MULTI-SENSOR 3D DOCUMENTATION OF THE MAYA SITE OF COPAN

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Commission V, WG V/4

KEY WORDS: Multi-resolution, Multi-sensor, Laser scanning, Photogrammetry, UAV, 3D modeling

ABSTRACT:

The article presents a work-in-progress on the reality-based, multi-resolution and multi-source documentation and digital reconstruction of a part of the ancient Maya kingdom of Copán, Honduras. This international and interdisciplinary project will provide digital 3D models for research and public education purposes. UAV and terrestrial images, together with terrestrial TOF laser scanner data were acquired, will be processed and seamlessly combined to produce a multi-resolution model which will fulfill measurement and archaeological needs. Preliminary 3D results are reported and discussed.

Figure 1. A panoramic view of the East Court of Copán with the Temple 22 in the background and a sketched 3D reconstruction of the entire site with the Acropolis (Hohmann and Vogrin, 1982).

1. INTRODUCTION

The continuous evolvement of new sensors, data capture methodologies, multi-resolution 3D representations and the improvement of existing ones can contribute significantly to the documentation, conservation and presentation of archaeological information and to the growth of research in the Cultural Heritage field. This is met by increasing requests and needs for digital documentation of archaeological sites at different scales and resolutions. Nowadays the generation of reality-based 3D models of large and complex sites is performed using methodologies based on image data (e.g. photogrammetry) (Remondino and El-Hakim, 2006), range data (e.g. laser scanners) (Blais, 2004; Cignoni and Scopigno, 2008), classical surveying (e.g. total stations or GPS) or graphical and procedural modeling. The choice depends on the required accuracy, object dimensions and location, surface characteristics, working team experience, project's budget, final goal, etc. More and more often the different methodologies are also combined and integrated trying to exploit the intrinsic potentials and advantages of each technique (El-Hakim et al., 2004; Lambers et al., 2007; Remondino et al., 2009).

In this contribution we report the ongoing 3D documentation work at the UNESCO World Heritage Maya site of Copán, Honduras, carried out with the permission and collaboration of the Honduran Institute of Anthropology and History. Due to the dimensions and complexity of the archaeological area, a multi-resolution and multi-sensor approach was selected to fulfill measurement and archaeological needs and to achieve a geometric resolution which varies according to the areas of interest and different types of objects.

2. THE MAYA SITE OF COPÁN, HONDURAS

2.1 Brief historical background

Ancient Maya architecture of Mexico and Central America lasted for almost 2000 years (600 B.C. - A.D. 1521) and is the best-preserved indigenous architectural tradition of the ancient Americas. Sophisticated mathematicians, astronomers and engineers, the Maya were the only New World people to develop the concept of zero and predict lunar eclipses. They also built roads kilometres long, bridges, canals and reservoirs holding water for cities of 200 000 people, as well as five-story palaces and temples thirty meters high. In some regions the builders even used a kind of cement, which is the reason that many structures in the northern Yucatan peninsula are still standing today.

Copán, located on the southern frontier of the Maya world, contains different courts and a large Acropolis (Figure 1) and it is called "the Paris of the Maya world" because of the high-relief stone sculptures found on its temples. Excavations at Copán have been underway since 1885, and archaeologists from the U.S.A, England, Japan, France, and Honduras have shown that the kingdom had a dynasty of sixteen kings that ruled over five centuries (AD 427-820). Archaeologists have been able to trace the development of Copán's architecture from packed adobe, to stone walls with plaster sculpture (Sharer et. al. 1992; Andrews and Fash, 2004). This progression culminated in the

9th century with stone walls and stone sculptures carved from rhyolite (a soft stone that led Copán's artists to carve detailed temple sculpture). The four-meter-high portraits of Copán's thirteenth ruler - King Waxaklajuun U'baah K'awiil (reigned AD 695-738) gives a sense of this kingdom's artistic accomplishments (Figure 2). This king commissioned the Temple 22 inside the Acropolis of Copán, which can be considered the "Parthenon of the Maya world" because it has over 3500 pieces of sculpture housed in museum collections around the globe. The most famous of these is the Maya Maize God, the "Crown Jewel of Maya Art," now at the British Museum. The Temple 22 was a daring experiment in true masonry architecture (built without adhesive mortar), but once the protective plaster and paint wore off, its upper facades and sculpture collapsed. Today only the first story remains and it is hard for visitors to imagine the glory of this ancient temple.

