Digitizing an Excavation: A Laser Scanning Database of Maya Architectural Remains

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Excavating an ancient Maya city requires a long-term archaeological project that entails adequate documentation procedures for the unearthed remains, frequently of monumental scale and with difficult preservation conditions. A digital laser scanner survey methodology was designed and implemented to document the exposed architecture and to follow-up the archaeological excavation of the Maya site of La Blanca (Peten, Guatemala). All scans collected during the different field seasons were stored and aligned in a common reference system. Thus, an accurate digital three-dimensional database was obtained, including all the architectural remains found, some of which had to be reburied to ensure their preservation. The resulting database is a helpful repository that facilitates to extract all the graphic outputs required for: planning the next excavation campaigns, monitoring the preservation of the buildings, studying the architecture and construction technology in detail, and disseminating the excavation results. This paper describes the methodology and procedures used to build-up this database.

Keywords:
Maya architecture, archaeological excavation, survey, laser scanner, architectural database.

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1. INTRODUCTION

Digital technologies have been transforming cultural heritage documentation and public outreach for several decades now [Pieraccini et al. 2001]. Particularly noteworthy is the increasing ease of producing and handling 3D models with a variety of technologies and at many different scales.

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Digitation extends to a whole of practices that allow not only volumetric recording but also data integration, storing, and sharing, while increasing efficiency and accuracy [Garstki 2020].

As technologies developed, the processes inherent in survey systems have only made them easier to apply and more affordable. In field archaeology, it is no longer conceivable to disregard digital documentation techniques. Because excavation is a destructive process by nature, archaeologists are required to transmit as much evidence as possible to future generations, and digitation has become the most effective strategy [Roosevelt et al. 2015]. However, in many cases there is still a latent need to move from locally stored isolated 3D models to integrated interactive databases to facilitate future research and dissemination.

In recent years, many archaeological projects have been testing the integration of digital survey techniques for excavation documentation, as well as the creation of digital databases to store the information from the entire excavation in a unified system [Garstki et al. 2018, Notarian et al. 2020]. This enables the diachronic documentation of the excavations and the availability of digital copies of the stratigraphy [Boyd et al. 2021].

In many cases, photogrammetry supported by topographic equipment —to provide scale, orientation, and georeferencing— has been chosen as the main survey method [Koenig et al. 2017, Garstki et al. 2018]. The so-called Structure from Motion (SfM) technology has recently become commonplace due to low cost and ease of data processing [Willis et al. 2016].

Terrestrial laser scanning (TLS) surveys have demonstrated higher geometrical accuracy (1-3 mm) and resolution [Hassan and Fritsch 2019], but the main drawback is that they remain expensive. When having a laser scanner is feasible, it enables to obtain an extremely detailed and geometrically very accurate model. Moreover, the resultant range-based model can be combined with a photogrammetric image-based survey to obtain 3D models of high photo-realistic quality, thus leveraging the intrinsic advantages of both survey methods [Lerma et al. 2010, Remondino 2011, Guidi and Frischer 2020].

TLS and close-range photogrammetry integration has proven to be very effective in documentation of architectural heritage [Bercigli and Bertocci 2017, Chiabrando et al. 2019, Alshawabkeh et al. 2020] and highly beneficial in documenting complex archaeological sites [Lerma et al. 2010], providing both accurate digital models and photo-realistic outputs.

Maya ancient architecture presents certain particularities and circumstances that make digitization even more essential for its research and conservation. This intricate cultural heritage is often endangered for different reasons, especially the aggressiveness of the tropical climate and natural environment, the threat of abandonment and looting, and the complexity of preserving the large number of ancient buildings that exist in the Maya area. In this architecture at risk, it is essential to conduct an exhaustive documentation using modern technologies to obtain a very accurate digital copy of the remains that will be available for future research.

The effective collaboration of a multidisciplinary team is of great importance for archaeological excavations in the Maya area, where most of the buildings –sometimes of monumental dimensions– have remained buried for centuries, thus requiring thorough, long-term archaeological excavations.

For some time now, more and more voices have been claiming the need to put conservation at the forefront, so that the vestiges of the Maya culture are not only a rich source of information for historical and anthropological studies, but also a heritage legacy for the present and the future [Fash et al. 1993, Quintana Samayoa 2013, Muñoz Cosme 2021]. In this sense, the use of digital technologies has been useful to ensure the best and most effective documentation of this heritage, the proper handling of which not only allows to correctly register, understand and characterize the remains, but also offers tools for its preservation and dissemination.

Maya architectural remains, once excavated and exposed to the elements, are subject to rapid deterioration due to climate conditions. The exposure of building materials that have remained buried in a stable situation for centuries requires effective protection systems and long-term preventive conservation programs. However, in some cases, due to the fragility of certain elements, one of the more adequate options is to rebury them to ensure their preservation. The concept of reburial has found increasing acceptance when provision for the proper maintenance of the excavated archaeological heritage cannot be guaranteed [ICAHM 1990, Agnew et al. 2004, Demas 2004, Williams 2011]. This is also an increasingly frequent practice in the Maya area, especially to ensure the preservation of fragile stucco masks [Hansen and Castellanos 2004, Kovác et al. 2015]. In some cases, replicas are installed in situ to show the reburied elements, as in Xunantunich [Crisell 1997] or Caracol [Bawaya 2003]. More recently, 3D digital models are disseminated to show inaccessible façade reliefs [Tokovinine and Estrada-Belli 2017]. In both cases detailed digital documentation becomes more than essential.

For 15 years, an archaeological research project has been conducted at the site of La Blanca in Guatemala, which has made it possible to unveil its monumental architecture [Vidal Lorenzo and Muñoz Cosme 2016]. In this project, a methodology for the accurate digital documentation of architectural remains by terrestrial laser scanner —complemented with close-range photogrammetry— was designed, applied and optimized. The results of all scanning campaigns have been stored in a digital database of the excavation, from which numerous outputs can be extracted for research, conservation, management, and dissemination purposes.

This paper shows the methodology and main procedures used for the survey of the architecture of La Blanca and describes how the digital repository of all the architectural findings of this long-term excavation was built. The final aim of this database is providing a digital copy of this Maya architectural remains, in order to make them available for both ongoing and future research.

2. THE ARCHAEOLOGICAL EXCAVATION OF LA BLANCA

The site of La Blanca, in the department of Peten in northern Guatemala, is one of the ancient settlements founded in the Salsipuedes River basin, part of the larger Mopan River system (Fig. 1), an area that became a strategic location for trade during the Late Classical Period (AD 600-850) [Muñoz Cosme and Vidal Lorenzo 2014]. This territory is located in the core of the Maya Lowlands, a region occupied by numerous ancient Maya cities, some of them of great cultural and political relevance, such as Tikal, Naranjo or Caracol [Quintana Samayoa and Wurster 2001].

