Handbook of Research on Emerging Technologies for Architectural and Archaeological Heritage

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Chapter 9
Surveying Ancient Maya Buildings in the Forest

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ABSTRACT

During the last few decades, 3D scanning devices and 3D digital image generating technology has been developed to the point where they significantly reduce errors and time during data collection thus making them highly appropriate tools in the field of archaeology. With regards to surveying, terrestrial laser scanning and digital photogrammetry, they are a viable alternative to traditional methods for measuring. Nevertheless, these technologies are rarely used in projects in the Maya region, even though they offer a wide range of applications, which could be explored and utilised in this subtropical environment. This paper presents the results of digital surveying involving two Maya archaeological sites in Guatemala: La Blanca and Chilonché, as well as demonstrating their effective application for "investigating into the past".

INTRODUCTION

Urban settlements in the Ancient Maya Lowlands were established in a subtropical rainforest environment where hundreds of archaeological sites are still covered with thick vegetation. These sites include a number of enormous monumental complexes entangled in massive roots of huge trees.

Even in major cities, like the capitals of the powerful Maya kingdoms such as Tikal in the Southern Maya Lowlands (modern-day Petén, Guatemala), which have been explored and investigated ever since the nineteenth century (Vidal & Muñoz, 2012), there are many buildings and other architectural complexes yet to be unearthed due to the complexity of excavating procedures within this heavily forested

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region. This factor explains why it is not always that simple putting together and interpreting the history of these urban centres and their interrelationship.

Generally speaking, Maya archaeologists conduct excavations of large-scale building complexes. The first step is to remove vegetation and structural debris, including the presence of trees often reaching 30m in height. Only then can research work begin on the buildings themselves. Somewhat dangerous at times, this process is labour-intensive and time-consuming, which means that meeting the agreed deadlines is essentially dependent on the technology available.

Traditionally, the techniques employed in recording these excavated monumental complexes include mapping, measured surveying (floor plans, building sections and building elevations) and photography. However, a number of archaeological projects in this field have started experimenting with more sophisticated tools.

BACKGROUND

Over the past two decades, the development and improvement of 3D acquisition through the use of active sensors (in particular those based on laser scanner technology) and more recently the use of passive sensors (Structure from Motion applications) have so far proven to be the best solution for performing rapid surveys of monuments, historical buildings and archaeological remains without actually physically coming into contact with the surfaces.

Pioneering experiments began in the 1990s, including both 3D reconstructions of the archaeological remains (cf. Anfiteatro Flavio 1994–1998) as well as the analysis of architectural façades and the analysis of sculptural complexes (Levoy et al., 2000). Since then, several archaeological sites from around the world have made use of these technologies for different purposes, resulting in a profuse quantity of literature documenting the results of these experiments (Balzani et al., 2004; Lambers et al., 2007; Frischer & Dakouri-Hild, 2008; Reindel & Wagner, 2009; Guidi et al., 2009; Rüther et al., 2009; Benedetti et al., 2010; Stanco et al., 2011; Guidi et al., 2013, 2014).

At Tikal and Chichén Itzá in the Maya region, CyArk developed on-the-ground laser-based scanning (Powell, 2009). Its aim is to produce an open access digital archive of World Heritage sites to be preserved or used for educational purposes. Copan, in Honduras, has also been chosen to test and demonstrate the capabilities of "QueryArch3D", another tool that enables the web-based visualization of interactive multi-resolution 3D models (Agugiaro et al., 2011; von Schwerin et al. 2013, Auer et al., 2015). However, while both being remarkable propositions, these technologies were not conceived for archaeological analysis nor for other scientific applications during archaeological excavations.

Another pioneering project was developed at Caracol (Belize), using airborne laser scanning technology (lidar). The data revealed the full extent of this archaeological site and demonstrated how it was structured, and how the ancient Maya radically modified their landscape in order to create a sustainable urban environment (Chase et al., 2011). Undoubtedly, this is a very useful tool for the study of Maya landscape and settlement patterns, but the resolution of these aerial lidar images is not sufficient for an accurate study of archaeological buildings and monuments, since this process requires terrestrial data acquisition (Pénard et al., 2005).

Thus, the La Blanca Project (*Proyecto La Blanca*), which has been conducting archaeological research and promoting cultural heritage in La Blanca and the neighbouring site of Chilonché since 2004, has employed terrestrial laser scanning technology and digital photogrammetry applications with the purpose of obtaining a more meticulous and careful record of Maya structures for archaeological interpretations during fieldwork. In this paper the results of the research work carried out on the respective Acropolises will be presented.

LA BLANCA AND CHILONCHÉ: TWO MAYA ARCHAEOLOGICAL SITES IN PETÉN, GUATEMALA

La Blanca and Chilonché are located in the Petén Department of northern Guatemala, a strategic position in the Salsipuedes River Basin, part of the great Mopán River system (Figure 1).

In the past, many political entities coexisted within this region. Even though they shared cultural traits, they also revealed marked differences regarding political integration and relations with neighbouring centres (Laporte, 1998: 152). Despite their small size in comparison to other major cities, some of them, such as La Blanca and Chilonché, feature outstanding architecture of high quality and spectacular proportions (Vidal & Muñoz, 2016).

La Blanca is laid out along a main north-south axis, aligned roughly 12 degrees west of the geographical North. The settlement's main buildings and other public spaces (Great Plaza, Acropolis, Causeway, Reservoir, West and South Groups) are located along this axis (Figure 2), extending from the highest sector, close to the bordering hills to the North, down to the lowest sector South, close to the river Salsipuedes (Muñoz & Vidal, 2014).

Figure 1. Salsipuedes River Basin, part of the great Mopán River system
(Proyecto La Blanca, 2012)

