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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 photo-grammetrically-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

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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].

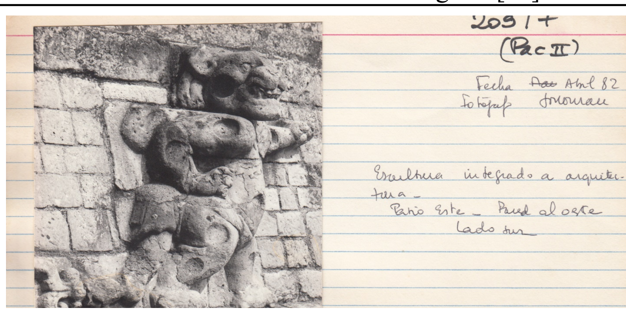

Fig. 2. Catalog card for Dancing Jaguar No.2.

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.

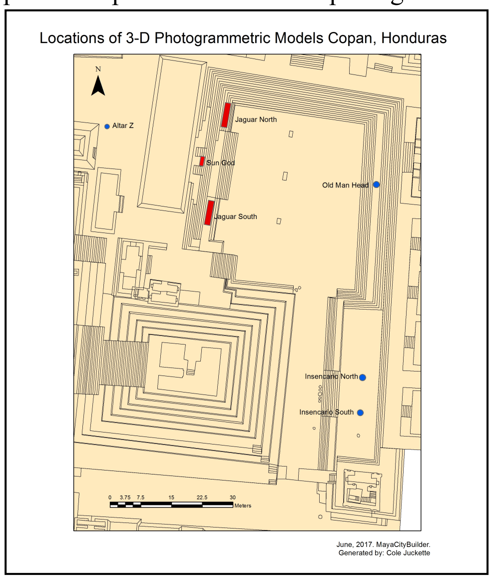

Fig. 5. GIS map of object locations in East Court, Copan.

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.

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