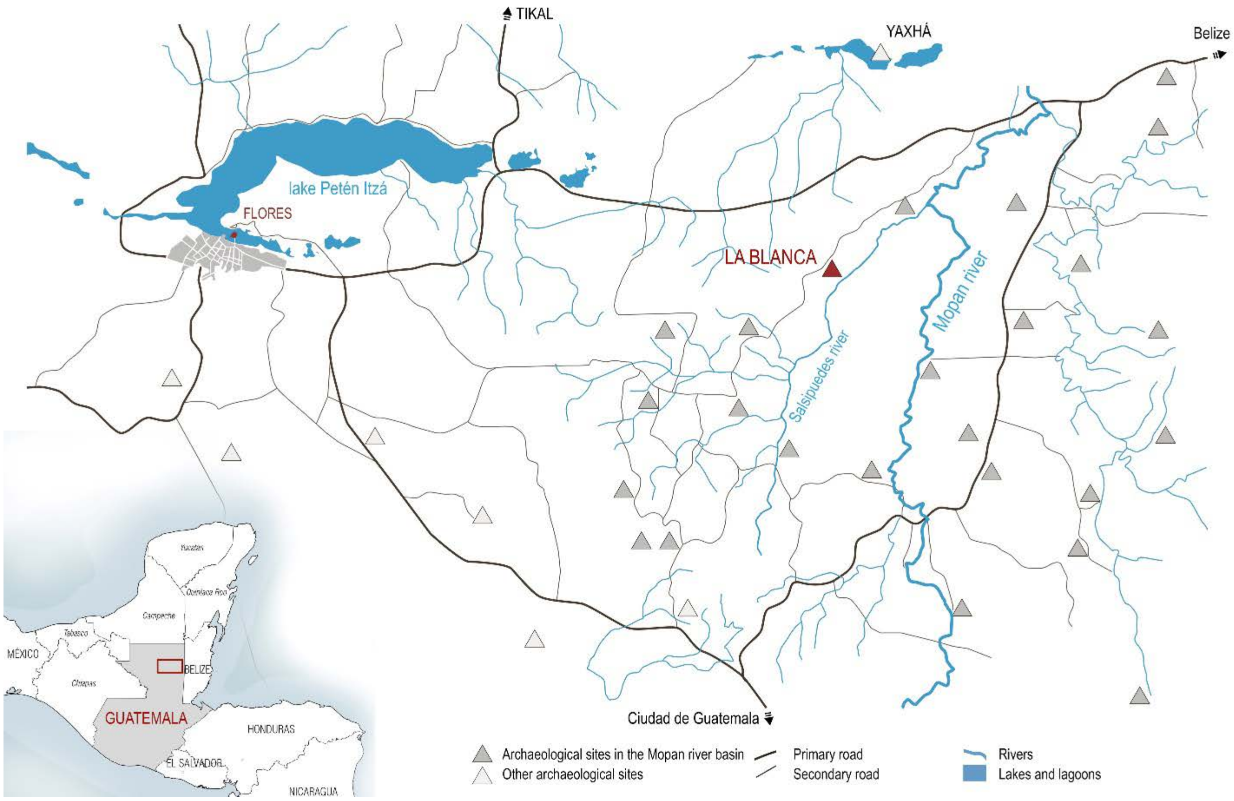

Figure 1. Location of La Blanca among other Maya ancient settlements in Peten, Guatemala.

Despite its small size compared to other major cities in the area, La Blanca stands out for the high quality of its architecture. With mainly administrative and commercial functions, this Maya site peaked during the Terminal Classic (AD 850-1000), when major constructive transformations were made to its main architectural complexes [Muñoz Cosme and Vidal Lorenzo 2014].

The urban settlement of La Blanca is structured along a north-south axis, aligned 12 degrees west of the geographical north. The main causeway connects the southern ceremonial group with the water reservoir and the residential groups to the west, finally reaching the large north square in front of the Acropolis, the place for the elite (Fig. 2).

After the abandonment of the monumental centers of this area in the 10th century AD, a process related to the decline of Maya Classic society [Demarest et al. 2021], the structures of La Blanca deteriorated progressively. Most of its vaulted roofs collapsed over time and the buildings were gradually covered by vegetation until they became large mounds.

Whereas the earliest record of La Blanca dates back to 1905, in a schematic plan where Teobert Maler [1908] refers to the site as "El Castillito" for its massive architecture, archaeological excavations started only in 2004 with the launch of La Blanca Project.