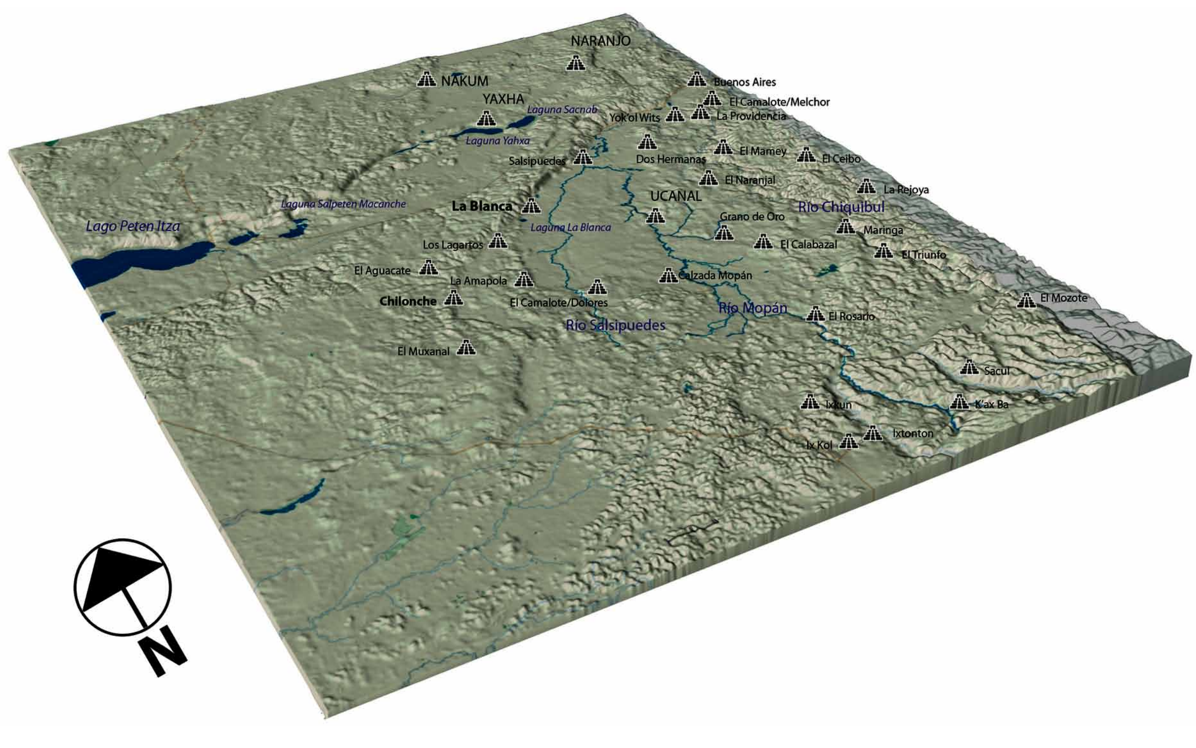
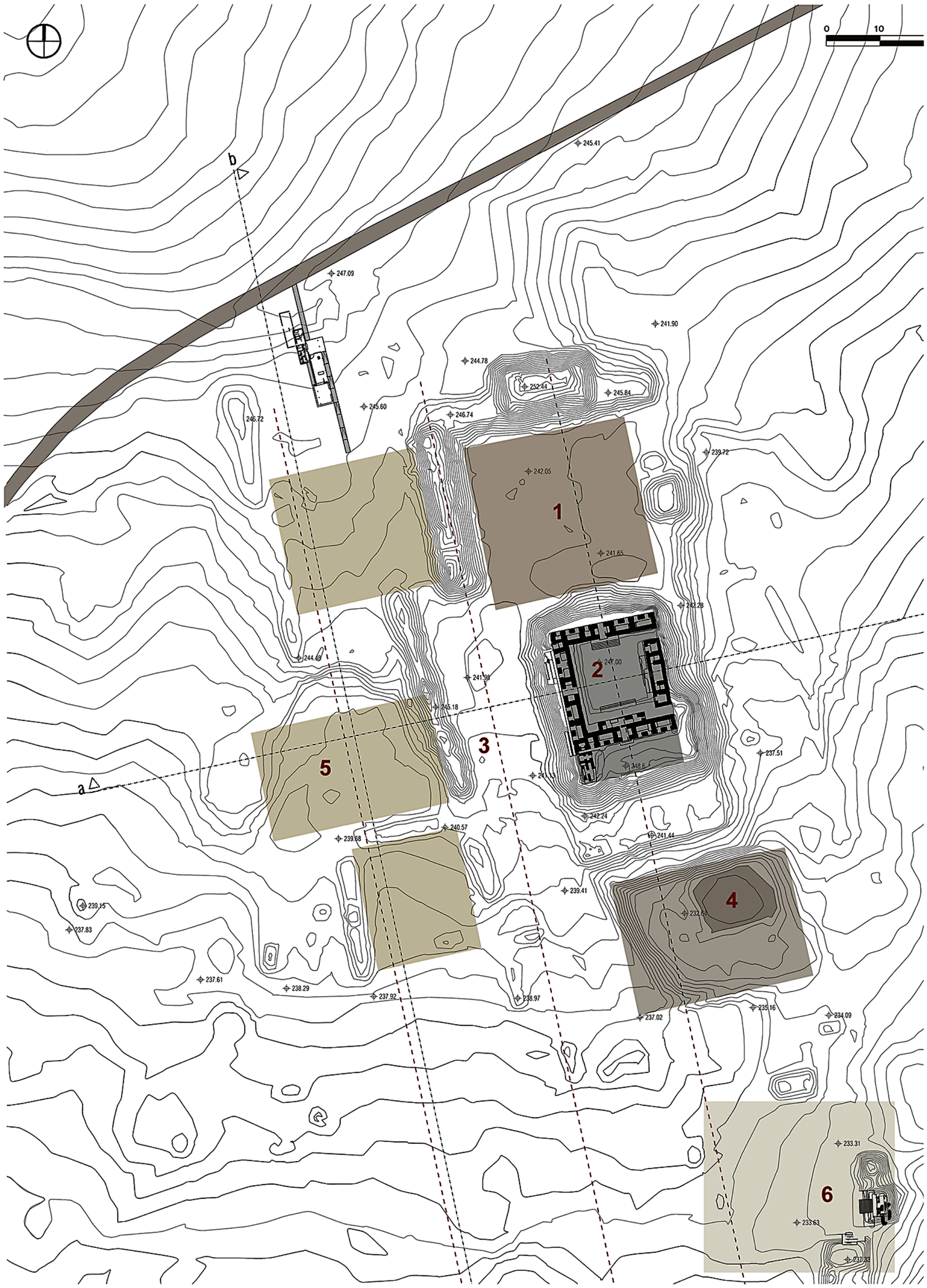
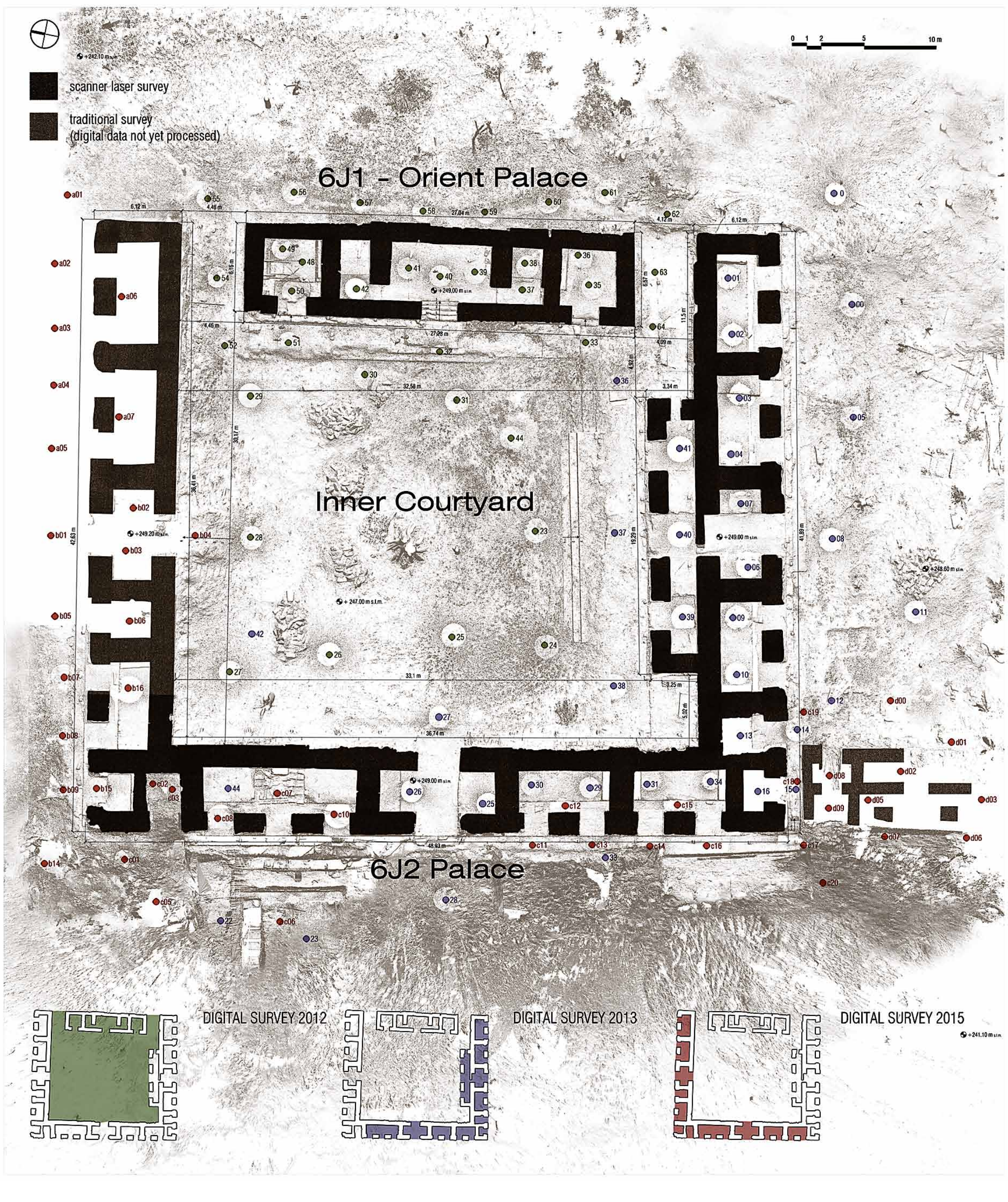


Figure 2. La Blanca: main buildings and other public spaces (1.North Square, 2.Acropolis, 3.Causeway, 4.Reservoir, 5.West Group, 6.South Group)
(Proyecto La Blanca, 2014)



The most important monumental complex at La Blanca is the Acropolis, crowned by two palaces (Structures 6J1 and 6J2). 6J2 is a U-shaped east-facing building, opening onto a courtyard measuring 36m on each side. This courtyard is completely enclosed by Structure 6J1 (also known as the Orient Palace), creating a very private space within (Figure 3). This palace was undoubtedly the residence of the city's ruler during the Late Classic (600-850 AD) and Terminal Classic (850-1000 AD) periods.

Figure 3. La Blanca: Acropolis, plan of the survey campaign
(Proyecto La Blanca, 2015)



The interiors of these palaces contain high-quality vaulted ceilings of exceptional height, reaching up to 4m (Figure 4). Although there are a number of buildings in major cities such as Tikal where such fine work can be admired, its presence in a smaller site such as La Blanca is truly surprising (Muñoz, 2006: 345). Both palaces were decorated with sculpted stone friezes and murals, most of which have disappeared today, and vast stucco surfaces covered with graffiti, some of which are of unquestionable quality and historical interest (Vidal & Muñoz, 2008: 5). Human burials were found under the floor of the main room of Palace 6J1. The death of these individuals is concurrent with the site's abandonment and they represent important evidence of the Terminal Classic Maya "collapse" in this region.

The Maya, like other Mesoamerican civilisations, used to erect their buildings above other structures from previous periods, thus generating the so-called "substructures", which in archaeological terms stands for ancient buildings being preserved beneath larger and more recent structures. Sectors of the international scientific community generally consider the discovery and analysis of such "substructures" a significant event, as the stucco reliefs on the walls and the ornamental elements on the buildings, having been protected from prevailing weather conditions for centuries, are most often well preserved and in good condition.

Figure 4. La Blanca, Palace 6J1, Room 2: high quality vaulted ceiling
(Proyecto La Blanca, 2015)

The existence of substructures inside the basement of the Acropolis at La Blanca has been known since the beginning of the Project. In 2010, an initial campaign began to systematically document them from the looting tunnel on the Western slope of the Acropolis, which was carefully explored to obtain a better view and subsequent understanding of the dimensions of such buried buildings. Only during the final two archaeological campaigns in 2013 and 2015 (which were primarily aimed at the excavation of the substructures present on the Western flank of the Acropolis) was it possible to formulate hypotheses regarding the architectonic quality of these earlier buildings. In 2013, a 7.5m long and 1.45m high stone relief, covering the West basement of Substructure 6J2-Sub.2, was unearthed (Figure 5); in the middle of this large relief mosaic sculpture, is the depiction of a mask, surrounded by other supernatural creatures of important religious and political symbolism in Mayan culture (Vidal & Muñoz, 2014: 82-87). Given the impossibility of maintaining this important find in the open air for the time being, because of difficult environmental conditions, the relief had to be covered over again.

During the subsequent campaign of 2015, the research team continued excavations on this Western side of the Acropolis, unearthing building façades on its Northern tip for the purpose of ascertaining whether or not the buildings were symmetrically aligned to the uncovered structures.

Chilonché is one of the most remarkable urban centres founded by the Maya during the Preclassic Period in this region (300 BC–250 AD), with about 59 architectural complexes and a monumental Acropolis in the centre of the city (Quezada, Chocón & Mejía, 1996; Muñoz, Vidal & Quintana, 2011).

The Acropolis, located on an elevated artificial platform, is made up of Late Classic Period palaces forming a square (Figure 6). The Northern and Western buildings are 6 and 10m high respectively and contain rooms with corbelled vaults and stucco-covered walls typical of the Maya, which in ancient times were most likely decorated with colourful murals.

Unfortunately, when the La Blanca Project began archaeological investigations of this site in 2009, some sixteen tunnels dug by looters were discovered and have been the cause of serious damage to this monumental compound. Several paintings were destroyed as a result of such vandalism, but fortunately,

Figure 5. La Blanca: Substructure 6J2-Sub.2 stone relief
(Proyecto La Blanca, 2013)

Figure 6. Chilonché: Plan of the main Acropolis
(Proyecto La Blanca, 2011)

after further excavation, other murals were found in relatively good condition (Muñoz, Vidal & Merlo, 2014).

Through to these illegal tunnels it was possible to penetrate the basement of the Acropolis and find remains of Pre-classic buildings. One of these substructures (3E1-Sub) features an extraordinary sculpture modelled on its façade (Figure 7), representing a supernatural creature, 3.43m in width and 2.96m in length, which was connected to ancient mythical cosmic events that led to the birth of a new era. By reproducing these images on monuments and paintings, Maya rulers heralded the birth of a new political order, political propaganda one could say. This type of sculpture, known as the *Mascarón of Chilonché*, is unique in an architectonic and urban context.

In the ensuing excavation campaigns, aimed at mapping and accurately documenting the looting tunnels, the first geophysical surveys were initiated on the palace just above the building containing the *Mascarón*, on the Northern wing of the Acropolis (Palace 3E1). This led to several hypotheses regarding the use of this architectural complex, which dates back to the Late Classic period. In fact, this building appears to be very similar to the Orient Palace at La Blanca (Muñoz & Vidal, 2014: 40), and apparently had been modified several times over the years; in particular, two new chambers to the East and West of it had been added. It was subsequently filled in with rocks and soil in order to build a new structure on top, which still dominates the Acropolis.

