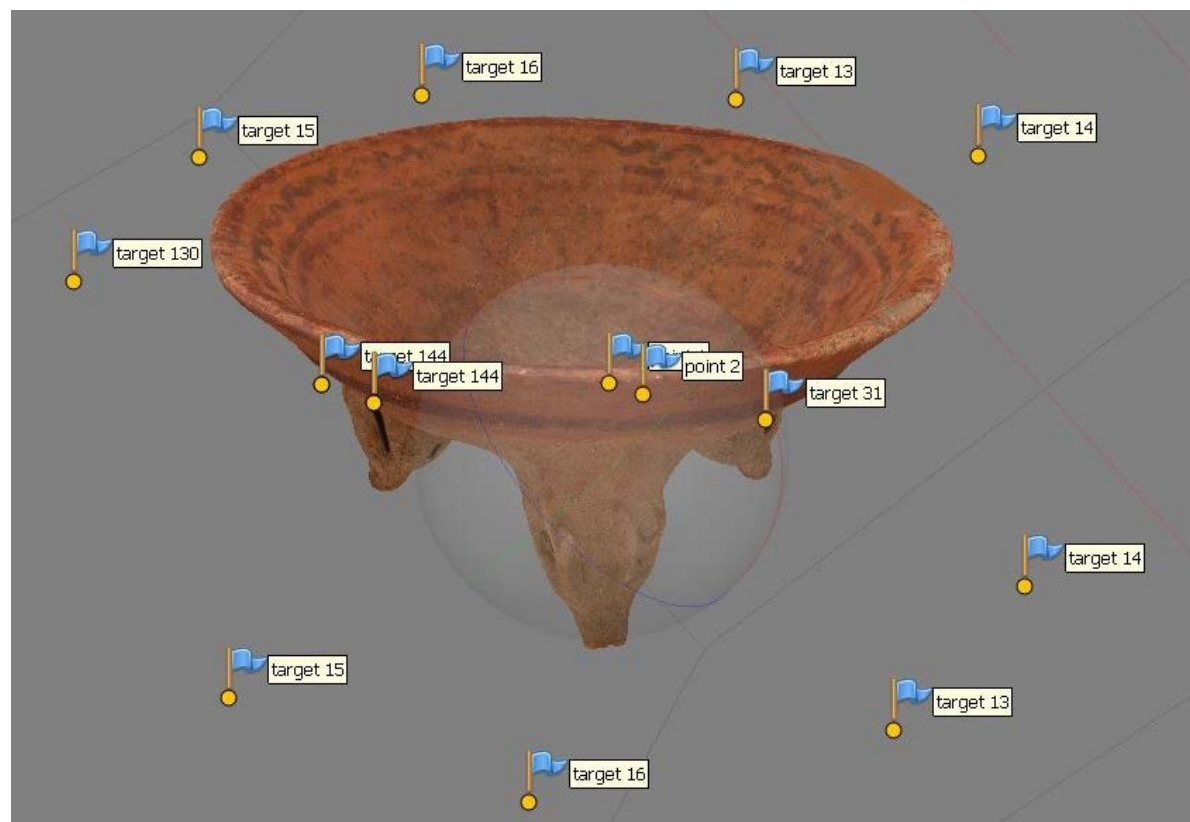**Figura 8: Las posiciones de la cámara calculados por el software (Agisoft)**

Figura 9: El modelo 3D con textura ilustrando los puntos de referencia
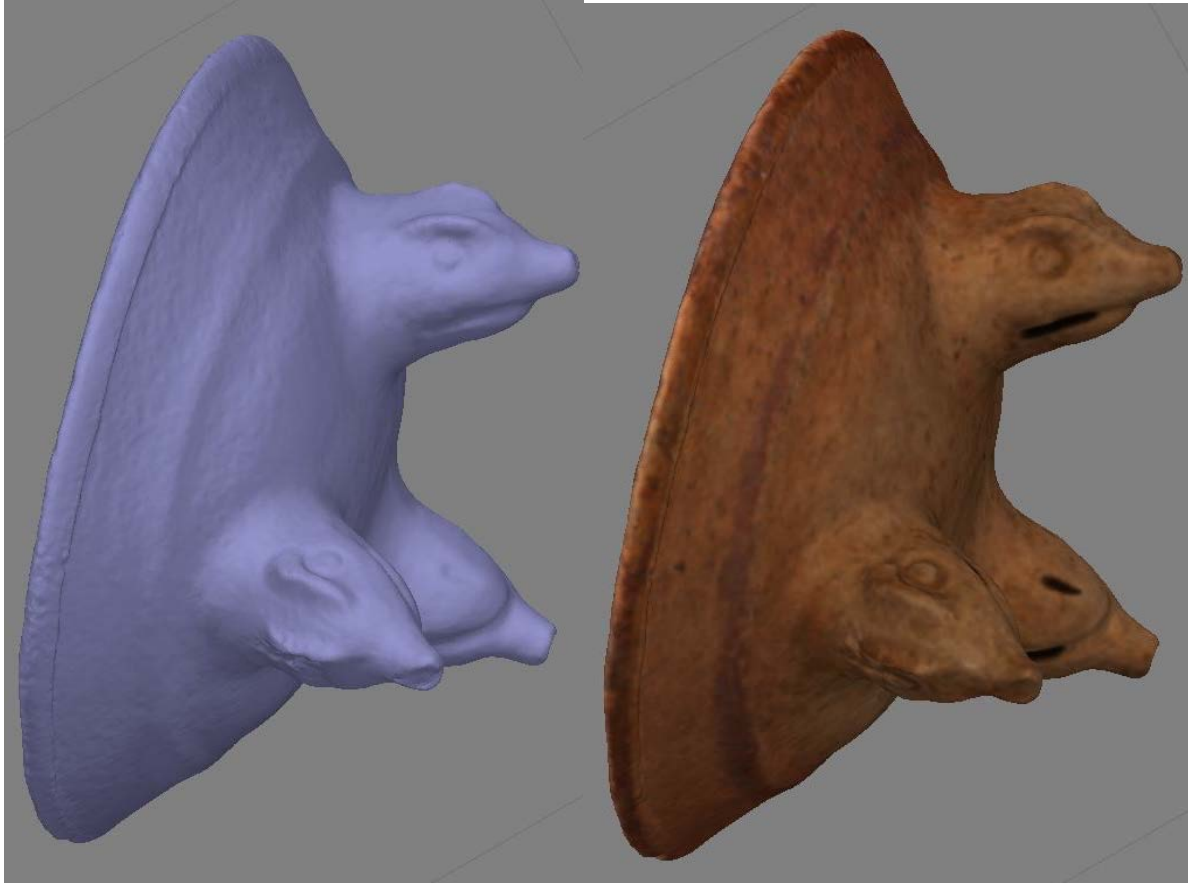
8