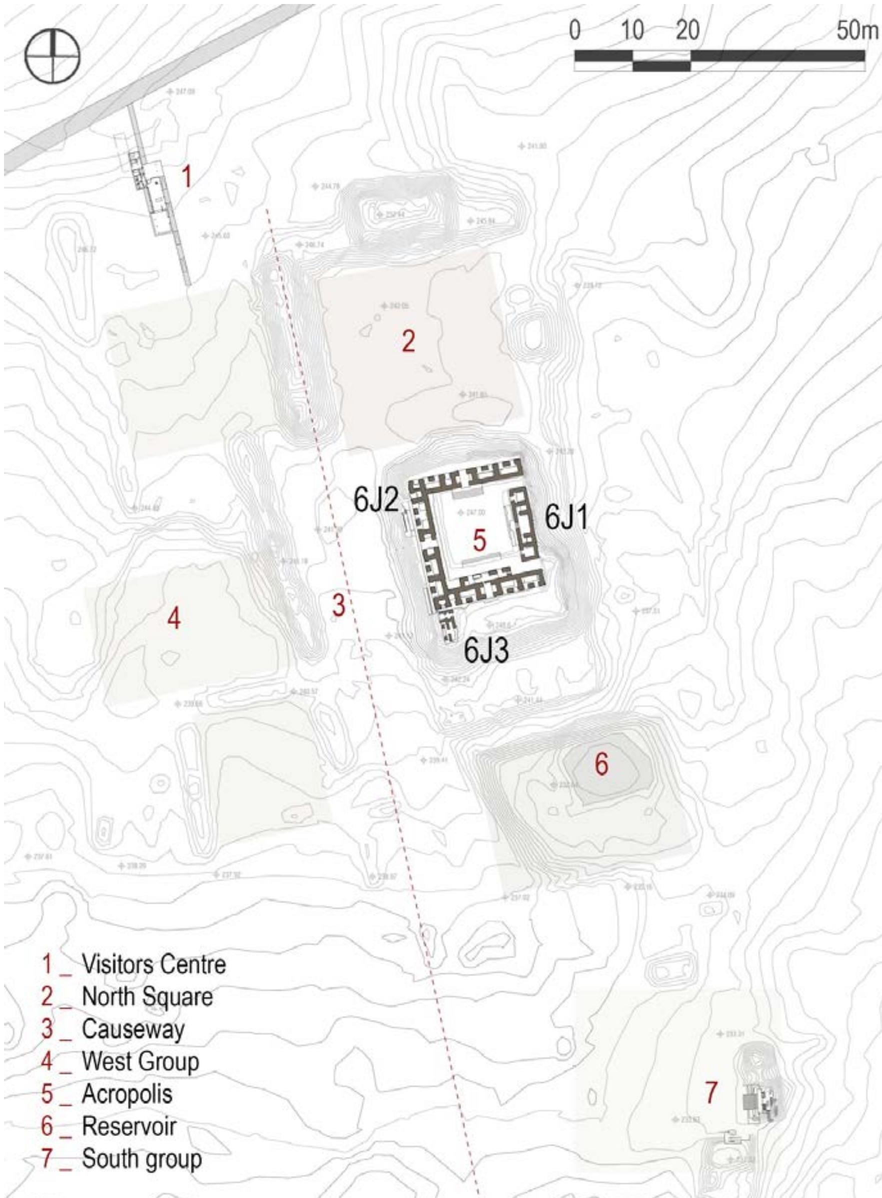

Figure 2. Plan of La Blanca with the Acropolis and main public spaces.

In order to reveal and enhance the value of these vestiges, a total of 15 archaeological campaigns were conducted between 2004 and 2019, with an annual field season of several months, together with subsequent desk-based work undertaken both in Spain and Guatemala during the rest of the year.

A considerable amount of field data was collected over this period, using different survey techniques depending on the technology and resources available at the time, from topography and direct manual surveys at the beginning to digital documentation and daily scanning of the architecture in process of excavation. Thus, the methodology for the architectural survey of La Blanca has been optimized over the years resulting in a specialized procedure to obtain an accurate 3D documentation of this heritage.

2.1 The Architecture of the Acropolis

The center of political power and the residence of the elite of La Blanca was placed at the so-called "Acropolis", a term of Greek origin used in the Mesoamerican context to describe large architectural ensembles resulting from the superposition of several construction phases [Gendrop 1997]. Thus, the last building of this complex is a quadrangle built on a stepped platform 8 m high, which was accessed from the north square via a monumental stairway (Fig. 2).

The Acropolis quadrangle measures about 50 m on each side and consists of the Palace 6J1, a free-standing building with a single bay and a 28 m length rectangular floor plan, and the Palace 6J2, a U-shaped building with three wings of outward-facing rooms which, together with the previous one, encloses an inner courtyard of approximately 36 m per side (Fig. 2).

The rooms of the buildings that make up this quadrangle, roofed with corbelled vaults, are larger than those of similar buildings of Peten [Gilabert Sansalvador 2020]. In Palace 6J2 interior spaces are 2.90 m wide and 6.50 m high, and the wooden lintels of the entrances were placed 4.00 m high (Fig. 3). Palace 6J1 stands out for the width of its rooms over 4 m, as well as for some unique construction solutions that demonstrate both the technical skills of its builders and the significance of the activities that took place there.

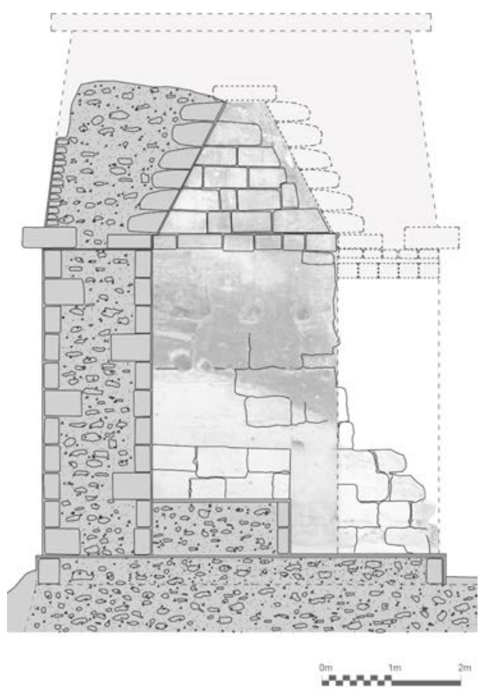

Figure 3. Construction section of 6J2 building.

The archaeological excavations revealed that the terrace in front of the 6J2 south wing was the result of a later modification [Vidal Lorenzo 2006]. At the western end of this enlarged platform was built the Palace 6J3 (Fig. 2), a smaller building around 12 m long and just over 5 m wide, which would have been inhabited by a member of the ruler's family [Muñoz Cosme and Vidal Lorenzo 2014]. Although the construction of this palace was based on the floor plan of 6J1, it was later renovated by adding a second bay to the front façade.

Evidences of another structure were found in the Acropolis while exploring a looting tunnel under the 6J2 west wing [Vidal Lorenzo and Muñoz Cosme 2010], a common practice in archaeological excavations in the Maya area [Estrada-Belli 2003, Fialko 2009, Nondédéo et al. 2018]. This building is known as 6J2-Sub2, a previous construction phase of the Acropolis that has been preserved beneath a larger, more recent structure. This practice of erecting new buildings over structures from earlier periods is a common one in Maya architecture, and excavating these subjacent buildings, which often contain well-preserved stucco decorations and mural paintings [Sharer et al. 1999], represents yet another challenge for the conservation of this heritage [Pires et al. 2021].

3. SURVEY PROCEDURES

Prior to the introduction of digital survey techniques in 2012, architectural documentation in La Blanca was performed through topography and direct measurements recorded in hand drawings. Drawing provides first-hand knowledge of the architectural remains and their interpretation in situ [Morgan and Wright 2018], so manual surveys were not completely discarded in order to ensure an in-person meaningful preliminary study of the remains [Sapirstein 2020] that definitely aids in the analysis of digital data. However, while this traditional survey provides a simplified documentation of the object of study –involves discretization of building geometries and representation of only a number of specific sections, i.e., 2D abstractions of 3D realities [Roosevelt et al. 2015]–, digital survey allows its complete documentation through a 3D high-fidelity and accurate model.