Figure 7. Chilonché: Mascarón, sculpture representing a supernatural creature during laser scanner survey
(Proyecto La Blanca, 2012)

Early in 2011, looters opened a hole in the vault of a room of this building. A hieroglyphic inscription painted on the wall at the spring point was visible through this hole. In order to understand and monitor the state of conservation of the building, a further expedition was organised, during which a room, approximately 4x2m, was identified. It was aligned on a North-South axis and had been filled in up to the springer of the vault by the same Maya. A 25cm-high strip covered with hieroglyphic inscriptions decorated three sides of the chamber. Beneath these inscriptions, more painted figures could be discerned, in the filled-in portion of the chamber beneath.

Only after the fill had been completely removed, was it possible to view the paintings decorating the North, South and West walls with their representations of male and female figures richly decorated in different colours (mainly ochre, red and black). The figures do not appear on the same level, but rather overlap: the heads of the figures at the top are aligned with the spring point level, whereas the characters at the bottom have their feet on a lower strip displaying a jaguar skin, which is itself represented above a red strip. The scene shows a strong sense of dynamism. Alongside some of the figures are the inscriptions of names.

Due to subtropical environmental conditions in the Mayan region, cases where mural paintings have survived to the present day are very rare. Thus, these paintings represent an important discovery and lead to a better understanding of the technical and stylistic aspects of Mayan mural paintings and the iconographic content represented therein.

In cases like this, a combination of laser scanning technology and digital photogrammetry are able to solve many of the issues raised during the recording of archaeological data (Figure 8).

Figure 8. Chilonché: recording archaeological data at Palace 3E1-Room 6
(Proyecto La Blanca, 2015)

Previous Works

Laborious fieldwork is required before starting an excavation. Following standard archaeological methodology, it is impossible to survey or measure buildings in the Maya Lowlands, unless vegetation is removed beforehand. In addition, a topographical survey is necessary so as to pinpoint the precise location of the structures and other urban features. Unfortunately, not all Mayan archaeological sites situated in the tropical rain forests can be surveyed using Total Station. Most of them have been mapped using basic techniques such as compass and tape measure, and at its best, theodolite mapping.

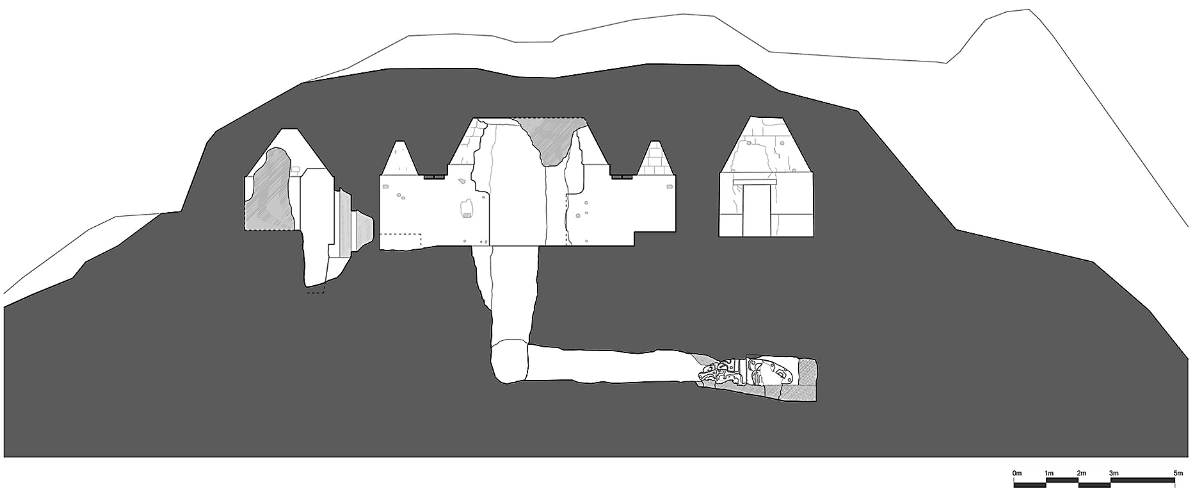
The resultant plans tend to accumulate errors when based solely on this data. In fact, they are unable to help archaeologists programme excavations thoroughly, or establish the exact orientation and position of the buildings, or even make future comparisons between the different archaeological sites; a serious problem in the interpretation of Maya archaeology.

Total Station topographic maps were created in La Blanca and Chilonché, and all the buildings were included as they were excavated.

Operations to document the architectonic remains on the Acropolis in La Blanca commenced in 2004 with a topographic survey using a total station GPT-3007-Topcon (Gil, 2005). Most of the chambers were still covered with earth and vegetation at the time, and only two of the 18 existing chambers were physically accessible.

At the same time, another architectonic survey was conducted using traditional measuring systems (sketches, photographs, metric tape and a laser distance measurer – Figure 9), designed to document the remains of the walls and vaults emerging from the ground (Sender, 2005).

Figure 9. Chilonché: Acropolis Section drawing after traditional survey
(Proyecto La Blanca, 2010)



Then in 2005, a team led by V. Calvo from the Polytechnic University of Valencia directed a new topographic survey, completing the documentation work of the previous year, using the total station Leica TC 307 (Calvo & Sánchez, 2006). In order to fully describe both the terrain and ruins, contour lines were drawn every 0.5m on the topographic plane.

Four years later, the same team carried out a topographic survey at Chilonché. The goal was to document the area on the Acropolis and its immediate surroundings, including the South Plaza and a minor Acropolis lying to the southwest of the main one, for an overall surface of about 2.5 hectares. Even in this case, the tool used was the total station Leica TC 307.

In both cases, once the topographic plane had been completed, all the fragments that had been unearthed and documented by direct surveying tools were compared with one another and geo-referenced according to the plane itself, thus ensuring both an effective measurement-control-tool in the final output maps and the structures' exact spatial positions.

A traditional photogrammetric survey was also performed in both Acropolises (La Blanca and Chilonché) using professional photos.

Finally, the graffiti were documented according to the methodology established by the La Blanca Project, including: location and identification of the graffiti, tracing, professional photography, formal analysis and selection, fine drawing, tracing and scanning the drawings, digital restitution, and iconographic analysis (Vidal & Muñoz, 2009).

Having such a vast amount of data was essential for the continuity of the excavations. However, this data was not sufficient to fully understand the observed structures, particularly the features contained.

Since 2012 the La Blanca Project, in partnership with the University of Florence, has adopted laser-scanning technology, and since 2015 digital photogrammetry applications which have both proven to be efficient methods for 3D measurement and 3D image documentation.

Introducing Laser Scanner Technology

Data Capture

In all surveys carried out on the Acropolis of La Blanca and Chilonché a Faro Focus^{3D} S120 laser scanner was used. This is a high-speed Terrestrial Laser Scanner (TLS), which offers efficient 3D measurements and 3D image documentation. In only a few minutes, dense point clouds can be produced which contain millions of points, providing very detailed 3D colour images of large-scale objects. With a measurement rate of up to 976,000 points per second, it can complete the work in half the time of other devices.

In addition, it is small and compact. These attributes, plus its integrated lithium-ion battery providing up to five hours of battery life, are important features when travelling over long distances during fieldwork to highly inaccessible archaeological sites where electricity is invariably unavailable, as is usually the case in the Maya area.

This device can measure anything in its range: 360° horizontal, 320°vertical and within a distance of 100m. It works with phase shift technology, calculating the distance of each point by comparing the times of the exit signal with the return one, i.e. the variation of the sent and reflected phase. The laser scan also assigns a colour pixel to every registered point. The process is extremely fast, since the system allows up to a million points per second to be measured with a margin of error of just 1.5 mm from ten metres away. If the distance is increased, this margin of error also increases, however never exceeding a 5mm limit.

In the 3D digital model, the entities represented consist of large sets of points (a point cloud), identified by three coordinates (x,y,z) and characterized by a colour value based on the value of the reflected signal (reflectance value). Each single scan is unique, with a centre and an orientation defined by three Cartesian coordinates where the zero value is located in the scanner itself. This obviously poses the problem of how to organically combine all the scans both during fieldwork and during the subsequent stages of data processing. In fact, when measurements are taken, the elements of measurement that are already known and easily recognizable (commonly known as targets) are put in the scanning area in sufficient numbers (a minimum of three) to allow the correct collimation of the point clouds.

As an alternative to targets, sphere references for scan adjustments can be used. The advantage of using these references is their highly accurate geometrical definition and the reflectance values. This facilitates recognition by the post-processing algorithm, reducing computation time.

Data Processing

Data filtering operations and the exportation of subsequent point clouds in PTX format are performed by the software Faro Scene, a programme specifically developed for 3D point cloud processing and managing. For each original FLS (Faro Laser Scanner) file, a version in PTX (PoinT eXchange) format is produced, which is accepted by all applications that manage point clouds and is very useful for the long-term storage of data.

Files with a PTX extension actually express in text format both the XYZ coordinates of each surveyed point and their chromatic code, with a numeric formula, using the RGB (Red, Green, Blue) additive synthesis. In addition to such information, the initial part of the file includes a roto-traslation matrix, which helps to position exactly an entire point cloud in the space even when relating to a different reference system.

The second step in this procedure consists in aligning each single point cloud until a single 3D model is achieved. This operation uses the software Leica Cyclone, which also permits the extraction of two-dimensional and three-dimensional elements, needed for subsequent processing with 2D CAD and 3D modelling programmes.

A model based on a point cloud is, by default, transparent as it is composed of discontinuous elements. It is presented to the user as a completely accurate representation of the geometric shapes of scanned objects, but it is nevertheless a long way away from how they actually look. In order to create a more realistic 3D model which can be done by using the commercial software package Rapidform XOR 3 (3D Systems Geomagic), the information inevitably needs to be simplified, as well as schematized and optimized to allow the transformation from point cloud to mesh, the latter being perceptually closest to reality (Merlo & Sánchez et al., 2013).

Scanning the Buildings of La Blanca and Chilonché

The Acropolis of La Blanca is approximately 45 x 50m in size and contains, as mentioned previously, two distinct architectural systems: a building block (Palace 6J1) and a U-shaped building (Palace 6J2). The view of the facades of the buildings is partly blocked by the thatched roofs that cover both palaces to prevent decay.

Considering the difficult operating conditions of the site, it was felt appropriate to choose a scanning grid (or density of points) set to a constant setting, which would be able to obtain data with a high level of detail within reasonable limits, thus avoiding any excess of data that would cause difficulties to both the project management of the survey and subsequent data processing. Most of the Acropolis was surveyed with a grid spacing of ¼ mm/10m (1 point for each 4mm up to 10m away), with greater density values in the areas immediately next to the laser scanner.

The data collected in 2012 of the courtyard and the Orient Palace on the actual Acropolis of La Blanca, amounted to about 1,350 million points, a sizeable quantity of information, obtained from 35 station positions during two days of work, with a high coverage of all buildings (Figure 10).