2.2 The 3D modeling project

The archaeological area of Copán, partly hidden in the dense tropical vegetation, is constituted by different large courtyards containing buildings, stairways and statues ("stelae"). The pilot project aims are (i) the reality-based 3D modeling of the East Court (ca 35x40m) with its Temple 22 inside the old Acropolis of the site, (ii) the precise 3D modeling of some of the famous Copán's stelae, (iii) the virtual reconstruction of different structures (mainly pieces of architectural sculpture) located in the local museum and also in foreign museums, together with their re-integration into the reality-based 3D model of the Temple 22. A successive larger project will face the linking of the digital 3D models with an archaeological database (for data management and access via internet) and the realization of a VR platform for the interactive visualization of the entire modeled archaeological area of Copán. Indeed it is planned to integrate data derived from satellite, aerial images, previous surveys and archaeological missions in order to model the whole larger area of the valley of Copán, which is dotted with Maya and pre-Maya remains.
In this contribution, the first results of the pilot project for the 3D digital documentation of part of the Copán's site are reported.

2.3 Related surveying works in Copán

The first 3D surveys of Copán were hand-drawn maps at scale and partly with elevation information. The first maps at 1:2500 were made by Galindo (Graham, 1963), and later, by Stephens and Catherwood in the 1840s (Stephens, 1841). Afterwards the maps became increasingly more detailed and Gordon (1896) and later Stromsvik (1947) published maps at scales of 1:1500. An unpublished map of Copán's Principal Group at 1:400 made by Shook is available in the Peabody Museum at Harvard University while Hohmann and Vogrin's map of 1982 is at 1:200. In the late 1970s, some archaeologists moved their focus beyond the Principal Group to the residential sites of the Copán Valley (Willey et al. 1978; Willey and Leventhal, 1979). The Proyecto Arqueológico Copán (PAC I) designed, managed and carried out the earliest systematic archaeological surveys within the Copán Valley (Baudez et al., 1983). The result was a volume comprised of 24 one-square km maps that contain archaeological sites, contour lines and hydrology mapped at a scale of 1:2000 (Fash and Long, 1983). Following PAC I, Sanders and Webster of Penn State University co-directed Phase II of the Proyecto Arqueológico Copán (PAC II). This phase of the project focused on excavation and large-scale mapping of elite architectural complexes in Las Sepulturas, a suburb of Copán (Sanders, 1986). Nearly a decade later, Hohmann (1995) created large-scale architectural drawings (many at a scale of 1:100) and 3D reconstructions of many of the excavated buildings from Las Sepulturas, using terrestrial photogrammetry (Hohmann and Kostka, 1995a,b;Kostka, 1995). More recently, Maca (2002) began one of the first GIS maps of the Copán Valley, focusing his efforts on Group 9J-5 and its nearby surroundings in the suburb of Comedero. Richards-Rissetto (2007) digitized and georeferenced the PAC I maps (covering 24 km^2) and integrated them with more recently available large-scale maps to create a GIS for the entire Copán Valley. Currently, the GIS contains (i) vector data of archaeological buildings and monuments, hydrology, contour lines and (ii) raster data of a Digital Elevation Model (DEM) of the valley (generated from contours ranging from 2-10 meters) and an Urban DEM of the valley's with more than 3000 buildings (with elevations derived from excavations, reconstructions and archaeological studies).
Since the advent of photogrammetry and remote sensing, surveys of Copán were made at various scales and projects have ranged from LiDAR surveys to structured light scanning of small hieroglyphs. The latter projects are led by the Getty Conservation Institute (Gray and Boardman, 2001) and the Peabody Museum of Harvard University to scan the 1900+ hieroglyphs of Copán's Hieroglyphic Stairway with a Breuckmann system. The goal of this project is to conserve the stairway and to virtually reconstruct the hieroglyphic blocks in their correct and original order (indeed the stairway was physically reassembled and reconstructed in the 1930s).