For this purpose, a Faro Focus^{3D} S120 Terrestrial Laser Scanner (TLS) was used –a small, compact model with up to 5 hours of battery life, which facilitates transport and fieldwork at the archaeological site (Fig. 4). This active sensor device offers a rate of up to a million points per second and 3D measurements in a range of 360º in the horizontal plane and 305º in the vertical plane, and within a distance of 120 meters. It calculates the distance of each point to the documented object by comparing the phase shift between the exit laser signal with the return one in an accurate process with a margin of error of 2 mm from a distance of 10 meters.

Digital photogrammetry –a passive sensor– has been used as a complementary survey method to obtain quality chromatic information of the documented objects. The remarkable success of photogrammetry in recent years is mainly due, firstly, as aforementioned, to the low cost of the tools used compared to that of a laser scanner and the increasing ease of data processing. Secondly, to the possibility of adapting the density of the photographs acquisition according to the complexity of the object to be documented. When possible, the integration of both methods allows to benefit from the advantages of each one and to obtain geometrically accurate 3D models complemented with a real photographic texture [Remondino et al. 2009].

As a general methodology, before starting the laser scanner data acquisition, it is necessary to plan the survey by defining the position of the individual scans and the reference points or targets that will later be used for the point cloud alignment. When planning the position of the scans, it must be considered that (1) all surfaces of the buildings need to be scanned, avoiding shadows –areas not visible to the scanner, (2) there must always be a minimum of 3 targets in common between 2 scans to ensure that they can be aligned correctly afterwards.

Whereas printed chequerboard targets were used during the first survey campaigns, expanded polystyrene spheres fixed to a wooden base were introduced from 2016 for two reasons (Fig 4). First, the highly accurate geometric definition and reflectance value of the spheres allows them to be automatically recognized by point cloud processing applications, which place a 3D sphere in the exact same position as the real one and take its geometric center as an unequivocal reference point to join the different point clouds. Secondly, their wooden base allows them to be easily placed and stabilized on walls, cornices, and irregular terrains without damaging architectural remains, and even fixed and kept in the same position for several days of field work[1].

Figure 4. Data collection with laser scanner during the 2017 field season, photo PLB.

The scans are performed at different heights and resolution[2] and quality[3] settings are adjusted according to: (1) the dimensions of the objects to be documented, (2) the distance between the scanner

[1] Registration software development has recently advanced to the point that physical targets are now not even necessary, as overlapping sections of the cloud can be automatically detected and aligned.
[2] Resolution indicates the number of points registered in relation to the distance between the scanner and the object, e.g. at a distance of 10 m, 1 point every 4 mm is obtained with a 1/4 resolution.
[3] In a 3x quality setting, the scanner measures the distance to each point 3 times, and the resulting measurement for each point is the average of the 3 values obtained. The higher the quality, the higher the accuracy but also the longer the scanning time required.

and the surfaces to be scanned, and (3) the degree of detail required based on the geometrical complexity of the objects to be surveyed. Thus, a fls (Faro Laser Scan) file for each individual point cloud is obtained. Subsequently, data filtering and registration operations are performed with the Faro Scene software to join the individual point clouds. This is an increasingly automated process, whereby a maximum error constraint of 3 mm is set for the resulting real-scale discontinuous 3D digital model of the documented objects, which accurately represents their geometry.

The specific methodology for architectural documentation in each case was designed according to the needs of the archaeological excavation and the specific conditions of each building. As digital survey was introduced some years after the beginning of the project, buildings 6J1, 6J2 and 6J3 were scanned after their excavation, consolidation and protection works had been completed. A specific digital documentation methodology was designed for cases in which reburial was the most convenient option. The collection of digital survey data for the 6J2-Sub2 building was conducted simultaneously with the excavation works, whereby an excavation follow-up procedure was implemented. The following is an explanation of these three different experiences of documentation developed in the project, whose results make up the digital architectural database of La Blanca.

3.1 Documentation of Exposed Architecture

Once the excavation has been completed, the project team assesses whether it is possible to leave the architecture visible without seriously compromising its preservation. This was the case of 6J1 and 6J2 buildings and, initially, of Palace 6J3. With the aim of exposing the architectural remains and make them visitable, it was necessary to carry out consolidation works and design a protection system. For this purpose, a wooden structure with palm-thatched roofs –a local technique using local materials– was installed over the buildings, to protect their construction fillings and stucco coatings from the rain (Fig. 5).

Figure 5. 6J1 and 6J2 buildings with their protective roofs, 2015.

The digital documentation of these buildings was carried out in 3 survey campaigns conducted between 2012 and 2015 (Fig. 6, Table 1), when the aforementioned protective roofs were already installed, which made scanner data collection impossible in the highest parts of the walls.

Documentation of the exposed architecture of the Acropolis was carried out following the consolidated workflow commonly used in architectural heritage surveys:

(1) Design of a survey project before each campaign.

(2) Placement of targets required for subsequent alignment of point clouds.

(3) Acquisition of the scans.

(4) Data filtering and alignment in laboratory at the end of each survey campaign.