As usual in the laser scanning process, the reflectance value of each scanned point gave the point cloud model an altered appearance, while photographs taken directly from the laser scanner's internal photo-camera indicated a description of the complex's colour, allowing the measured objects to be perceived and interpreted more easily.

For a more flexible file management, the point cloud model is divided into various parts respecting the semantic value of each one. This procedure makes it possible to consider the polygonal models that occur in succession in a different way, leading if necessary to their destruction, by means of advanced optimization algorithms.

The first objective of the project was to perform a survey and reconstruct a three-dimensional model of the Acropolis Courtyard and Palace 6J1, which would accurately define the geometry of the architectural units and show how they were arranged in relation to each other. This step would allow for the verification of architectural surveys previously carried out using traditional systems: floor plans, elevations and sections (Figure 11). Following this comparison it was fortunately possible to conclude that there were no significant differences between the location, shape, orientation, etc. of the buildings on the traditional plans and the new laser scanner surveys. This demonstrates that it is a very reliable method and besides it can offer a variety of interactive features.

Figure 10. La Blanca: point clouds model of the Acropolis inner Courtyard and the Orient Palace
(Proyecto La Blanca, 2012)

Table 1. Technical data related to the inner Courtyard of the Acropolis at La Blanca

LA BLANCA, Acropolis – Courtyard	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	¼
Quality:	4x
Average distance between instrument and object:	5 m
Number of scans:	9
Time spent:	8 h
Photographs:	✓
Point Clouds Model	
Number of points:	400x10^6 pt
Registered overall accuracy of the model:	3 mm
.imp file size:	21812 Mbyte

Table 2. Technical data related to the Orient Palace of the Acropolis at La Blanca

LA BLANCA, Acropolis - Orient Palace (6J1)	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	¼
Quality:	3x
Average distance between instrument and object:	2 m
Number of scans:	26
Time spent:	4h 30m
Photographs:	✓
Point clouds Model	
Number of points:	1156x10^6
Registered overall accuracy of the model:	3 mm
.imp file size:	31700 Mbyte

Figure 11. La Blanca, Orient Palace: floor plan and sections
(Proyecto La Blanca, 2012)

Due to the highly convincing results achieved, the same method was adopted to document all the remaining visible ruins on the Acropolis during the subsequent campaigns in 2013 and 2015: in 2013 operations focused on the South wing and partially on the West wing of the Acropolis (Palace 6J2), whereas in 2015 efforts were concentrated on completing the surveys of both the West and North wings together with small building 6J3.

In both cases, on the completion of the point cloud 3D model of the surveyed chambers, comparisons were made with the results obtained from the previous campaigns; in this case, not having used any targets, the procedure was to register each point cloud using mutual points identified directly on the piece of architecture.

Point clouds, once aligned, are exported from Cyclone in PTX file extension format to 3D System Rapidform software, which allows the triangulating of the discontinuous models to create surfaces. Eventually, high-poly 3D models were obtained after working on the meshes to eliminate all possible imperfections.

Together with the job of documenting the architectural artefacts, three particularly important experiments were accomplished in terms of research in reverse engineering, both in the divulgation and sharing of resultant 3D models derived from active and passive sensors. The first one concerns the survey of the graffiti present in the lime plastering covering the walls of the buildings on the Acropolis, the second relates to the survey of the relief decorating Substructure 6J2-Sub.2 and, finally, the third one involves the documentation of the archaeological excavations in-the-making.

Table 3. Technical data related to the South wing of the Acropolis at La Blanca

LA BLANCA, Acropolis – South wing	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	¼
Quality:	4x
Average distance between instrument and object:	5 m
Number of scans:	24
Time spent:	9 h
Photographs:	No
Point clouds Model	
Number of points:	652x10^{6} pt
Registered overall accuracy of the model:	2 mm
.imp file size:	16814 Mbyte

Table 4. Technical data related to the West wing of the Acropolis at La Blanca

LA BLANCA, Acropolis – West wing	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	¼
Quality:	4x
Average distance between instrument and object:	5 m
Number of scans:	26
Time spent:	11 h
Photographs:	✓
Point clouds Model	
Number of points:	793x10^{6} pt
Registered overall accuracy of the model:	2 mm
.imp file size:	15974 Mbyte
Polygonal Model	Cuarto 10
Number of polygons:	18 x10^{6}
.xlr file size:	432 Mbyte

Table 5. Technical data related to the North wing of the Acropolis at La Blanca

LA BLANCA, Acropolis – North wing	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	¼
Quality:	4x
Average distance between instrument and object:	5 m
Number of scans:	24
Time spent:	8 h
Photographs:	✓
Point clouds Model	
Number of points:	630x10^6 pt
Registered overall accuracy of the model:	2 mm
.imp file size:	13262 Mbyte

Table 6. Technical data related to the Structure 6J3 of the Acropolis at La Blanca

LA BLANCA , Acropolis - Structure 6J3	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	¼
Quality:	4x
Average distance between instrument and object:	2 m
Number of scans:	13
Time spent:	12 h
Photographs:	No
Point clouds Model	
Number of points:	314x10^6 pt
Registered overall accuracy of the model:	3 mm
.imp file size:	8260 Mbyte

Table 7. Technical data related to the South Group buildings at La Blanca

LA BLANCA, South Group	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	1/4 e 1/2
Quality:	4x
Average distance between instrument and object:	5 m
Number of scans:	19
Time spent:	15 h
Photographs:	✓

Another experimental project related to the use of this new technology was carried out at La Blanca, namely a laser scanner survey of the walls containing graffiti. As previously mentioned, these unique artistic expressions carved on the stucco walls of the Acropolis palaces are particularly abundant at this archaeological site, but recording and analysing them involves a complex and often difficult process due to their poor visibility.

Until recently, the scientific community had paid little attention to the study and research of Mayan graffiti. Nevertheless, following the publication of the monograph *Los grafitos mayas* (Vidal & Muñoz (Eds.), 2009) several archaeological projects have included among their objectives the documentation and study of graffiti, hence the possibility of applying the new technology in this field was considered thoroughly appropriate.

In order to decide how to record such graffiti, three different walls were selected, and a new laser scanning survey with different levels of resolution was performed, using the same instrument that was used for scanning in architecture. The graffiti selected included a procession of warriors in Palace 6J1 Room 5, a set of pyramid temples in Palace 6J2 Room 10 and the depiction of a deer in Room 4 of the same Palace.

Although the technique employed was not the most suitable for surveying surfaces with features measuring just a few millimetres, it did allow a detailed record of the graffiti to be made. In fact, it was possible to obtain snapshots of 15000 x 5947 pixels from the high point density model, which emerged after high resolution laser scanning (1:1), where the images of the finely carved drawings were quite reliable.

The use of the laser scanner's internal photo-camera also allowed the corresponding RGB value of the photograph to be mapped to each scanned point. The quality of the resulting images (which are reasonable considering the camera is a low-resolution camera of just 2-megapixels) further enhanced the designs, making them much clearer. The polygonal model created in Rapidform, which has a lower density point cloud than the previous one, preserved the geometric characteristics of the scanned features almost perfectly, after being suitably edited. The model was able to provide good quality images of the graffiti, illuminated from a sharp angle and with visible texture (Figure 12).

Like the *Mascáron* in Chilonché described later on, the stone relief found in La Blanca in 2013 represented a typical example where an extremely valuable finding needed to be documented accurately and quickly.

The use of the laser scanner allowed all the elements making up the relief to be digitally rendered so as to better study them *ex post*, whilst at the same time allowing the divulgation of this important find to a much wider audience, the general public, and not just the scientific community (Figure 13).

Figure 12. La Blanca: 6J2-Room 4 polygonal model of the Graffiti
(Proyecto La Blanca, 2014)

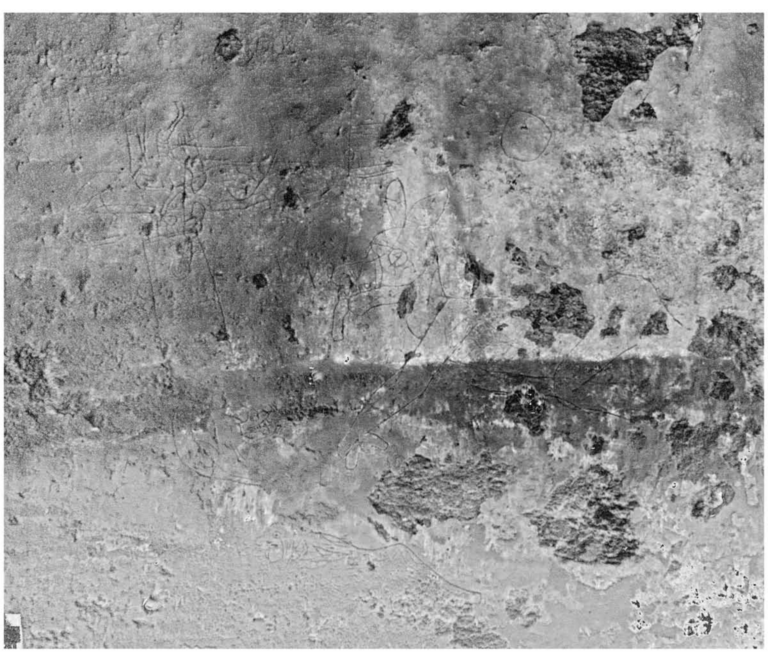


Table 8. Technical data related to the graffiti of the Acropolis at La Blanca

LA BLANCA , Acropolis – Graffiti	**Scan 044**	**Scan 045**
Acquisition Parameters		
Tool used:	Faro Focus^{3D} S120	Faro Focus^{3D} S120
Resolution:	1/1	½
Quality:	3x	4x
Average distance between instrument and object:	70 cm	70 cm
Number of scans:	1	1
Time spent:	36.27 m	18.56 m
Photographs:	No	✓
Point clouds Model		
Number of points:	153x10^6	38x10^6
Registered overall accuracy of the model:	1 mm	1 mm

Table 9. Technical data related to the relief of the Acropolis at La Blanca

LA BLANCA, Acropolis – Relief	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	¼
Quality:	4x
Average distance between instrument and object:	1 m
Number of scans:	8
Time spent:	2 h
Photographs:	✓
Point clouds Model	
Number of points:	207x10^6
Registered overall accuracy of the model:	2 mm
.imp file size:	13900 Mbyte
Polygonal Model	
Number of polygons:	3 x10^6
.xlr file size:	333 Mbyte

Figure 13. La Blanca: laser scanner survey of the relief at Substructure 6J2-Sub.2
(Proyecto La Blanca, 2014)

The day-to-day documentation of the digging operations by means of active sensors had never been used in the Maya region. Data collected in the field and processed on the same day, acquiring plans, sections and elevations to help archaeologists in the interpretation of the remains as they came to light, represent a profoundly effective support tool to correctly direct excavating operations on the following day. In fact, having a full understanding of the artefacts' geometry, correct spatial position and, most importantly, geo-referenced relationship with other finds leads to a more focused workflow, concentrating excavation efforts only on where other remains are thought to lie.