Figura 10: El modelo 3D sombreado (izquierda) en comparación a un modelo 3D con textura (derecha) para ver características que no están visibles en fotos o con la textura

Objectivo no4: cómo exportar modelos 3D

Finalmente, les mostramos cómo exportar modelos 3D para Agisoft. Enfatizamos dos tipos de archivos: OBJ y PLY. OBJ se usa a menudo para subir a SketchFab (https://sketchfab.com/ - servidor gratuito en línea utilizado a menudo por arqueólogos cuando se requiere un procesamiento posterior adicional o un análisis del modelo 3D. Por ejemplo, presentamos a los estudiantes a MeshLab http://www.meshlab.net/)— software gratuito de código abierto para procesar y editar mallas triangulares 3D. Meshlab ofrece un conjunto de herramientas para editar, limpiar, inspeccionar, representar, texturizar y convertir mallas o redes. También ofrece herramientas para la medición y el análisis como la visualización de la curvatura.
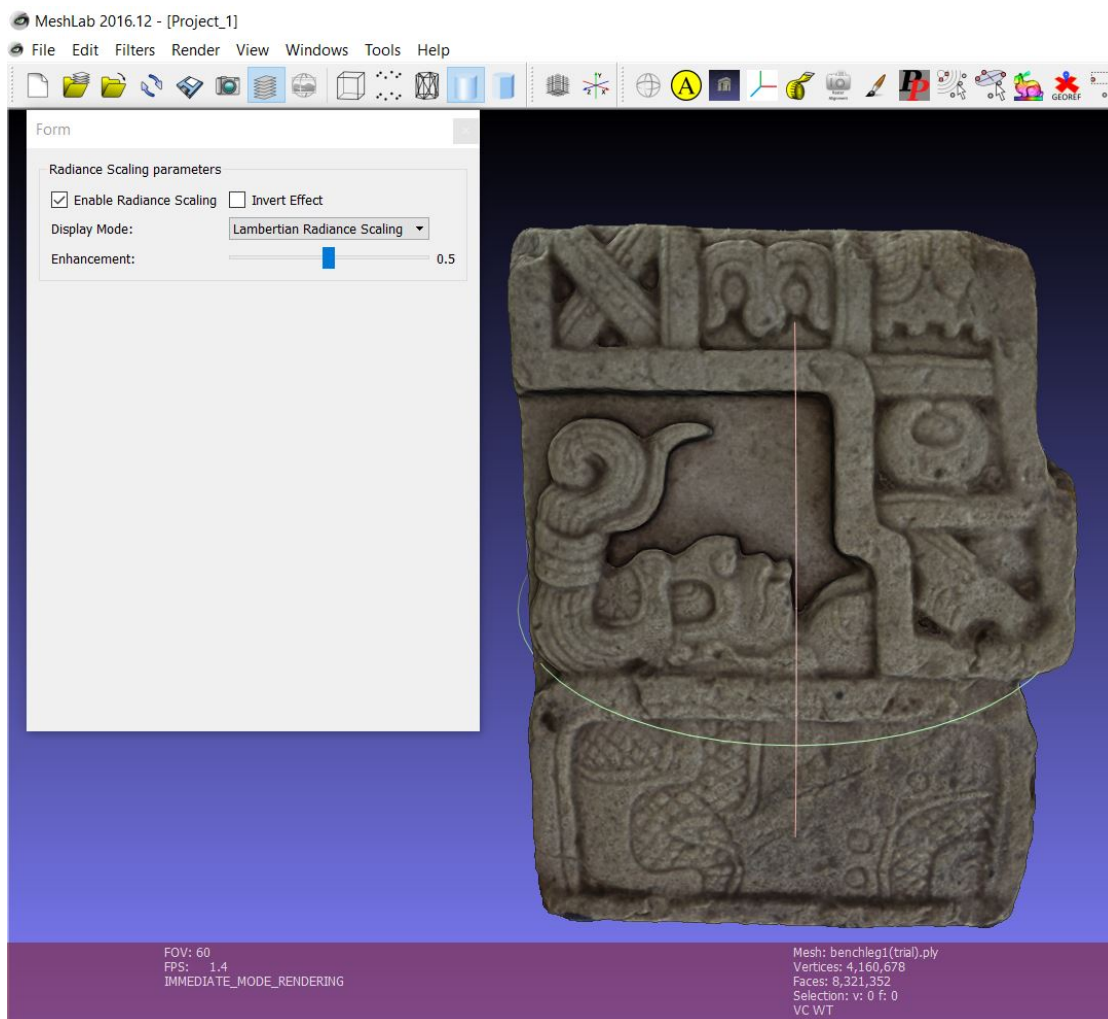
Figura 11: Escala de radiante de una pieza de banco (CPN 999) para ilustrar las características generadas utilizando MeshLab

Por ejemplo, la Figura 11 ilustra la escala de radiante de una pieza de banco (CPN 999) almacenada en CRIA. Los modelos 3D también se pueden convertir a PDF 3D para permitir un acceso mayor utilizando Adobe Reader (gratis).

Objetivo no 2: Creación de modelos 3D para IHA

Los modelos 3D digitales proporcionan datos x, y y z sobre artefactos arqueológicos y sus características. Utilizando fotogrametría, los datos 2D se recopilan y procesan para crear y 3D los datos. Este proceso captura un objeto en su estado actual permitiendo un modelado basado en la realidad. Estos modelos 3D que se generan sirven de ayuda a los administradores del patrimonio cultural y a los arqueólogos en la toma de decisiones con fines de preservación, conservación e investigación. Los datos digitales se proporcionan como un registro del estado de un artefacto en un momento específico en el tiempo y los modelos 3D se pueden procesar

en una fase posterior con el empleo de un software como MeshLab para iluminar detalles que no son visibles a simple vista y que permitan mediciones más precisas.