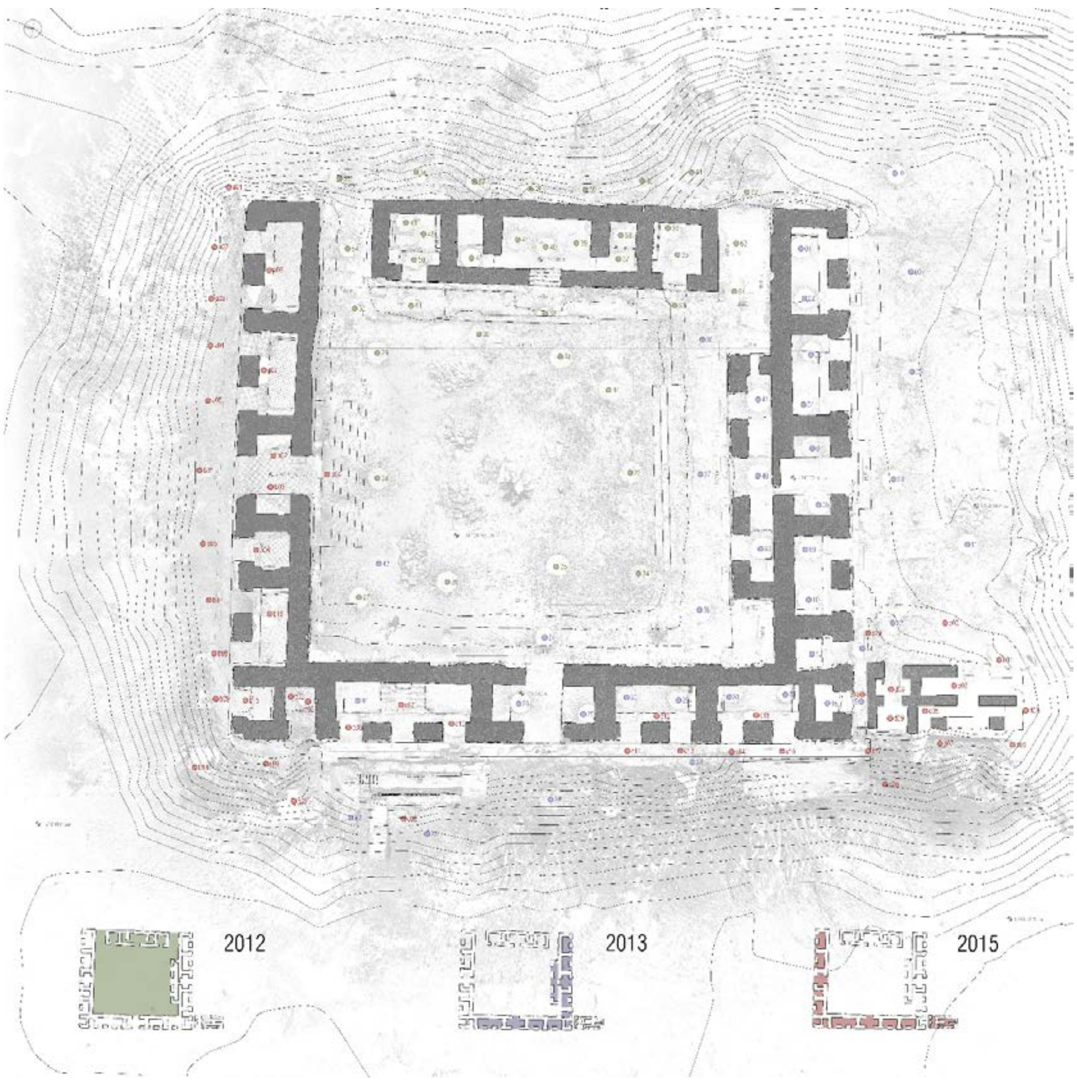

Figure 6. Floorplan of buildings 6J1, 6J2 and 6J3 with scan positions.

Table 1. Data collection per year in the Acropolis buildings.

Field season	Acropolis areas	Number of scans	Time spent
2012	6J1 & courtyard	36	12h 30'
2013	6J2 (south & west wings)	36	12h 30'
2015	6J2 (south, west & north wings) and 6J3	46	15h

During the 2012 field season, the operations were focused on building 6J1 and the central courtyard, resulting in a total of 36 scans (Table 1), 26 for the documentation of building 6J1 and 10 for the courtyard. In 2013, the goal was to scan the south and west wings of building 6J2. Although a total of 36 scans were collected, difficult weather conditions meant that these were not sufficient for a complete and satisfactory documentation. Therefore, in 2015, after completing the survey of the quadrangle by scanning the 6J2 north wing, it was necessary to integrate the data from the previous campaign to complete the documentation of the south and west wings (Table 1). A total of 46 scans were collected during this field season, 13 of which were dedicated to building 6J3.

In order to obtain a constant scanning grid (point density) for the data acquired during these 3 campaigns, a similar distance between the laser scanner and the objects was maintained, thus achieving a 3D model with homogeneous point distribution. At the end of each field season, the collected scans were filtered and aligned, setting a maximum error of 3 mm.

After the last campaign, the point cloud models were aligned with each other into a single master file. For this purpose, common points were identified in the architectural remains of the 3 models since it would not have been feasible to maintain unalterable targets during several years.

A total of 118 scans were acquired, most of them at 1/4 resolution[4], at 4x quality, and at an average distance of 5 m between the laser scanner and the objects. The resulting reality-based point cloud model of the Acropolis (Table 2) showed a very high geometric accuracy and was the starting point of the project's architectural digital database.

Table 2. Acropolis acquisition parameters and resultant point cloud model data.

Acquisition parameters	
Laser scanner	Faro Focus^{3D} S120
Resolution	1/4
Quality	4x
Average distance scanner-object	5 m
Number of scans	118
Point clouds model	
Number of points	3,790 x 10^6
Registration accuracy	3 mm
Database file size	85 Gb

[4] In some cases resolution was reduced to 1/5 or 1/8, depending on the features of the object to be documented and the distance to the scanner.

3.2 Documentation Prior to Reburying

As aforementioned, the environmental conditions of the subtropical zone of Peten, with cyclic variations of humidity and temperature, rapidly deteriorate the exposed building materials, especially remains of mural painting and lime stucco modeling and coatings [Straulino et al. 2013, Ortega-Morales et al. 2013]. Moreover, the architectural remains are soon colonized by bacteria, lichens, mosses and higher plants [García De Miguel et al. 1995], and even large trees grow into the construction joints. Therefore, when the preservation of the architectural remains cannot be properly guaranteed, reburial seems as the most convenient option. At La Blanca this decision was adopted in two different cases: for the entire building 6J3, and for a sculptural relief found during the 6J2-Sub2 building excavation, where specific documentation procedures were applied.

The Palace 6J3 was investigated between 2006 and 2007 and documented, back then, by means of traditional survey techniques. Once the excavation was completed, this building was also protected by a roof. However, due to its fragile state of conservation, in 2015 it was decided to rebury it, making its digital documentation essential to obtain a high-fidelity 3D copy of the building available for future research.

As this was the first time that a building excavated in La Blanca was to be completely reburied, a specific documentation methodology was designed, which could be applied to other similar cases. This procedure consisted of 4 stages:

(1) Reviewing all the existing documentation to know in depth the information deduced from its excavation and analysis.

(2) Conducting a new architectural survey using traditional methods to carry out a complete direct inspection of the building and to verify in situ the information already available on the building.

(3) Performing a detailed digital survey using laser scanner and close-range photogrammetry to obtain an accurate digital model of the building.

(4) Reburying of the building, using sieved earth in the areas in contact with the construction elements and providing it with a final shape that guarantees the rapid evacuation of rainwater.

As aforementioned, 13 of the 46 scans acquired in 2015 (Table 1) were dedicated exclusively to the thorough documentation of the building 6J3, all of them acquired at 1/4 resolution and 4x quality. Data processing and registration resulted in a 3D point cloud model of the building of about 210 million points with an error below 3 mm (Fig. 7).