In this case, the Faro Laser Scanner Focus 3D^{S120} parameters were set to guarantee speed in data collection and, at the same time, an appropriate density of points and overall file dimension ranging between 2 and 6 Gb (1:4 resolution, 3x precision), thus easing the subsequent management of the point clouds. Consequently, no scan exceeded 5 minutes. The data collected day-by-day and ordered by date, were then included in a general file, which reached the final size of 55 Gb by the end of the campaign.

According to the excavating operations, the number of scans taken each day ranged from between 5 and 7, for an overall time of no longer than 40 minutes. In order to avoid interference with the workers' activity on the site, scans were taken during the lunch break.

The correct position of the scans was ensured by a number of targets that were firmly fixed on the pillars of the structure covering the rooms on the Acropolis. The 12 targets were made on the spot using wooden boards 10x10 cm and 2 cm thick, which were then painted with four squares forming the cross of St. Andrew. Alternating turns over a period of 27 days, the operators managing the scanner, were careful to include at least three targets in each scan, in order to correctly align the resulting point clouds with one another.

The daily routine consisted in:

- Transfer the data and convert it into PTX exchange format.
- Import the data in the point cloud alignment software and generate a complete 3D model of the daily set of scans.
- Extract a pre-ordered stock of screenshots able to accurately document the dimension and geometry of the surveyed artefacts in relation to their surroundings.

Overlaying these illustrations in the image-handling software led to the assessment of the excavation's diachronic progress (Figure 14).

In Chilonché, given the above successes, a new experiment was carried out on the *Mascarón* laser scanning.

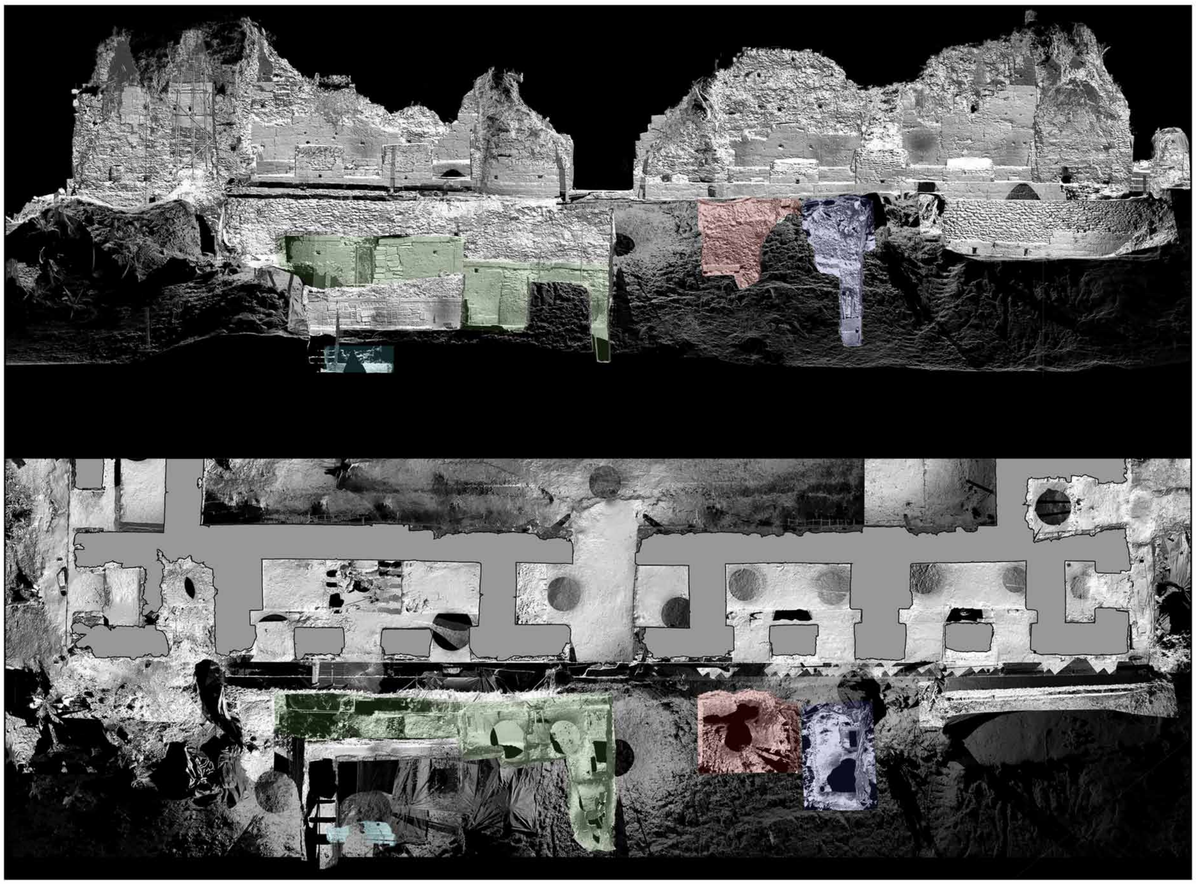
The position of the sculpture – accessible only through a network of underground tunnels – and its articulated structure lends itself well to 3D scanning techniques. To avoid obstructions on the surface of the monument, the tunnel walls were the target of the scan, rather than the sculpture itself.

The lighting produced by incandescent lamps, was not the best, consequently the photographic image was of poor quality. The point clouds created near the spotlights were difficult to read.

The first stage of the work consisted of recording the entire laser scanning captures. The floor plan and the elevation obtained from the point cloud model made it possible to verify all the available graphic materials.

The survey of *Cuarto de las Pinturas* (Palace 3E1-Room 6) in Chilonché was accomplished using both laser scanner and digital photogrammetry. In the first case, an active sensor was used to obtain the necessary information in order to document the chamber in all its geometrical-dimensional aspects. So

Figure 14. La Blanca: daily documentation of the excavation of the Western basement of the Acropolis (Proyecto La Blanca, 2015)



as to link the chamber with the Acropolis, and lacking topographic support, it was necessary to complete four scans of the north side of the Acropolis, moving each time closer and closer to the chamber.

Modelling the Buildings of La Blanca and Chilonché

In the meantime, a high-poly mesh model of all the structures was made. As these models are supposed to be used for archaeological analysis, the primary issue to be considered in generating the mesh is to ensure that it deals adequately with the errors introduced during the process, in order to faithfully reflect the geometric characteristics of the scanned entities.

The standard procedure implemented in the majority of mesh processing applications is aimed at "healing" the mesh from all topological errors such as dangling faces, small polygon clusters, non-manifold faces, etc. Thanks to Rapidform XOR powerful global re-meshing tools it was possible to resample the whole mesh before any further modelling phases; these kinds of commands improve the mesh quality by calculating a new mesh whose triangular edges are nearly equal to an average measure calculated by the program, or directly expressed by the user. The resulting isotropic mesh is smoother than the original

Table 10. Technical data related to the Mascarón of the Acropolis at Chilonché

CHILONCHÉ, *Acropolis* - **Mascarón**			
Acquisition Parameters			
Tool used:	Faro Focus^{3D} S120		
Resolution:	1/5		
Quality:	4x		
Average distance between instrument and object:	60 cm		
Number of scans:	7		
Time spent:	2h 30m		
Photographs:	✓		
Point clouds Model			
Number of points:	199x10^{6}		
Registered overall accuracy of the model:	2 mm		
.imp file size:	3368 Mbyte		
Polygonal Model	*High poly*	*Medium poly*	*Low poly*
Number of polygons:	39x10^{6}	5x10^{6}	8x10^{3}
.xlr file size:	789.287 Mbyte	210.614 Mbyte	1.1 Mbyte

Table 11. Technical data related to the Cuarto de las Pinturas of the Acropolis at Chilonché

CHILONCHÉ, Acropolis – Palace 3E1-Room 6	
Acquisition Parameters	
Tool used:	Scanner laser Faro Focus^{3D} S120
Resolution:	¼
Quality:	4x
Average distance between instrument and object:	1,5 m
Number of scans:	5
Time spent:	1 h
Photographs:	No
Point clouds Model	
Number of points:	194x10^{6} pt
Registered overall accuracy of the model:	2 mm
.imp file size:	50222 Mbyte
Polygonal Model	
Number of polygons:	45x10^{6}
.xlr file size:	1080 Mbyte

one and characterized by better connectivity of triangles and, even if it cannot be considered a structured one, it produces good shading results once rendered.

Nevertheless, this high-poly model does not adapt to "comfortable" UV mapping in entertainment applications because it is still too heavy. Consequently, to achieve real-time visualization and animations it was necessary to apply a standard procedure based on the relevant reduction of polygons by means of decimation tools capable of taking into account the model curvature (optimize mesh command). The model was then transferred in Luxology Modo. This programme also provides useful tools aimed at calculating normal maps by means of render-to texture solution: the normal maps of the high-poly model were encoded inside the (u,v) reference system of the optimized mesh.

The next step is to provide this model with a correct apparent colour texture, applied by means of the same (u,v) system used for the normal map that, in this case, also provides a good reference for understanding how reliable the mapping of images was on the model's surface.

The projection of an un-oriented set of eleven images on the mid-poly model was achieved thanks to EOS System Photo modeller, a popular photogrammetry application, also capable of calculating the camera re-sectioning for each photo, based on the position in the space of a sufficient number of homologous points (between the picture and the object).

Once exported from Rapidform using the DXF file format, point sets can be introduced as reference inside the Photomodeller: by picking 3D vertices and the corresponding pixels on the photos, the programme orientates a camera for each photo. Once the position of every camera is obtained, it is possible to export them to Luxology Modo using the FBX file format and then re-project the images on the mid-poly model.

The resulting model can be used in different rendering applications being normal and colour maps applied by means of a standard UV reference system.

For example, the inherent shape of the sculpture made delineation very difficult using traditional systems of representation; for this reason, during the second stage of this process, a high-poly mesh polygon (39 million polygons) duly edited in Rapidform to become a full-size prototype, was created (Figure 15).

Within this same model, which was simplified thanks to the application of annihilation algorithms, the available photographic images taken by a professional photographer were re-projected, which created a low density polygon model (equal to 1/100th of the initial one) but with high resolution texture mapping, which proved useful, in order to better navigate in real-time and rendered options and also enabling high quality orthographic representations (Figure 16).

Since 2015, two distinct procedures (later integrated into one) have been used to create mesh models: the first generated polygonal models starting from the point clouds obtained with laser scans, whereas the second created such models using digital photogrammetry.