En 2017, para apoyar los esfuerzos de digitalización y conservación para IHAH, consultamos con Arq. Héctor Eliud Guerra, Subdirector del Parque Arqueológico de Copán, y Norman Martínez, Gerente de CRIA, para identificar objetos de alta prioridad para generar modelos 3D. Basado en sus comentarios y en nuestros intereses de investigación para el entorno de realidad virtual, adquirimos fotos de los siguientes artefactos y piezas de escultura. Consultamos con Reina Flores de la Biblioteca CRIA para determinar los números de CPN y obtener información básica sobre los objetos, cuando estén disponibles. [Escaneamos estos documentos para incluirlos en la versión digital del informe.] En 2018, nuestras investigaciones (por dos días) enfocado en del banco de trabajo no 1 (CPN 999) con Norman Martínez y Arq. Héctor Eliud, además creamos otros modelos 3D incluye el vaso trípode y un silbo (CPN-C-1692). En 2017 adquirimos datos (fotos) para construir un modelo 3D de las cinco partes del banco y cuando regresamos a UNL, construimos cinco modelos 3D—depositamos estos modelos 3D con CRIA. Sin embargo, tenemos poca información sobre el banco, por lo tanto, en 2018 nuestro objetivo fue para descubrir más sobre el banco.

Figura 12: Un silbo (CPN-C-1692) (arriba) y el modelo 3D con textura (abajo)


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Banco con glifos:C PN 999 1-4 (4 piezas)

Esto banco con glifos es del Grupo 9K-47 y se encuentra en cuatro piezas almacenadas en el almacén CRIA. El banco se rompe por la mitad (2 piezas) y tiene dos soportes. Norman Martínez preguntó si podíamos hacer modelos en 3D de las cuatro piezas para ayudarles a comprender mejor cómo podrían haber encajado las piezas originalmente. En el pasado, la pieza había sido expuesta en el Museo en Tegucigalpa, Honduras. No encontramos más información sobre esta pieza en la biblioteca CRIA. Hay fotos archivos en la biblioteca de CRIA pero estas fotos ilustran el banco con dos piezas (CPN 998-1, 998-2) que no son un parte actual del banco (Figura 13). Vea el dibujo de Barbara Fash (Baudez 1994) por otra reconstrucción (Figura 15).

Figura 13: Fotos del banco (CPN 9991-4) con dos otras piezas (CPN 998 1-2) de la Sala de Exposición en el Museo de Antropología en Tegucigalpa (circa 1983)
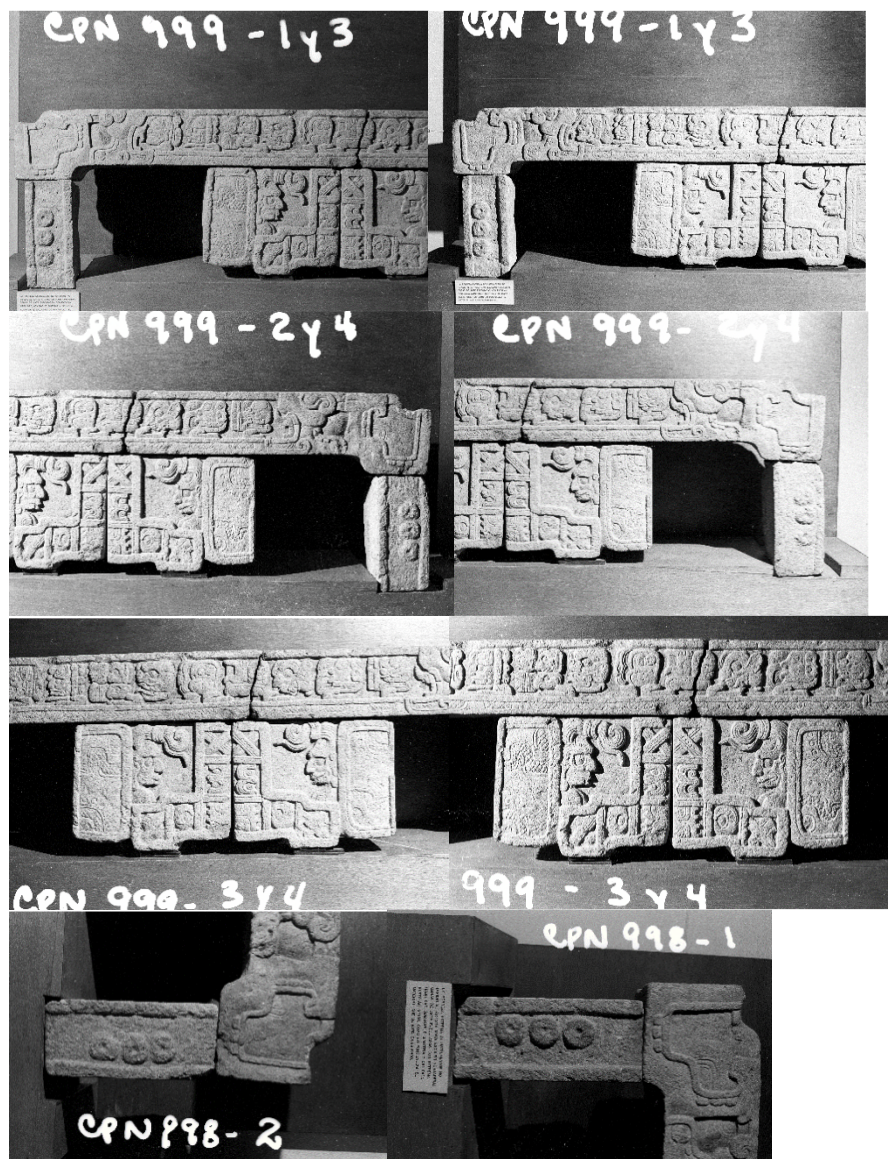
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La reconstrucción de la Sala de Exposición en el Museo de Antropología en Tegucigalpa fue dibujada por Bertold Riese (1978). Vea sus notas del campo (Figura 14). (Vea Apéndice B para las notas.)
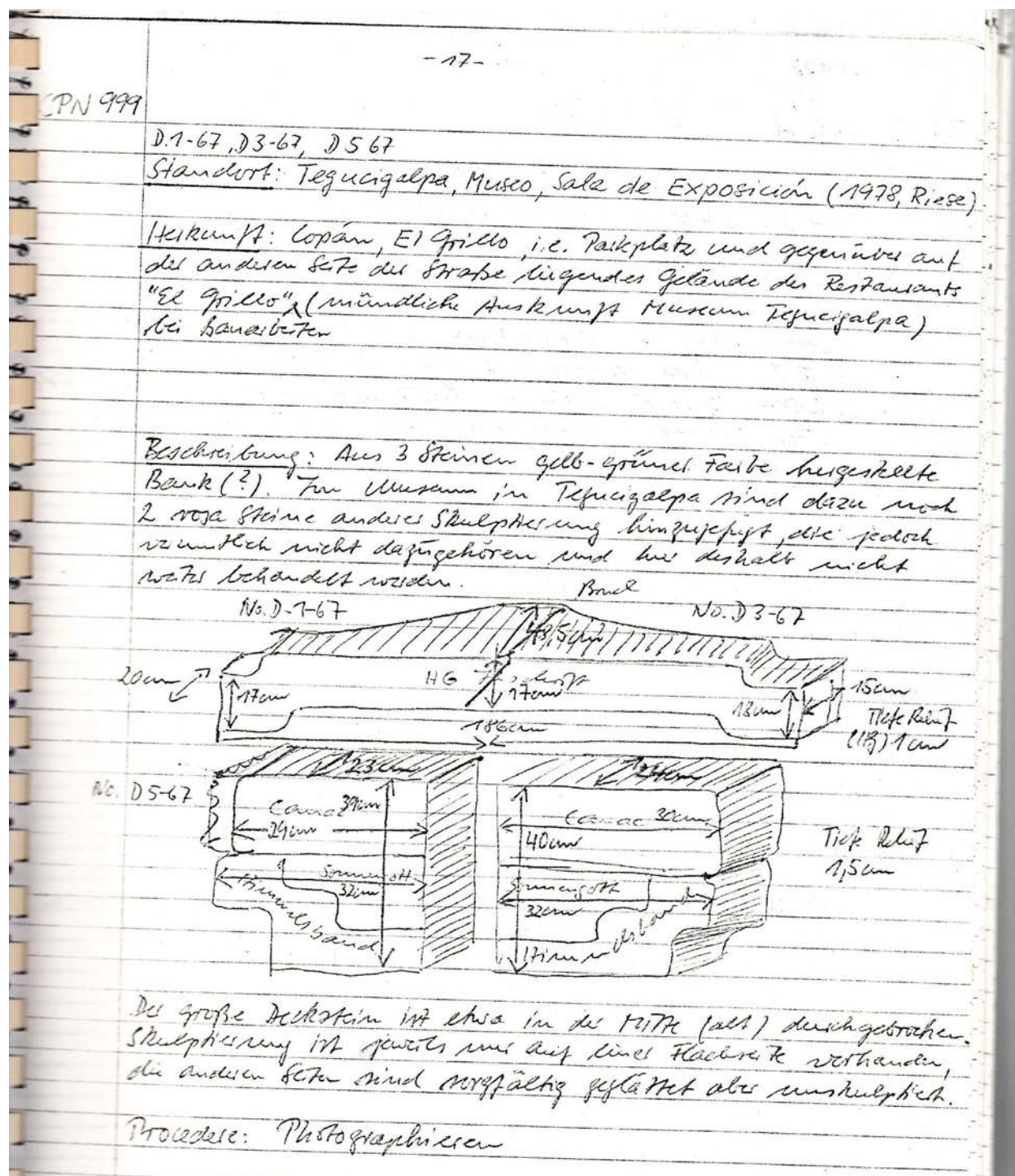
-17-