In order to record the real color of the building surfaces, a complementary digital photogrammetry survey was performed (Fig. 8). For this purpose, several photographic sets were acquired from different angles and heights, using a Canon 70D reflex camera equipped with a EF-S 18-135mm f/3.5-5.6 IS STM lens.

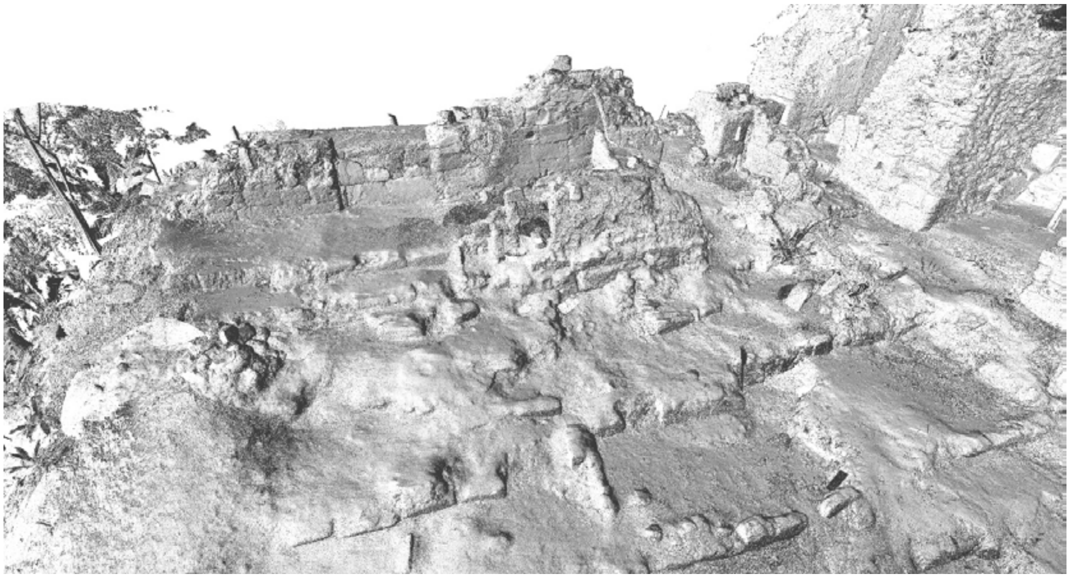

Figure 7. Point cloud model of building 6J3.

Figure 8. Photogrammetric point cloud model of building 6J3.

The first step was to study the scene lighting conditions and plan the photogrammetric data collection when the building was indirectly illuminated, thus avoiding contrasted shadows. Adjacent photographs were taken with a minimum overlap of 60% to facilitate alignment and always maintaining a constant focal distance. The diaphragm and shutter speed were set in order to obtain correct exposure and proper depth of field. All the images were acquired in .raw format and a color-checker chart was included in the scene in the first photograph of each set in order to perform white balance before converting the images into .tiff format and proceeding with the creation of the model. This is crucial to homogenize the chromatic data and obtain a high-quality photographic texture [Russo, 2017].

Data processing was performed through the usual Agisoft Photoscan (now Metashape) workflow, which leads first to the alignment of all photos with each other and then to the construction of a point cloud model. This model was referenced to the laser scanner model by identifying common points on the architectural remains, labeled as markers in the photogrammetric model and as targets in the range-based one. The coordinates of the targets were exported and fed into the photogrammetric model, so that the markers moved to the new coordinates and the photogrammetric model was automatically scaled, oriented, and referenced in the laser scanner reference system.

In order to verify the correct scaling and orientation process both point cloud models were exported to the reverse engineering software 3D System Geomagic, which allows comparing the two point clouds and assessing the overlapping of their surfaces. Through this process, we were able to verify that the mesh deviation between the two models was within a range of ±0,35 mm, resulting in high correspondence between the two models.

Once performed this accuracy verification, in the next step we get back to the Agisoft Metashape workflow and built a 3D polygonal mesh with photographic texture [Remondino 2014]. As a result, a second full-scale 3D model with high accurate chromatic information of the building was obtained (Table 3).

Table 3. Photogrammetric model of the 6J3 building.

Acquisition parameters	
Number of photos	362
Resolution of the photos	5472 x 3648 px
Acquisition Format	RAW (Canon CR2)
Focal distance	24 mm
Superposition of the photos	60% horizontal - 60% vertical
Point cloud model	
Number of points	93,6 x 10^6 pt
Polygonal model	
Number of polygons	5324x10^3 pl
Size of the exported .obj file	614MB
Texture	
Resolution of the texture	16384 x 16384 px
Size of the exported .jpeg file	49,2 MB

Both digital models –range-based and image-based–can be integrated, resulting in a very accurate geometric and chromatic complementary documentation of the reburied building: e.g., the photogrammetric point cloud can be imported into the range-based model management software to integrate the shadow zones that may have been generated in the documented scenes. They can also be integrated into reverse engineering software to produce 3d models optimised for various purposes and extract accurate 2D drawings and scaled ortophotos.

Thanks to the application of this method, that involves the use of the photogrammetric survey for documenting the reburied 6J3 building, After this specific pre-rebury documentation methodology, an accurate digital copy of the building remains completely accessible for future research without the need for re-excavation.

The second case in which the reburial strategy was applied was the sculptural relief found in the 2013 excavations, a supernatural mask surrounded by geometrical symbols [Vidal Lorenzo and Muñoz Cosme 2014]. This well-preserved relief 4.75 m long and 1.50 m high made of carved stone mosaic refined with lime stucco, decorated the west basement of the 6J2-Sub2 building (Fig. 9). Exposure to the elements could rapidly deteriorate it, so it was decided to conduct emergency consolidation actions and document it thoroughly prior to rebury it.

Figure 9. Sculptural relief found in La Blanca in 2013.

Due to its geometrical complexity, the relief required a high detailed survey, which was conducted in a limited space available, a trench only one meter wide. Therefore, despite the small distance between the instrument and the object, the Faro Focus^{3D} S120 was set to 1/4 resolution and 4x quality, in order to obtain a high detailed point cloud model. 14 closely spaced scans were collected by placing the laser scanner at different heights and angles to cover all possible shadow zones caused by the intricate relief morphology. Some of the stations were placed in the surroundings of the trench in order to record its location relative to the Acropolis quadrangle. The later filtering and alignment of the scans allowed to obtain a model of 300 million points of the relief with a maximum error of 2 mm (Table 4).

Table 4. Acquisition parameters and final point cloud model of the relief.