Figure 15. Chilonché: high-poly mesh polygon of the Mascarón
(Proyecto La Blanca, 2012)

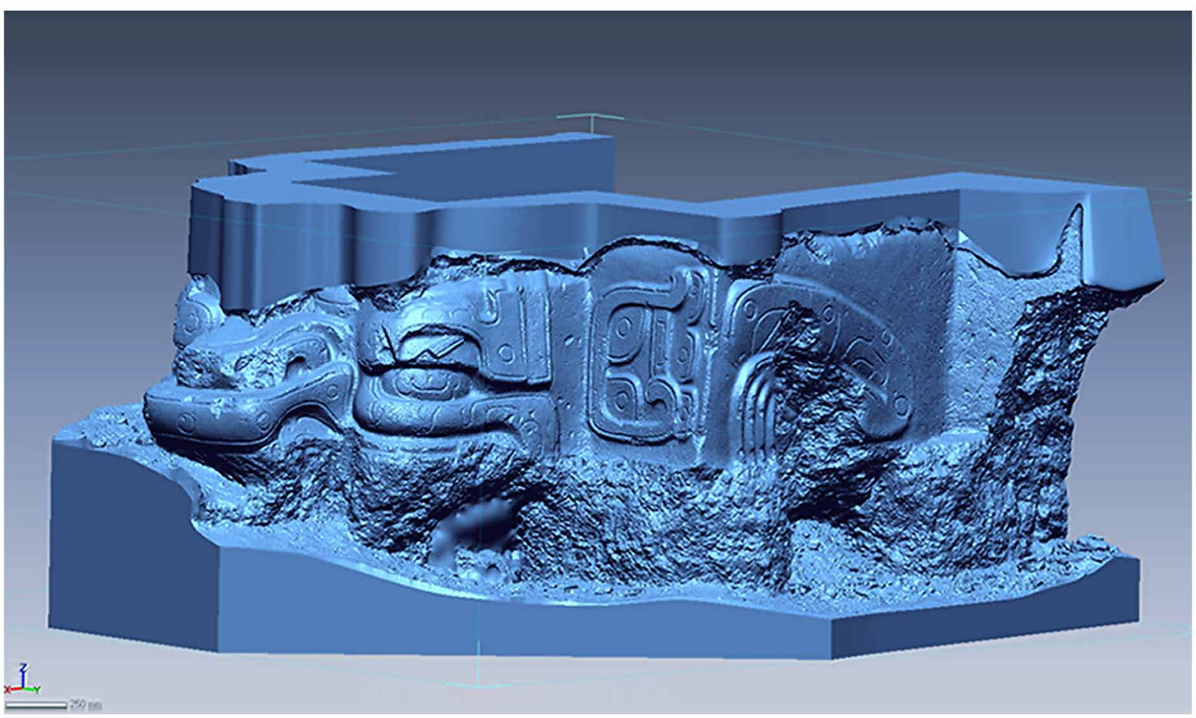
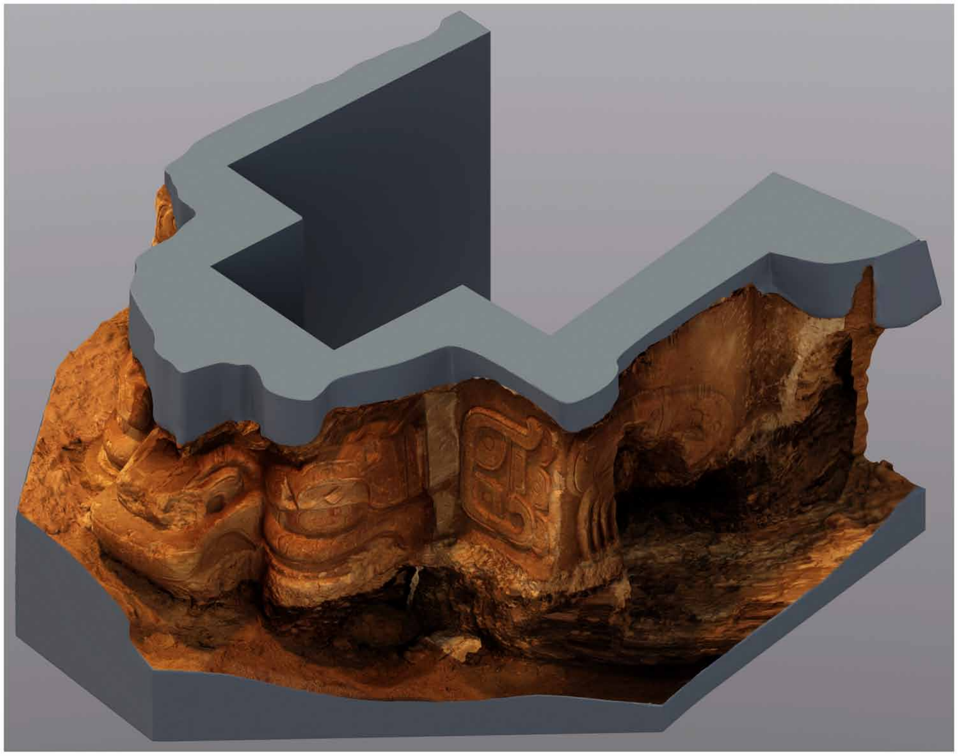


Figure 16. Chilonché: isometric representations of the Mascarón
(Proyecto La Blanca, 2012)



Introducing Digital Photogrammetry Application

Data Capture

Methods based on the metric elaboration of images use collinearity equations, starting with the definition of homologous points identified on the photograms, and then transforming the data acquired from the images into 3D coordinates. In fact, the images already include all the necessary information to reproduce both the geometry and the colour of the object photographed, making possible the creation of properly texturized polygonal 3D models.

The photogrammetric survey campaigns were carried out using a digital reflex camera Canon EOS 70D with two different sets of lenses: 18-55 mm and 18-135 mm IS-STM. The pictures were taken from different angles trying to maintain the same distance from the object and allowing an overlap of at least 60% between each shot. In the interior spaces, the scene was lit using incandescent lights fed by a generator; in these cases, a tripod was used to guarantee optimal exposure time. The Raw format used, includes a higher amount of information thus enabling the users to set the white balance later on, using the software Camera Raw from Adobe. In order to conclude this operation, a colour-checker had to be placed in the scene beforehand and taken away prior to each set of images.

Data Processing

Images saved in RAW format were then converted and imported into the software Agisoft PhotoScan that was used to generate a dense point cloud and, subsequently, to calculate a mesh model and texture of the apparent colour associated with it.

These models appear to be precise from a geometrical point of view, however they are not yet to scale. With the availability of the laser scanner to ascertain their correct dimensions, the procedure was to take one or more scans of the same artefact; once the markers (clear points in common in the two models) which are regularly distributed over the total surface of both models, have been identified, it is possible to place the photogrammetry generated model within the same reference system used for the general point cloud model generated with the laser scans. Thanks to these markers it is possible to resize the image-based models directly within Photoscan, simply by importing a text file generated with Rapidform, containing the information of the name of each point (marker) along with its Cartesian coordinates.

In order to have 3D models that could also be used for real-time visualisation, UV mapping tools were used (Merlo & Fantini et al., 2013). Starting with the data from the laser scanner (which is generally more complete compared to the image-based models), a low-poly version of mesh models was created through the retopology process (a technique which reconstructs a model using "tracing" operations based on the use of dominantly quadrangular polygons), built on Modo software, by Luxology.

Resultant meshes are much lighter than the original ones, but vastly simplified, as they are formed by quadrangular polygons defining the essential geometry of the artefacts, and thus free of detail. To overcome this problem and still have lighter meshes, but at the same time, being able to deliver the same visual detail of high-poly models, Normal Maps (bitmap developed in the u,v reference system containing information about the behaviour of light on the surfaces of a polygonal object) were calculated starting from "dense" models that render an excellent degree of detail once applied to the respective low-poly meshes, even if only in appearance. Once this elaboration is completed, the low-poly meshes are exported in .obj format, which is able to save all information contained on the UV map, and imported into Photoscan's workspace, maintaining the same reference system of the image-based models generated with the photogrammetry.

Subsequently, the aligned images that had been used to create photogrammetric models were projected onto the new low-poly meshes, thus generating colour maps. Applying the two maps on each simplified model leads to models close to reality as regarding their geometric perception and the chromatic rendering of the material. Finally, thanks to their lightness, such models can be utilised in common software for different visualisation possibilities. The extraction of photoplans from all the images concerning the artefacts was once again made possible by using Modo by Luxology.

Photographing and Modelling the Buildings of La Blanca and Chilonché

In 2012, the absence of a photographic campaign focusing on the use of software in digital photogrammetry meant that colour maps had to be produced and applied to the mesh models through a complex procedure called camera resectioning. Since 2015, both at La Blanca and Chilonché, photogrammetric surveying has run parallel to the laser scanning operations and has been specifically used to integrate the data associated with the apparent colour of the three-dimensional models.

The central hall of the west wing (6J2-Room 10) of the Acropolis at La Blanca, once scanned, was the subject of a photogrammetric survey designed to test this procedure on buildings covered by layers of plaster and, therefore, chromatically homogeneous.

The sets of images were completed without the use of a tripod; given lighting conditions were satisfactory for correct camera exposure and pictures free of micro-movements during the takes. The focal length was kept at 35mm for some photographic sets, and at 18 mm for others, based on the distance from the object in question. The images were taken when possible, in overcast conditions, so to create uniform light; the wooden shelter blocked direct sunlight on the artefact, which would have generated areas of light and shade and thus partially compromised the outcome of the operation. The presence of a colour checker on the scene made possible colour balancing *ex post* of each set of photograms.

The regularity of the walls, where present, did not require special precautions to ensure the correct take of pictures, whereas for the documentation of the inner "sack", an increase of the number of pictures per unit of surface became necessary. The constant disparity of the small stone surfaces forming the "sack" meant shooting an increased number of photos to avoid areas with no chromatic information.

The higher parts of the walls were not documented for both safety reasons and the scarce utility of such information.

Seven different photographic sets were taken: two for the central hall, one for each of the other three chambers forming the west wing, one for the elevation overlooking the patio and another one for the inner elevation. In addition, more sets of pictures were taken to fully document the transition areas between each group; hence, it was possible to handle each set separately obtaining, in each model, vast overlapping areas which facilitated the alignment of all groups into one single file.

The 551 photograms, treated with Agisoft Photoscan software, generated a mesh model formed of 1 million polygons and a texture resolution of 8192x8192 px (Figure 17).

In the *Cuarto de las Pinturas* (Palace 3E1-Room 6) in Chilonché, the photographic acquisition project had to deal with several problems due to the specific context in which the paintings were found. First, it was necessary to compensate for the lack of natural light inside the chamber; the limited amount of light coming through the entrance was insufficient to guarantee correct light exposure for the camera. To solve this problem, two incandescent lights, powered by a generator, were placed in the scene and positioned so as not to generate shadows on the wall surface, where possible.