3. MULTI-SENSOR AND MULTI-RESOLUTION METHODOLOGY

Multi-resolution data are nowadays the base of different geospatial databases, visualization repositories and VR platforms. Probably the best and most known examples are given by Google Earth or Microsoft Virtual Earth. Data span from tens meters resolution (both in geometry and texture) down to few decimeters (only in texture). The user can browse through the low-resolution geospatial data and get, when necessary, high-resolution and detailed imagery, often linked to other 2D/3D information (text, images, city models, etc).
In a multi-resolution survey, we should be distinguished between (i) *geometric modeling* (3D shape acquisition, registration and further processing) where multiple sensors and resolutions are combined to model features with the most adequate sampling step and (ii) *appearance modeling* (texturing, blending, simplification and rendering) where multiple images are used for realistic appearance and various LOD are used to face 3D models complexity during the visualization.
For the 3D documentation of large and complex sites, the state-of-the-art approach uses and integrates multiple sensors and technologies (photogrammetry, active sensors, topographic surveying, etc.) for the derivation of different geometric LOD of the scene under investigation, both in geometry and texture. Each LOD shows only the necessary information while each technique is used where best suited to exploit its intrinsic modeling advantages.

3.1 Related works

Since the nineties, sensor fusion has been exploited for industrial, military and mobile mapping applications. Afterwards the sensor and data integration methodology was applied also to Cultural Heritage 3D documentation. Stumpfel et al., (2003) digitally reunified the Parthenon of Athens and its sculptures using photogrammetry and stripe projection systems. Gruen et al. (2005) used a multi-resolution image-based approach to document the entire valley of Bamiyan with its lost Buddha statues and produced an up-to-date GIS of the UNESCO area. El-Hakim et al. (2008) integrated terrestrial photogrammetry and different laser scanners to produce a textured 3D model the Erechteion of Athens. Guidi et al. (2009) used a multi-resolution and multi-sensor approach to digitally reconstruct the entire Roman Forum in Pompeii. Remondino et al., (2009) integrated drawings, images, range data and GPS measures for the detailed modeling of castles and their surrounding landscapes. Takase et al. (2009) used old maps, aerial and street photos, paintings, archaeological records and LiDAR data for 3D the reconstruction and visualization of the historic city of Kyoto in Japan.

Figure 2. Stelae A and B (ca 3.5 x 1 x 1 m), two masks inside the East Court (ca 3 x 1 m and 1.5 x 1.5 m respectively) and an aerial view (mosaic of different UAV images) of the entire East Court with Temple 22 located on the left and partly covered by the tree.

4. THE MODELING PROJECT

For the 3D modeling of the archaeological area of Copán, a multi-resolution and multi-sensor approach was adopted mainly for these reasons:

a) employ the most suited surveying methodology with each artifact contained in the area and derive the most adequate level of information (e.g. conventional photogrammetry for large flat walls, laser scanning for irregular or partially broken structures, photogrammetric dense matching for small detailed decorations, etc.);
b) introduce a level of redundancy in the acquired data useful (i) to optimize the model accuracy, (ii) identify possible metric errors in the model and (iii) seamlessly merge the boarding areas at different geometric resolution;
c) fulfill all the measurement and archaeological needs and requirements and achieve a geometric resolution which varies according to the areas of interest and different type of objects.

Our field mission was part of a Workshop, conducted for Honduran archaeologists and site managers in Copán. Therefore it was only the first phase of the data acquisition. At this point neither the data acquisition nor the data processing is completed. In the successive sections, we show only a part of the data and the initial processing results.

4.1 Sensor and data acquisition

The data (Table 1) consists of UAV and terrestrial images as well as terrestrial TOF laser scanner point clouds. Due to time constraints for the data acquisition only 2.5 days were available

Platform / System	Sensor	Goal	Geometric resolution
UAV images	Nikon D2X (35 mm and 24 mm lens, 12 Mpixel)	Modeling of the site at medium resolution and texturing from above	1 – 3 cm
Range data	Leica Scanstation 2	Modeling at medium resolution	3 mm – 5 cm
Terrestrial images	Kodak DCS Pro (35 mm and 50 mm lens, 13.5 Mpixel) Nikon D2X (35 mm lens, 12 Mpixel) Sony DCS-T100 (5.8-19 mm zoom lens, 8 Mpixel)	Modeling of small finds and detailed areas at medium/high resolution and terrestrial texturing	1 – 5 mm

Table 1: The multi-sensors and multi-resolution data used for the 3D modeling of some areas of the Copán site.