Acquisition parameters	
Laser scanner	Faro Focus^{3D} S120
Resolution	1/4
Quality	4x
Average distance scanner-object	1 m
Number of scans	14
Acquisition of photos	Yes
Point cloud model	
Number of points	300 x 10^6
Registration accuracy	2 mm
Database file size	13,9 Gb

At the end of the 2013 fieldworks, this sculptural relief was completely reburied so that it is no longer visible. Nevertheless, the accurate 3D model obtained (Fig. 10), integrated into our general digital database, preserves the information it contains for the future, facilitating the analysis of its iconography and the dissemination of this relevant finding. Therefore, digital surveys also offer rapid and accurate documentation under challenging circumstances.

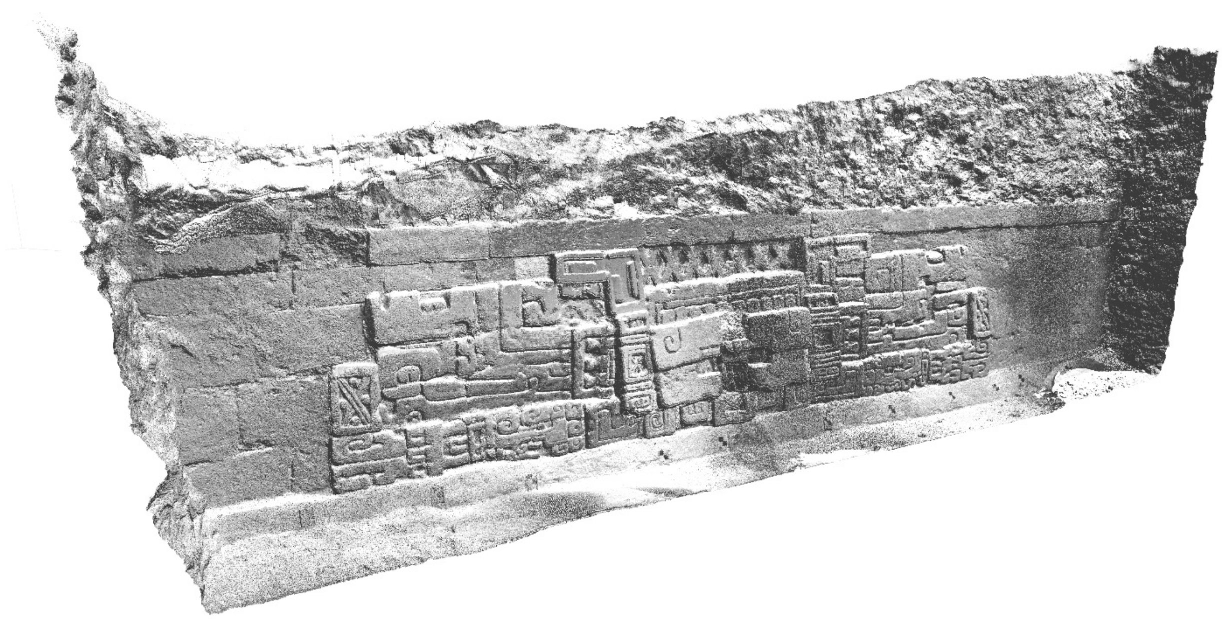

Figure 10. Sculptural relief point cloud model.

3.3 Following up the Excavation of an Architectural Complex

Interpreting the remains of a large architectural complex buried for centuries under later buildings during an excavation is an intricate task due to the need to relate parts of the building that usually appear in trenches distant from one another.

After the experience gained in documenting the exposed architecture, it was decided to experiment an excavation follow-up procedure of the 6J2-Sub2 building, discovered under the west wing of the Acropolis quadrangle. For this purpose we designed and applied another specific methodology to survey the process of the archaeological works with active sensors and on a daily basis.

The aims of this experience were to: (1) support archaeologists in the interpretation and formulation of hypotheses about the architectural remains of the 6J2-Sub2 building by providing daily graphical material to spatially relate all the elements of this earlier building to each other and to the superimposed buildings; (2) adjust the planning of the following excavation operations based on the results obtained; and (3) perform a detailed documentation specifically addressed to the architectural remains as they appeared during excavation.

For this follow-up procedure, 5 to 7 scans per workday were collected, processed, and aligned to the reference system in a master file containing the 6J2 west wing. In this case, the laser scanner was set to 1/4, 1/5 or 1/8 resolution depending on the distance between the objects and the sensor. It was also set to 3x quality to reduce the scanning time to less than 5 minutes, thus obtaining reasonable file sizes that could be processed quickly. Data collection was generally performed at noon, during the lunch break, and was completed in no more than forty minutes, so as not to interfere with excavation operations. Although, in case of relevant findings, data collection was repeated at the end of the daily work.

Correct alignment of the scans, which was conducted during a daily phase of laboratory work after the fieldwork, was ensured by a series of targets fixed to the pillars of the 6J2's protective roof and used during the 17 days of scanning.

The daily routine consisted of the following steps:

(1) Data collection.

(2) Data transfer to the computer.

(3) Data import and filtering.

(4) Alignment of the new point clouds to the master file, organized in layers per day.

(5) Extraction of a set of screenshots to relate the findings to each other, and to the rest of the Acropolis buildings (Fig. 11).

The master file of the excavation season was built by importing the west wing of the Acropolis point cloud from the general architectural database, and progressively aligning all the daily collected point clouds to it. Thus, all the architectural findings of the ongoing excavation were referenced to each other and to the building above.

The screenshots extracted daily from this master file provided the team with scaled plans and elevations (Fig.11) for analysis. Interpretation of these illustrations was very useful for ongoing assessment of the excavation and planning the next day's operations as illustrated in the following two examples.