Secondly, given the great amount of detail, pictures at multiple detail levels were necessary. On the one hand, the small size of the actual artefact (4.24x2.2m, h max 3.63m) sped up photogrammetric operations, which in turn led to a reliable model with just a few shots; on the other hand, the richness of detail required a higher number of images to render them correctly.

The photo sets were therefore split into six groups: four for the walls, two for the floor and the vault, each of which was made up of a first sub-group of pictures used to render the portion with a resolution of 50472x3648 px, and other sub-groups that would acquire the data, where necessary, with higher detail.

The photos were taken with the aid of a tripod, setting the auto-click to 2 seconds, so to avoid the risk of micro-movements while clicking with the finger. The focal length was kept at 18 mm so as to include a larger portion of the wall in the picture and facilitate the horizontal and vertical overlap of the images. In the connecting areas between one set and the next, a higher number of photos were taken to simplify precise alignment.

During the photographic campaign, a colour checker was used so the white balance could be corrected later on, resulting in a more realistic chromatic base. The use of the colour checker was particularly use-

Figure 17. La Blanca: mesh model of 6J2-Room 10
(Proyecto La Blanca, 2015)

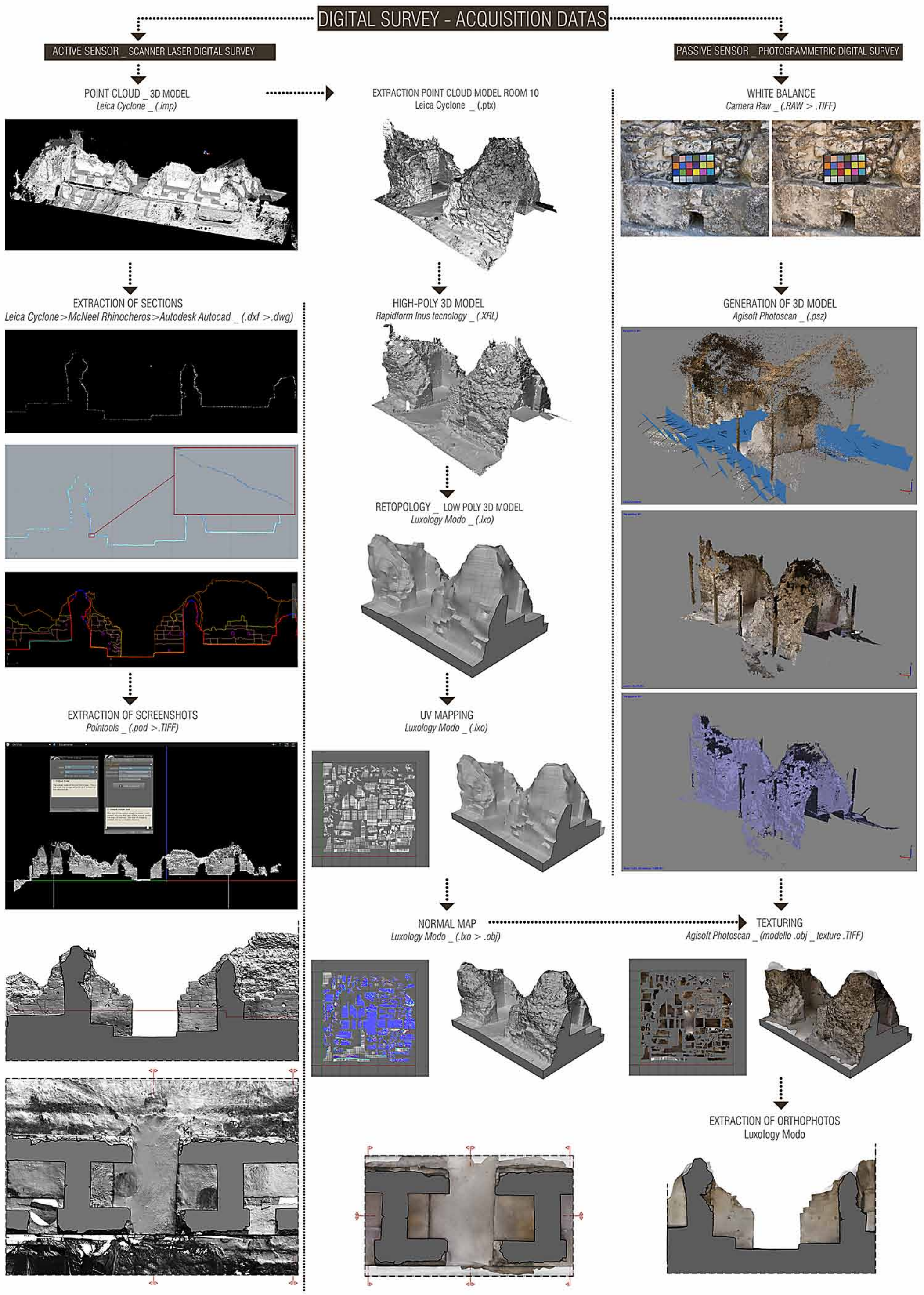


Table 12. Technical data related to 6J2-Room 10 of the Acropolis at La Blanca

LA BLANCA, Acropolis – Palace 6J2-Room 10	
Acquisition Parameters	
Number of photos:	551
File format:	RAW
.raw size file:	30 Mbyte each one
Point clouds Model	
Number of points:	$44x10^6$
Registered overall accuracy of the model:	2 mm
Polygonal Model	
Number of polygons:	$1 x10^6$
.obj file size:	128 Mbyte
Texture	
Texture dimension:	8192x8192 px
.tiff file size:	163 Mbyte

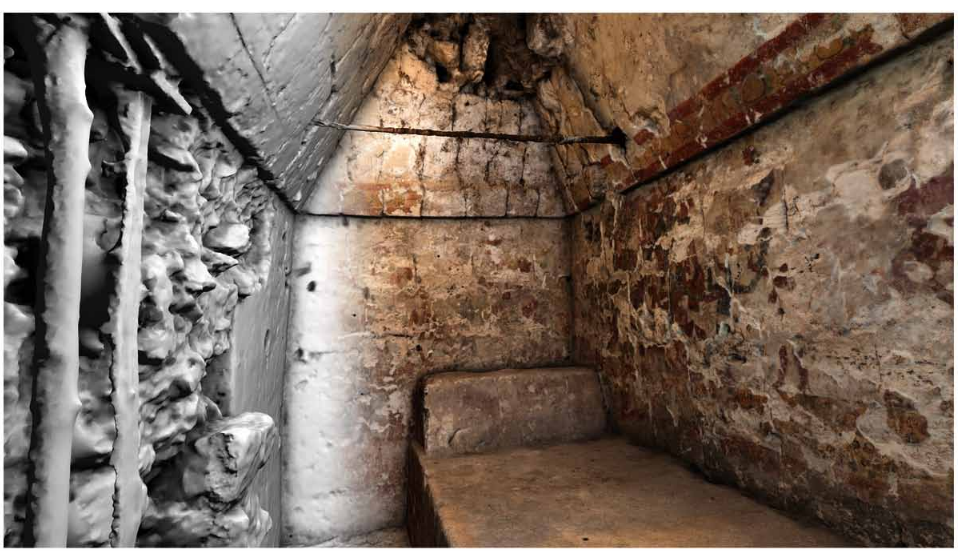
Table 13. Technical data related to the Cuarto de las Pinturas of the Acropolis at Chilonché

CHILONCHÉ, Acropolis – Palace 3E1-Room 6	
Acquisition Parameters	
Number of photos:	304
File format:	RAW
.raw size file:	30 Mbyte each one
Point clouds Model	
Number of points:	$311x10^6$
Registered overall accuracy of the model:	2 mm
.ply file size:	8.41 Gbyte
Polygonal Model	
Number of polygons:	$1.5 x10^6$
.obj file size:	159 Mbyte
Texture	
Texture dimension:	8192x8192 px
.jpg file size:	10 Mbyte

ful in handling the marked difference in lighting near the entrance due to the presence of both artificial/warmer and natural/colder light.

Even in this case the 304 photograms, treated with Agistoft Photoscan, generated a mesh model made up of 1.5 million polygons, with a texture resolution of 8192x8192 px (Figure 18).

Figure 18. Chilonché: mesh model of the Cuarto de las Pinturas (3E1-Room 6)
(Proyecto La Blanca, 2015)



RESULTS AND APPLICATIONS

Modern 3D modelling technologies allow a structure to be represented through a digital model that combines the visual potential of the images with the accuracy of a survey, thus becoming a support for both the display and measurement of monuments or other objects of historical interest (Ippolito, 2015).

At La Blanca, the 3D model delivered a faithful visual representation as well as accurate dimensions of the Acropolis palaces. The possibility of generating sections in any selected point of the 3D model to reveal its inner details and 3D visualisations from different viewing angles are big advantages over conventional manual maps.

For example, this model has permitted a detailed study to be carried out of the building systems that were employed in both palaces. It has also allowed the number and dimension of the wall slabs and keystones of the vaults to be ascertained with great accuracy, and their geometric shape to be observed with absolute precision. Thus, at the Orient Palace (6J1), on the section of the upper walls where the mortar layer finish had been lost, it was possible to appreciate in detail a building system created with stones of small size, which was very different from the slabs employed in the middle and lower sections of its façades. This is an important feature to take into account for the stylistic study of this architecture and its chronology.

Likewise, in the case of Palace 6J2, which was built in different phases, all the geometric details provided by the 3D model have allowed the successive alterations to be analysed and a chrono-typological sequence to be established, which is crucial for the archaeological interpretation of the whole monumental complex.