CPN 999

D.1-67, D3-67, D5 67
Standort: Tegucigalpa, Museo, Sala de Exposición (1978, Riese)

Herkunft: Copán, El Grillo, i.e. Parkplatz und gegenüber auf der anderen Seite der Straße liegendes Gelände des Restaurants "El grillo" (mündliche Auskunft Museum Tegucigalpa) bei Bauarbeiter

Beschreibung: Aus 3 Steinen gelb-grüner Farbe hergestellte Bank (?). Im Museum in Tegucigalpa sind dazu noch 2 rosa Steine anderer Skulptierung hinzugefügt, die jedoch vermutlich nicht dazugehören und hier deshalb nicht weiter behandelt werden.

Der große Deckstein ist etwa in der Mitte (alt) durchgebrochen. Skulptierung ist jeweils nur auf einer Flachseite vorhanden, die anderen Seiten sind sorgfältig geglättet aber unskulptiert.

Procedere: Photographieren

Figura 14: La reconstrucción por Bertold Riese de sus notas del campo (1978)

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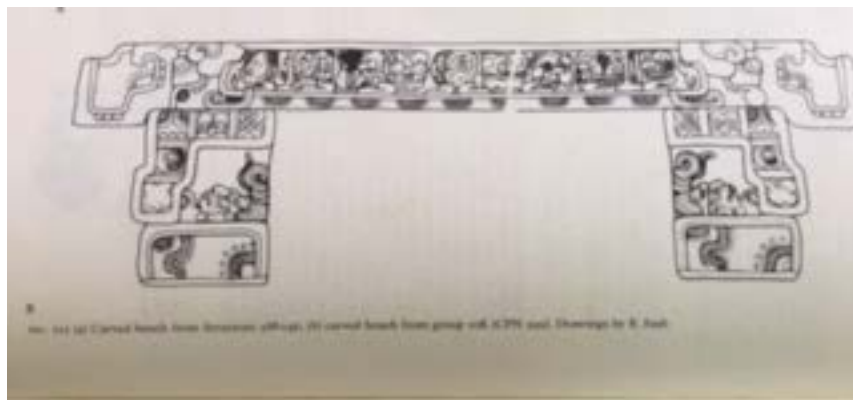
Figura 15: Un dibujo de una reconstrucción del banco (CPN 999) por Barbara Fash (Baudez 1994)

De las materiales en la biblioteca de CRIA, conversaciones con el personal de CRIA y hemos recogido esta información sobre la ubicación original del banco (Figura 16).