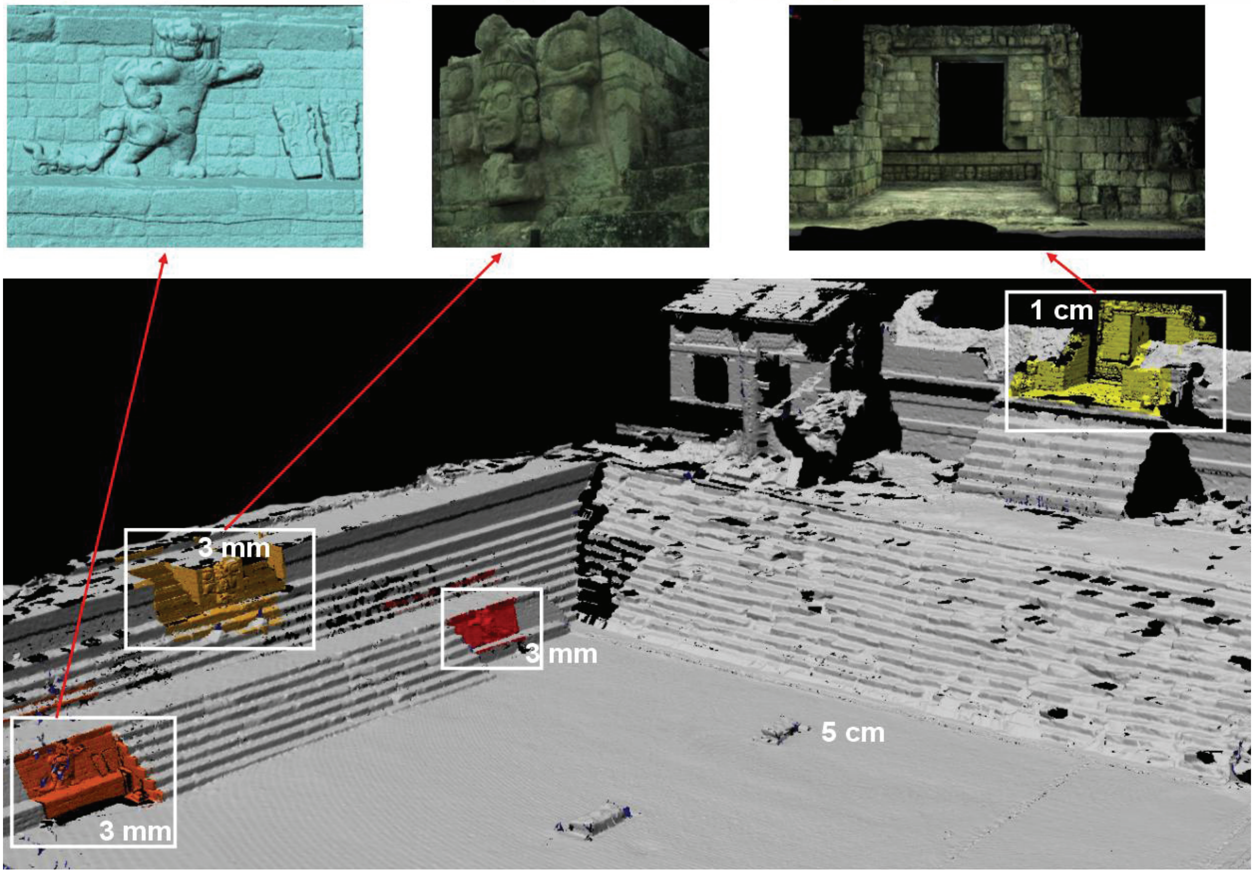

Figure 3. The multi-resolution range data of the East Court area. The geometric resolution spans from the 3 mm of the masks to the 5 cm of the ground and surrounding structures. The holes in the point cloud are mainly due to vegetation and self-occlusions. They will be closed integrating the TOF range data with the point cloud (DTM) derived from the UAV images.

for the entire area, including recording work of stelae, corner masks and walls in the local museum. The UAV system is an autonomous model helicopter (Eisenbeiss, 2009) which mounts a Nikon SRL digital camera with 12 Megapixel, equipped with different objectives. The flying height was approximately 100 m above ground and the UAV system acquired ca 250 images over the two main courts of the site. Due to the complexity of the site and the archaeological needs, the East-Court and some Stelae were also scanned with a Leica Scanstation2 TOF instrument at various geometric resolutions (Figure 3). In addition terrestrial images were acquired for texture mapping purposes and to model some detailed areas in high geometric resolution and to provide for better edge information in case of smoothing effects of the laser scanner data.

4.2 Data processing

All the data will be processed and combined to produce a seamless 3D model useful for interactive visualization, archaeological documentation and presentation, database linking, educational purposes, etc.