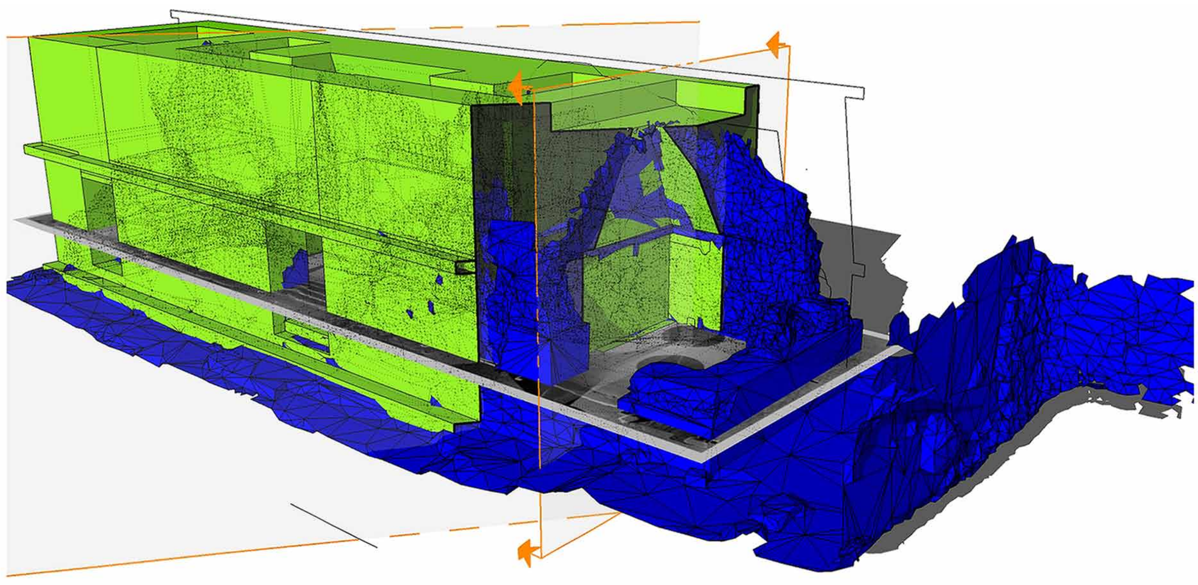
This model can also provide a 3D matrix that extends the traditional 2D diagrams by placing the archaeological finds into a geographical context that helps to better understand the spatial connections among them. A good example of this is the analysis that we are carrying out of the context in which the Terminal Classic burials were found inside the Orient Palace and their relationship between other Terminal Classic and Post-classic burials unearthed in the inner courtyard of La Blanca Acropolis.

Furthermore, the success in achieving high-precision 3D models has opened up a range of possibilities for ways to promote the region's cultural heritage, museum exhibitions and opportunities for "augmented reality visualizations". The promotion of new ways of understanding archaeological vestiges is one of the objectives of the La Blanca Project, and is aimed at the communities surrounding the archaeological site, in order to help them learn more about the Maya history of this region of Petén, and to integrate that knowledge into the modern society as a part of its rich cultural heritage.

In fact, these 3D models have been used to support the virtual reconstructions of La Blanca which will allow people to "visit" the site (Herguido & López, 2012) (Figure 19) and for the first experience in augmented reality carried out in Palace 6J2 Room 4, which has created a uniquely blended interactive experience in Maya archaeology (Peiró & Matarredona, 2014).

The results obtained from the graffiti laser scanning are also promising, although initially there was some doubt about the effectiveness of this tool, especially designed to obtain volumetric information, but less for detailed features like these thin incisions on stucco surfaces. But indeed, a correct projection of the texture of the scanned graffiti was achieved in the reconstructed model, which completely reflects the formal characteristics of the ancient strokes. This information is essential to distinguish between distinct artistic techniques and skills, as well as where different graffiti overlaps, due to being drawn throughout several phases of occupation of these rooms.

Figure 19. La Blanca: Calculated volume of the Orient Palace at La Blanca and low poly mesh during the reconstruction process
(Herguido & López, 2012)



In comparison to the methods usually employed for the documentation and registration of ancient Maya graffiti, the use of laser scanning technology offers faster *in situ* data collection and final results that are easily usable in digitalized imaging systems with the purpose of incorporating them into architectural surveys and reproducing them accurately. Additionally, a large range of applications can be previewed, in particular those related with museology and those with the possibility of placing the graffiti on the walls of the augmented reality 3D models, enabling virtual visits to buildings with all the decorative elements placed on the walls.

Laser scanning technology has also provided excellent results at Chilonché, where the working conditions inside the narrow tunnels were extremely challenging. The available documentation of the large zoomorphic sculpture (drawings and measured survey) was not suitable at all to define in a precise manner this smooth-edged object with large curved volumes. The high quality photographs, taken with professional equipment, also had limitations due to lack of space inside the tunnels that made it impossible to find a suitable approach.

The use of the laser scanner inside the intricate network of tunnels enabled us to establish the precise location of the sculpture and other substructures inside the basement of the Acropolis. This is crucial for establishing appropriate excavation strategies with the purpose of obtaining enough information to allow reasonable interpretations of this Preclassic complex, whilst avoiding extensive excavation works in this area.

This new method also allowed us to carry out measurements of all the curvilinear surfaces of the sculpture, which were really difficult to take by hand, giving us a realistic and high-resolution 3D model (see http://www.carlos-sanchez.com/CHNT17). An on-line 3D simulation also allows disseminating tangible cultural heritage through the Internet. By using this technology, we are able to show users all over the world the generated 3D model of the *Mascarón*.

This model has all the necessary details so that it could be used for the sculptural and architectural analysis of an object from a distance, once the excavation were concluded and the tunnels sealed for the protection and safeguarding of the substructures found inside.

Furthermore, this model was printed on a small 3D printer, and an experiment was also done with a 3D printer connected to a robotic arm that provided a real-size replica of this large sculpture, with excellent results.

Another useful tool for the scientific visualization of this sculpture was the projection of the 3D model in a virtual cave at the Polytechnic University of Valencia. The CAVE (Cave Automatic Virtual Environment) is a cube composed of display screens that completely surround the user (viewer) creating a virtual environment and the illusion of being immersed inside the projected object: to navigate around the *Mascarón* it is only necessary to physically move inside the simulation space. This allows researchers to achieve new ways of experiencing the archaeological site and allows remote archaeological remains to be transported to academic scenarios located a long distance away (Figure 20).

This interaction interface is very interesting for researching purposes because the end-user does not need any kind of ground knowledge in complicated 3D interfaces to fully visualize the model. It is also interesting since the simulation is immersive, and the user is therefore totally surrounded by the environment and, as it is an augmented reality simulation, the user can also see himself. In this way, the scale sensation, when navigating inside a virtual environment, makes the simulation much more descriptive than a regular visualization displayed on a traditional screen.

Given the computational performance offered by the hardware, high definition textures and high poly models of the *Mascarón* have been used in order to create a very realistic visualization.

However, working in a CAVE environment presents an extra rendering cost: since we work in a stereoscopic 4-display environment, for each simulation frame 8 images have to be calculated: one for each eye, for each display. This means that the rendering time is eight times greater than the rendering time of a traditional simulation.

To simulate the immersive experience, the image shown in each display must be calculated by correcting the projection matrix of the 3D camera according to the user's eye's relative position respect to

Figure 20. Projection of the 3D model of the Mascarón in a virtual cave
(Proyecto La Blanca, 2012)

each display. These calculations are however performed rapidly thus overcoming the main performance problem, i.e. the need to generate eight images every simulation frame.

The potential uses of properly textured high-poly 3D models are therefore innumerable: from a virtual visit of the site, with a low level of interactivity, to immersive multimedia or augmented reality. The tools used do not belong to the traditional disciplinary domain of surveying cultural heritage, but rather to the entertainment industry. From a computer graphics point of view, the software used for the design of videogames is sensibly more advanced than those commonly used in architecture or archaeology and, if properly used, can lead to the creation of effective products such as multimedia representations, saving all the necessary information which can then be analysed from a scientific point of view (geometrical and chromatic data conservation).

The remaining part of the finds, like *Cuarto de las Pinturas* in Chilonché and the high-relief in La Blanca (see www.rilievourbano.org/LA_BLANCA/Friso_8.mp4), can be documented with the same system used to survey and represent some of the sculptures and architectural artefacts belonging to the two archaeological sites, thus making the history of these urban settlements readily available to the general public, without confining it to the traditional sources of information used by the international scientific community. The difficulties are many: the hardships inherent in reaching the places where these finds are located, the often hostile environment, both anthropic and natural, and the problems connected to the correct conservation of the ruins. Today, for example, the tunnel leading to the *Mascarón* is no longer accessible due to a large landslide obstructing its entrance, and then, the relief at La Blanca has once again been interred, after having been restored, to safeguard it from the natural elements.

CONCLUSION

The key contribution of this research has been to provide new alternatives in the field of archaeological surveying by using laser-scanning technology, especially in the Maya area.

This technology has not yet been established as a valuable method of surveying in this area, even though it offers interesting advantages over traditional methods. One of these advantages is the quick capture of the physical measurements of any physical entity, which saves time in collecting data during fieldwork. This information is indispensable for subsequent analysis should this physical entity be interred once again after the excavation process. However, it is important to remember that data treatment is still a time-consuming process. So, the main benefit of this method is the type of product created by this technology.

The 3D models produced after data processing at the Acropolis of La Blanca and Chilonché have therefore contributed to archaeological interpretations since they have increased our knowledge of the entities scanned and have established the spatial connections between the archaeological finds. These models are also useful instruments for planning future excavations of these monumental complexes and can be used in exhibitions and multimedia.

The wide range of options that this technology can offer for the conservation of cultural heritage should also be taken into account, even though many of these are still considered experimental. From this point of view, all the images taken in 2012 at La Blanca and Chilonché are important documents due to their testimonial value. In the future, these images can easily be compared with others obtained from new scans thus increasing the effectiveness of the control and supervision of protecting archaeological heritage and the planning of future works.

Finally, the development of an integrated system using a combination of terrestrial and aerial laser scanning technology in the whole Maya area would be of utmost interest, especially for archaeological interpretations. This however is not a feasible proposition at present due to the elevated costs involved in aerial laser scanning technology.

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KEY TERMS AND DEFINITIONS

Active Sensors: The field of digital survey, an active sensor is a device that uses a coded electromagnetic radiation (like laser) in the measurement process. An active sensor that employs a laser is generally called range camera or laser scanner.

Camera Re-Sectioning: The process of finding the true parameters of the camera related to a certain photograph.

Digital Photogrammetry Applications: Methods based on the metric elaboration of images that use collinearity equations, starting with the definition of homologous points identified on the photograms, and then transforming the data acquired from the images into 3D coordinates.

Laser-Scanning Technology: Taking advantage of active sensors, the reflection of laser light is used to compute the distance from a surface. Generally every second up to 1 million spatially accurate sets of three coordinates are collected. The millions of points computed are used to produce a point cloud, which defines the geometrical surface of an object.

Normal Map: In the field of 3D graphic, normal map is a special kind of image that allows adding surface details to a low-poly model. It represents in fact how light behaves, simulating the aspect of a high definition model.

Passive Sensors: In the field of digital survey, a passive sensor is a device that measures natural energy of the light (like Structure from Motion applications).

Reflectance Value: The visible light that is reflected from a surface when illuminated by a light source, like one emanated by a laser.

Reverse Engineering: In the field of digital survey, reverse engineering is a process which allows duplicating an object starting from the analysis of its physical size.

Total Station: An electronic theodolite integrated with an electronic distance meter to read distances from the instrument to a particular point.

UV Map: In the field of 3D graphic, it is a 2D image that contains the unwrapped faces of a 3D model. The UV mapped version of a mesh may be used for encoding the "apparent colour" and the "normal vectors".

(u,v) Reference System: in the field of 3D graphic, (u,v) is a bidimensional reference system used to describe a 3D object.