Figura 16: Una mapa del grupo potencial del banco que creamos utilizando información de CRIA y SIG

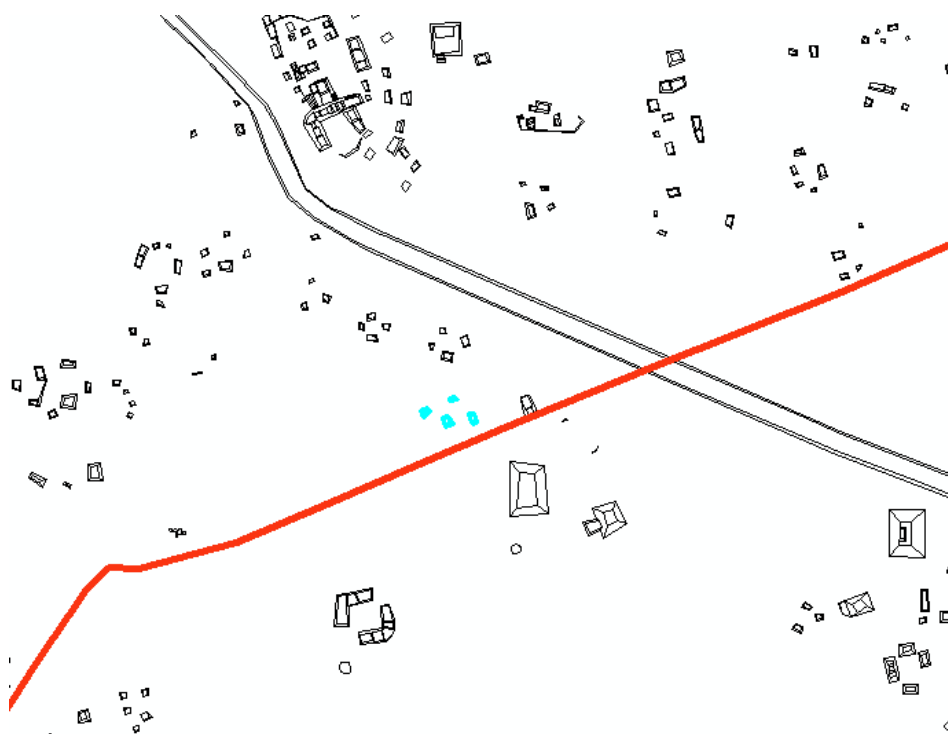Figuras 17-20 muestran las fotos que sacamos este año del banco (CPN 999).

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Figura 17: Fotos del banco no 1 (CPN 999-1); delante (arriba), detrás (abajo)

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Figura 18: Fotos con objetivos del banco no 2 (CPN 999-2); delante (arriba), detrás (abajo)

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Figura 19: Fotos del banco no 3 (CPN 999-3); delante (arriba), detrás (abajo)

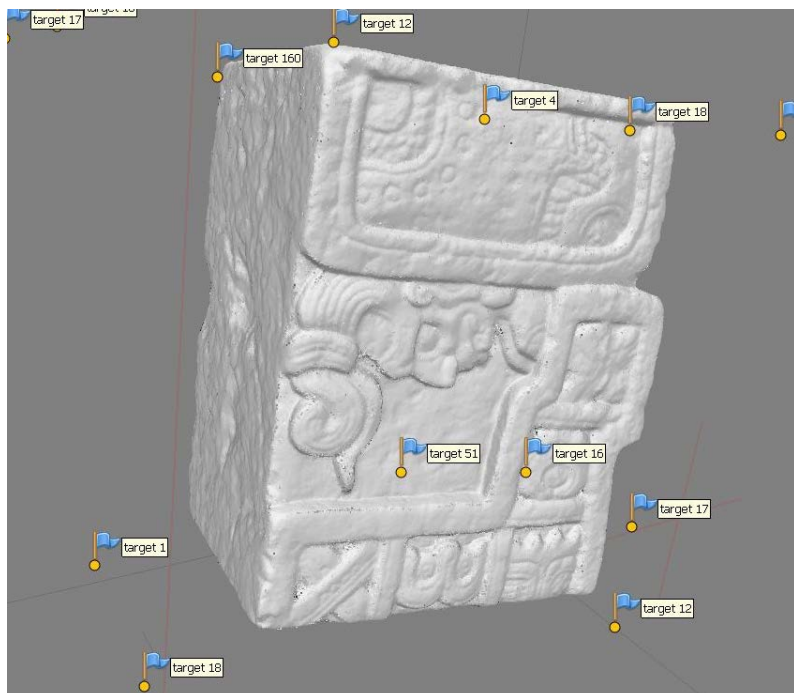**Figura 20: Fotos del banco no 4 (CPN 999-4); delante (arriba), detrás (abajo)**

Figura 21: El modelo 3D sombrado del parte del banco (CPN 999-3)

Figura 22: El modelo 3D con textura del parte del banco (CPN 999-3)

Después la temporada de campo, creamos modelos 3D de cada parte del banco y creamos modelos 3D en resolución baja y resolución alta. Además, exportamos los modelos 3D a 3DPDF para facilitar el intercambio y la visualización con la personal de IHAH. También utilizamos el software gratis (Meshlab) para explorar reconstrucciones el banco e importamos el modelo 3D en un ambiente virtual para explorar en realidad virtual inmersiva (el software—Unity 3D) (Figuras 23-25).

Figura 23: Una reconstrucción del banco en realidad virtual inmersiva (CPN 999)

Figura 24: Una reconstrucción del banco en realidad virtual inmersiva (CPN 999)


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Figura 25: Las participantes de la práctica utilizando la realidad virtual inmersiva para explorar una versión virtual de Copan en el parque arqueológico

APPENDIX D: PHOTOGRAMMETRY PROCEDURE

This procedure represents the workflow taught by Heather Richards-Rissetto and Cole Juckette to the students from the Honduran academy. This procedure consists of a workflow that is designed to be the most effective for capturing landscape, architecture, and individual items, truly attempting to be fitting for any prospective need. While this procedure affords a high degree of versatility it is not entirely without limitations; for instance, there is still an intense degree of difficulty in capturing glossy or "shiny" objects, and in addition to that the program used to generate these models requires expensive and powerful computer hardware in order to run quickly. These limitations are not insurmountable however, glossy objects can be captured to a degree using specified and at times "improvised" photography techniques, and while less expensive and less efficient computer hardware is not ideal for processing photos in Agisoft, it is not impossible, or in many cases inviable.