The UAV flights were planned to achieve an average footprint of 1 cm over the East Court while for the terrestrial images of the masks the footprint was approximately 1 mm. Some of the image data was processed with the commercial packages SAT-PP and CLORAMA, developed in the previous years as research works at ETH Zurich (Zhang and Gruen, 2004; Zhang, 2005; Remondino et al., 2008) and now distributed by 4DiXplorer AG (www.4dixplorer.com).

The range data (Table 2) were processing with the typical pipeline (Cignoni and Scopigno, 2008) using Innovmetric Polywork. The geometric resolution of the scan data spans from 5 cm of the ground down to 3 mm on the masks and Stelae.

4.3 Results

Each single data set was separately processed and then the results will be joined together by means of georeferencing and resampling. The first results from the UAV images are promising (Figure 4), although some manual intervention is still mandatory due to the numerous vegetation occlusions, producing also blunders. The steps and numerous edges of the court will be correctly modeled and this will help to overcome the lack of edges in the TOF range data. Furthermore, the produced 1 cm orthoimage combined with other terrestrial images, will serve to texture the entire East Court 3D model.

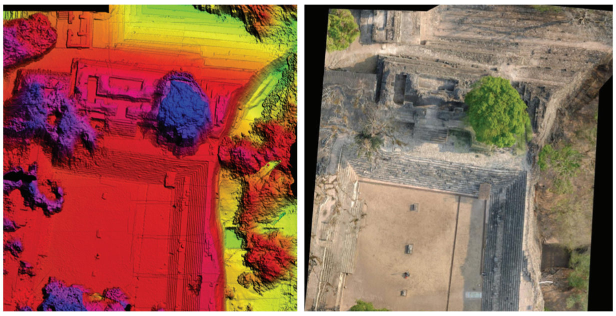

Figure 4: First results from the UAV images over the East court and Temple 22, partly hidden by the vegetation. Left: DSM with 5 cm resolution. Right: Orthoimage with 1 cm resolution.

From the terrestrial images, a detailed 3D model of a mask was produced as shown in Figure 5.
Stelae A and B, modeled with range data (Table 2) at 3 mm geometric resolution, were then textured with various images to produce photo-realistic 3D models as shown in Figure 6. The time required for the entire modeling was 4 and 5 days respectively.

	Sampling step	**Stations (points)**	**Final mesh**
East Court	5 cm	5 (15 Mil)	16 Mil
Temple 22	1 cm	2 (2 Mil)	90 K
Left Mask	3 mm	2 (3.9 Mil)	285 K
Central Mask	3 mm	3 (4.8 Mil)	290 K
Right Mask	3 mm	2 (4 Mil)	285 K
Stela A	3 mm	8 (6.6 Mil)	2.7 Mil
Stela B	3 mm	6 (4.9 Mil)	3.9 Mil

Table 2: Range data for the East Court and Stelae, with acquired points, resolution and final number of polygons.

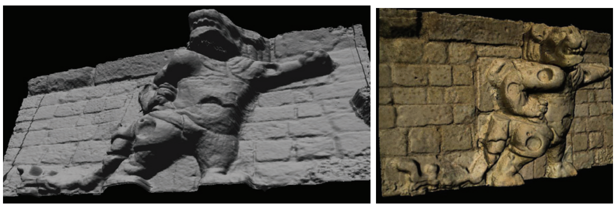

Figure 5: Image-based 3D model of the sculpture shown in Figure 2 derived using 6 images and advanced image matching procedures (software CLORAMA).

5. CONCLUSIONS AND OUTLOOK

Some preliminary results of the multi-sensor and multi-resolution 3D Copan project are reported. The acquired UAV and terrestrial images, together with terrestrial TOF laser scanner data, were processed to derive accurate and detailed 3D models which will be seamlessly combined to produce a multi-resolution digital model of the archaeological area with geometric resolutions varying according to the areas of interest and to fulfill the archaeological needs.

After the entire modeling phase, the project will face the development of a 3D WEB-GIS and database to store and interactively visualize the data created in the project (as well as coming from other sources) and ultimately be used to assist archaeologists and cultural heritage managers to study and conserve the architecture of the ancient Maya city of Copán.

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Figure 6: Range-based modeling results of Stelae A (above) and B (below). From left: aligned point clouds, shaded and textured 3D model.

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