Setup

The first stage for workflow design is setting up your program correctly. After acquiring the software and beginning your first project it is important to set up a few necessary functions in your workflow. First use the file drop down to save your new project as a specifically named "photoscan Archive" file or a .psz. This is in opposition to the .psx or "project" file format which does not save photos to the project file and can make it difficult to edit a project after completing
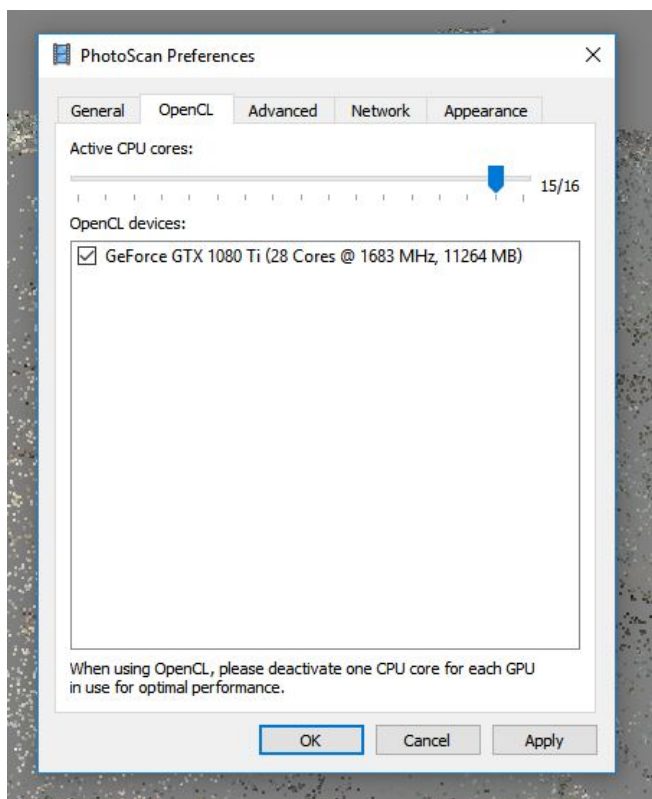
the processing. At this stage you may check if your computer has an available integrated graphics card by finding the preferences pane from the main toolbar and clicking the GPU tab, here you can configure your card to be used for GPU acceleration in the dens cloud stage of the process. Leave this turned off for now if you have an available card and if the tab shows nothing listed or an "Intel HD ___" you should not attempt to activate this option. Next you must set up your photos and "chunks" respectively, the easiest method is to already have your photos organized in different folders on your computer before you begin the program, i.e. having each chunk separated by folder. In this case "chunk" of course refers to all the photos of a subject presented in the same way or of a specific area, such as having separate chunks for each orientation of an artifact or for large areas of space in a landscape or architectural project that seeks to showcase detail and each of these will be processed separately and then combined later. As an example, consider a vase on a table, taking

photos of it standing normally would all be in one chunk and taking photos of the vase while it is inverted to show its bottom would be another separate chunk.

Markers

If you have used markers in your scene, it is first necessary to detect them in photoscan to continue processing while using them. This can be accessed via the tools tab on the main toolbar. Here you will have the option of bit number, and tolerance. For this example we will always use 16 bit markers and tolerance will vary depending on how well the camera is capturing the markers in your scene. If your marker detection returns to many "false markers" (random points and pixels mistaken for calibrated markers) you may want to lower your tolerance setting until it detects only markers that you set up in the scene. We will typically use tolerance settings between 50-80 for the best results. Once a best scenario for markers is found you can delete any markers with excessively high error values, shown in the reference pane, any value of 1 or greater should be considered for deletion, as well as any markers that show very few projections (number of recognized appearances in the photoset).
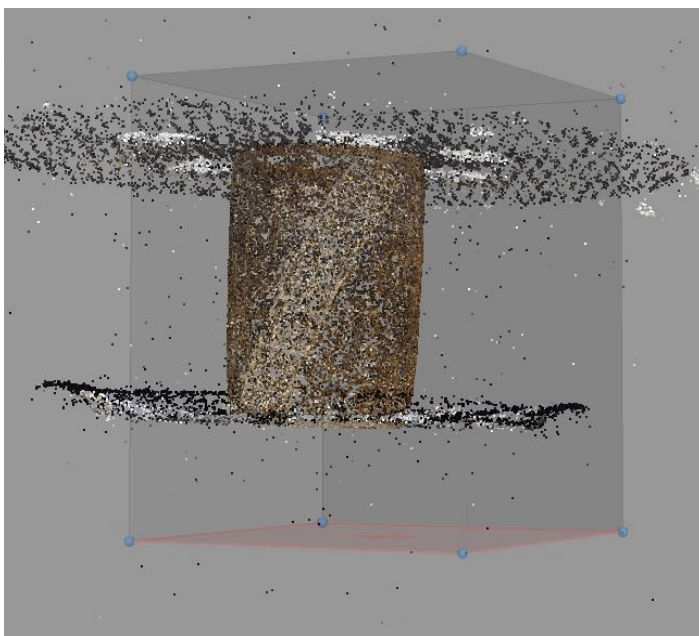Save.
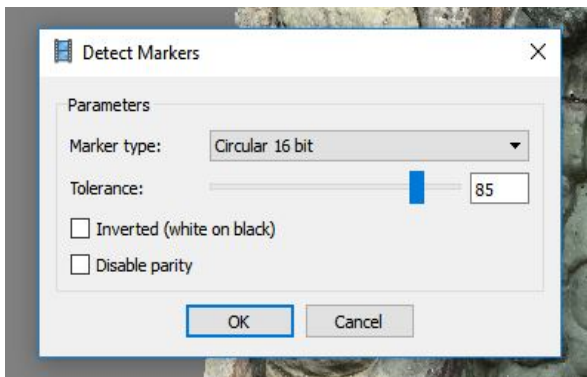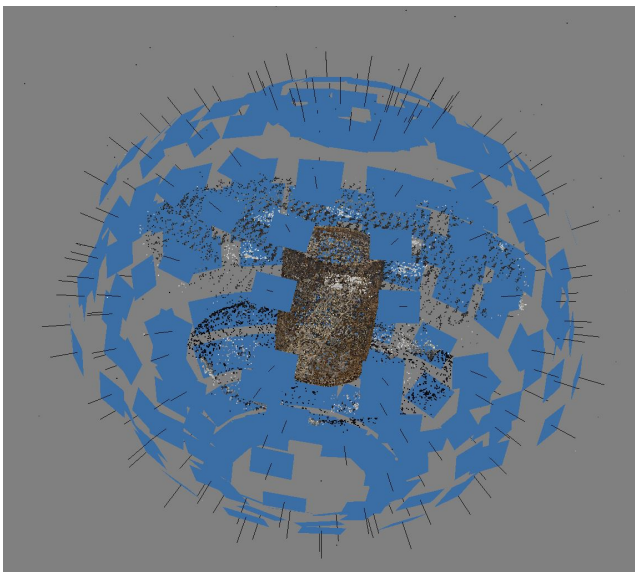
Alignment

During the alignment stage all of the photos for a given chunk or project are aligned and given location data in regard to the location of the frame to the location of the object. During this process similar points are assigned between frames which allow the software to recognize how an object is moving in the photoset. You will find the Align photos command in the workflow tab where you should set the accuracy to medium for our examples and turn pair selection to generic. Higher accuracy will lengthen the amount of processing time needed to align the photos and disabling pair selection will potentially speed up smaller photosets. In the advanced settings you should set the key point limit to 50,000 points and the tie point limit to 5,000, when using a more powerful computer or a series of processing nodes you can change these numbers to 100,000 and 10,000 for even more accurate alignments.

Save.

Adjustment

After alignment has finished you should check your scene carefully for problems or errors. The assembled points should look vaguely like the object you are attempting to capture and its surroundings. In the reference pane you should check for high error values and low projections (1 or above, and lower than 5-10 respectively) and consider removing the photos with these errors by right clicking on them and clicking remove. Adjust your bounding box using the toolbar so that only the object is contained within it and as little of the background is showing. Sometimes it helps to select points to remove around the object first

using the remove tool also located in the toolbar.
Save.

Low Quality Dense Cloud

For the first dense cloud we will be running the process on its lowest setting since we will only be using this first model to capture the very basic geometry of the object in order to create the mask.
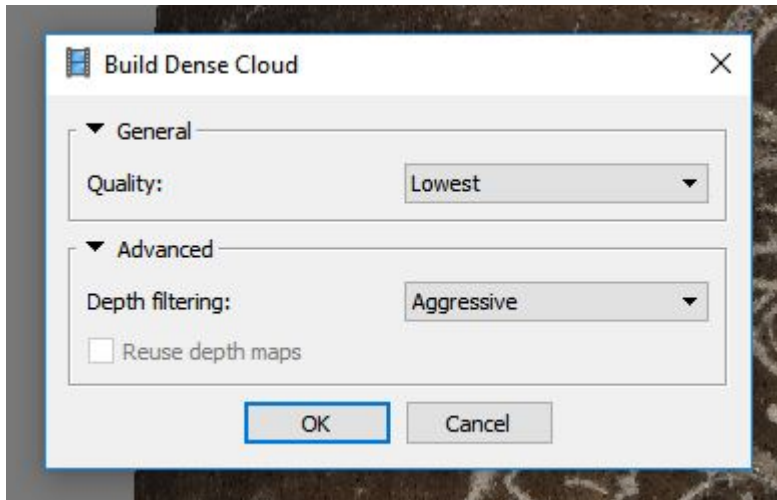
Select build dense cloud in workflow and set the quality to the lowest setting, in advanced options you should set depth filtering to aggressive. Before running this step, if you have a computer with dedicated graphics you may configure these now in the preferences window. Running the dense cloud usually takes the most amount of time in the process sometimes lasting many hours, but in this low setting stage it should be much faster. Save.

Mesh

After the Dense cloud is completed it is time to finish "cleaning up" your object in the scene. Use the free-hand delete tool to remove all points not pertaining to the subject, if you are using chunks
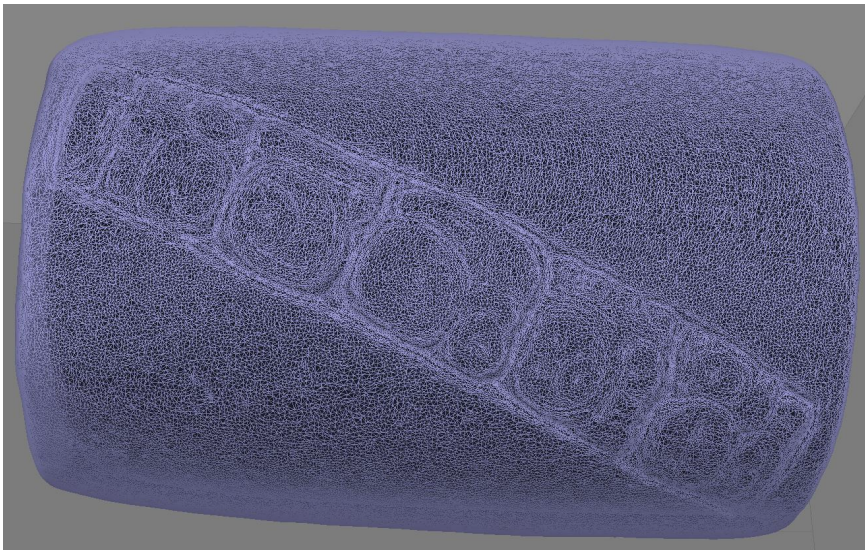

do not worry about cutting off small parts of the object including its entire base in this phase. Once only the subject's points remain find "build mesh" in the workflow tab, here you should make sure that surface type is set to arbitrary, source set to dense cloud, and set your face count to 0 so that it generates as many as possible (this is actually faster than setting a lower number as the computer would generate the faces regardless and then process the object again to decimate it taking more time). Save the project.
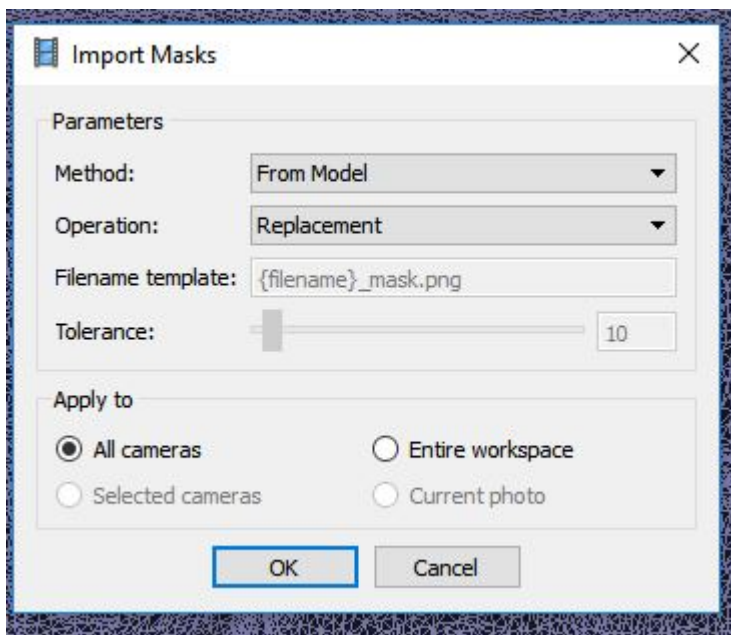
Masking
Once you have created the first low quality model you can use this shape to create an automatic mask for the object which deselects all of the objects surroundings and generates points only for the surface of your subject. In the tools drop down you will find the command import, and then import masks, select this and set method to "from model" and the operation as "replacement" with the apply to box marked next to "all cameras", click ok.
Save.
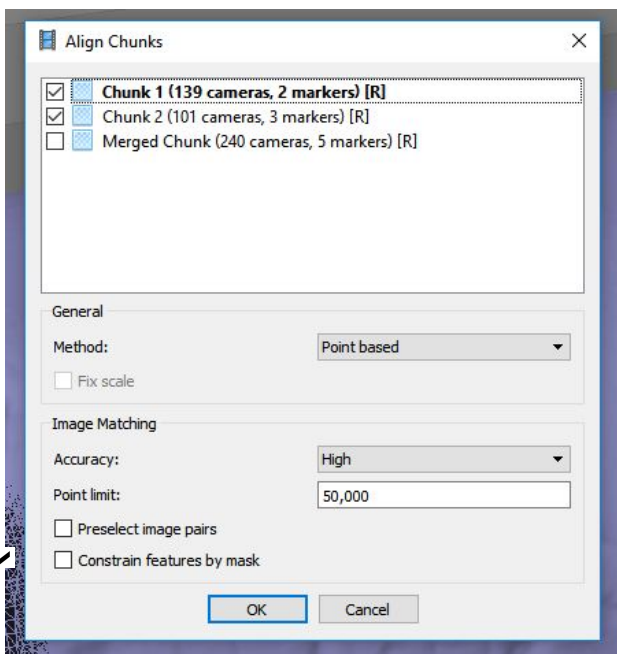
Chunk Alignment and Merging
Once you have imported masks for both or all chunks select the align chunks command form the workflow dropdown. In the command settings set accuracy to high, set method to "point based" and make sure that the option "constrain features by mask" is selected. With both chunks selected for processing run this process and when finished select merge chunks in the same workflow dropdown. With both chunks selected check the boxes "Merge dense clouds", and "merge models", **Do not select "Merge Markers".**
Run and Save.

High Quality Dense Cloud

After examining your merged chunk to make sure that the halves were aligned properly you will run a second dense cloud with higher settings. You can choose which setting based on the speed of processing, in this case we will likely use low or medium settings since the masks will remove any extraneous points. During this phase, again it is highly recommended to turn on the OpenCL GPU acceleration if you have it available.

Mesh

Run another mesh with the new dense cloud keeping the same settings keeping face count listed at 0 and checking to make sure that the chunks were properly aligned.
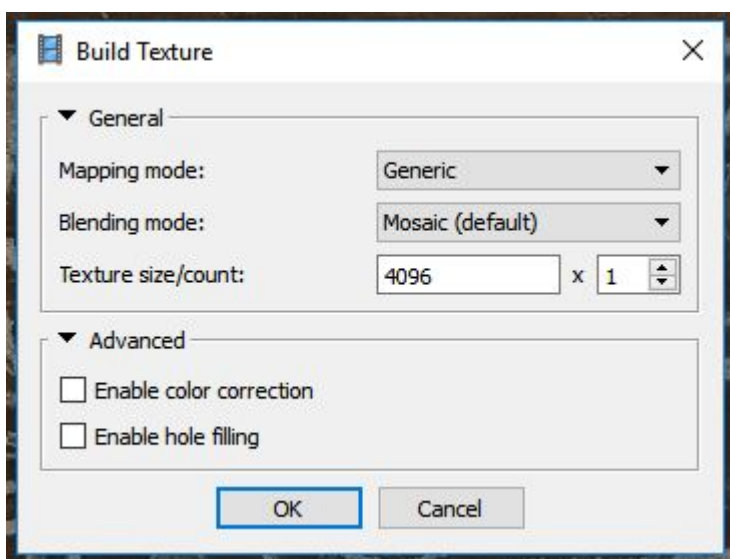
Texture

If your mesh comes out as intended you will find "build texture" in the workflow drop down. Set mapping mode to generic, blending mode to mosaic, and make sure the texture size reads 8219x1. If you run this process and find color distortions in your model like large black spots or areas that are obviously discolored compared to the photos you can run this process again with color correction turned on but it will take much longer to process. You can also choose a lower texture size (4096x1) if you need to reduce it in order to upload to a site like Poly.

Export

Once your model is complete you should save it as a "finished" version and you can export the model by selecting export model in the file drop down, naming it, and exporting as either a .obj file or a .ply file (these will be the file types you use most often, but if you need a specific type agisoft supports almost all 3D files). In the settings window that appears after you select where to save the export make sure that "export normals" and "export texture"-"JPEG" are selected. If you need to reduce the size of your model in order to upload it to a site simply select the "decimate Mesh" command from the tools drop down and give it a face count value of 300,000-600,000. Once this function completes re-run the texture and export the model again under a different name.

Scaling

At any point after the initial alignment stage you can choose to give your model a scale bar for its geometry by either using the markers in your scene or making sure that you place a measuring device of some kind in the physical environment so that it shows up in as many pictures as possible. The first method simply requires you to carefully measure the straight-line distance between your markers before you take your pictures so that when you process them, you can select the markers in the reference pane, by clicking and then clicking again with the command key held down, with both selected right click and select "create scale bar". Once created, the two points will show up in the scale bars section of the reference pane and you can apply the measurements to each scale in meters. The second method requires you to manually input markers in the photos themselves. To do this, select a photo in edit mode and find a point on your measuring device in the photo, zoom in as far as possible so you can get as close to pixel accuracy as you can, right click and select "create Marker", finally check the next few photos in the succession to make sure that your marker is being automatically placed in each one. You may have to manually set the markers position more than once to make sure the software is placing them with accuracy. This is usually represented by a red and white line crossing the page and you should "place" the marker again where that line intersects the physical point you wish to capture. Once you have a series of markers along the measuring device you've chosen you can edit these markers in the reference pane the same way that you did in the other method by selecting two points, creating a scale bar, and inputting the measurement between them. Try to include at least five or six different scales in this process to increase scale accuracy.