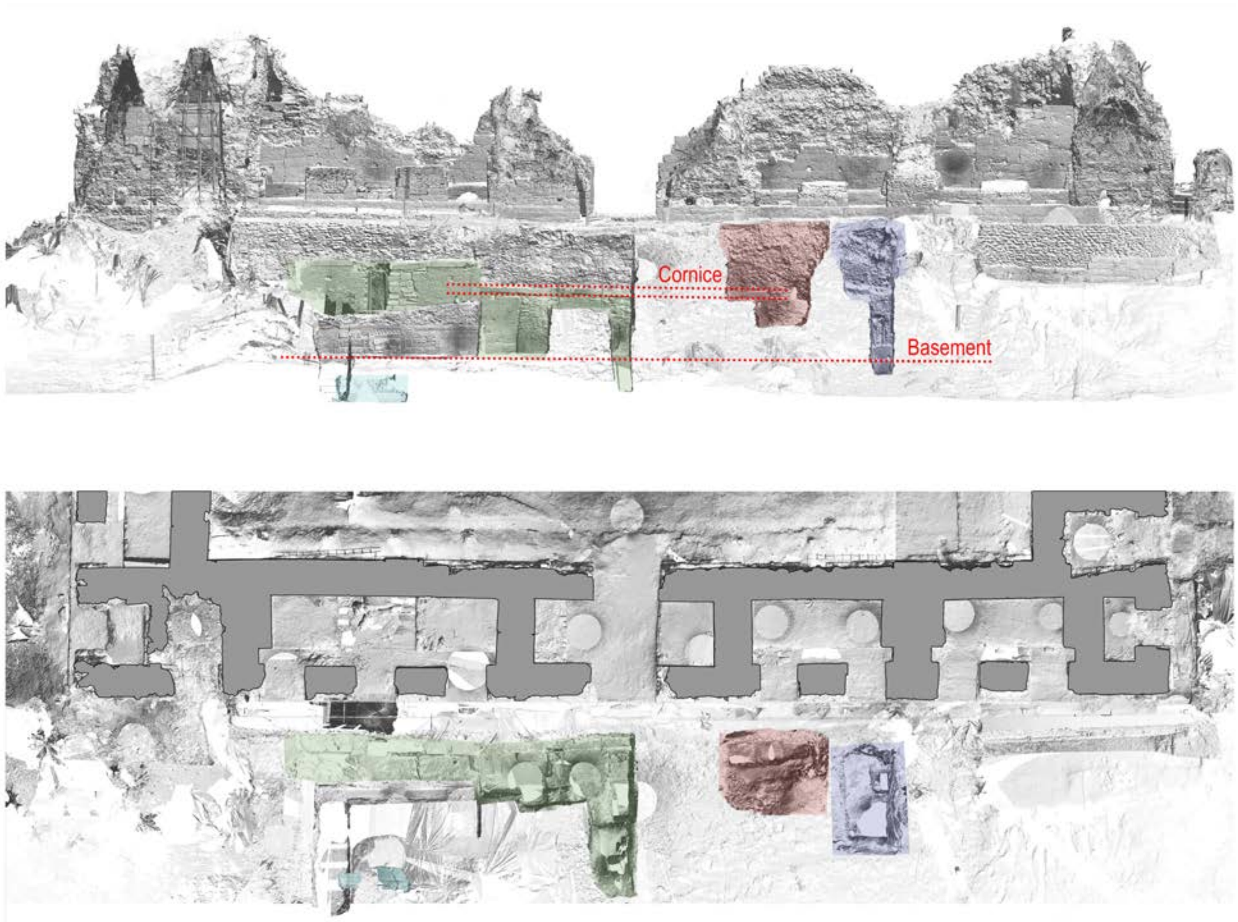

Figure 11. Plan and elevation of a workday excavation in 2015.

In the 2015 field season, the exploration of the 6J2-Sub2 building led to discover, in two distant isolated trenches, a cornice that might belong to the same section of a building. The application of this follow-up methodology facilitated verifying that indeed they were perfectly aligned and thus belonged to the same building (Fig. 11). Therefore, it was decided to extend the trenches in order to reveal the entire façade of the building and search for the possible entrance openings. Similarly, thanks to this methodology we verified that a basement with a drainage hole found in a trench located further south was perfectly aligned with the basement of the building 6J2-Sub2, so it was interpreted as part of the same structure (Fig. 11).

Due to the success of this first experience, this methodology of monitoring the excavation of the buildings with laser scanner was definitively implemented for the following excavation campaigns at La Blanca. It was also improved over the years, for example in 2016 the classic 2D targets were replaced by expanded polystyrene spheres that are automatically recognized by the point cloud management software, further speeding up daily data processing.

After each season of fieldwork, the parts of the point clouds with the relevant results of the excavation were selected and imported into the general architectural digital database.

4. RESULTS

The architectural digital database of La Blanca is a 3D repository in which the most relevant survey data regarding the architectural features excavated in each field season are collected once filtered and processed. Thus, it offers a storage system for all the results of the architectural documentation located in the same reference system, which allows the analysis, comparison, and exploitation of the data as a whole.

This repository includes also the elements that, after being excavated and documented, were reburied to ensure their preservation, as the building 6J3 or the sculptural relief of 6J2-Sub2. Therefore, rather than an updated model of the excavation, this digital database is a 3D anachronic archive of all the architectural findings, interventions, and results of the excavation process.

It is stored and managed by the Leica Cyclone software. The choice of this software for storing the general point cloud is based on the greater manageability and editability of the point clouds it offers compared to other similar programs. The .imp file is organized by layers corresponding to different excavation stages and campaigns, which can be turned on and off to display or export to other applications the parts of the model required in each case (Fig.12).

This database has been progressively built up over the course of successive field campaigns. The starting point was the whole model of the Acropolis built between 2012 and 2015 (Fig. 6). During each excavation season, all the collected point clouds were included in a master file containing part of this initial model as a reference. For example, during the excavation campaigns of the building 6J2-Sub2, located under the west side of the Acropolis platform (Fig. 11), the master file of the season contained the west wing of the Acropolis quadrangle, and every single point cloud was referenced to it.

After each season of fieldwork, the parts of the collected point clouds with the most relevant results regarding architecture were finally imported into the general database. The selection excludes repeated recordings of the same architectural element at close stages of excavation, thus avoiding data redundancies. Aside from the architectural general database, every season master file containing all the collected scans is also stored safely, so they can be accessed at any time if needed.

The final file thus stores a digital 3D copy of all the architectural remains found over the years in this long-term excavation. Besides serving as a storage of the survey results, this digital database allows to extract the 2D and 3D elements needed for processing with CAD drawing and 3D reverse modelling programs. Therefore, it is the starting point for generating all the graphic outputs to:

- Plan the following excavation campaigns. The possibility of analyzing all the excavated architecture as a whole facilitates the formulation of more accurate hypotheses about what remains to be excavated, as well as the identification of priorities for future campaigns according to the research questions raised.
- Monitor the state of conservation of the exposed buildings, measuring possible movements by comparing documentation from different years. This is of particular relevance on a long-term conservation project and especially useful when performing maintenance and replacement works on the site's protective roofs (Fig. 5).
- Analyze in depth the architectural remains from a typological, formal, and constructive point of view, including those no more exposed. Since burial is a cost-effective and practical form of conservation in challenging situations, the creation of a digital copy of the known part of the buildings is a necessity for research to continue.
- Disseminate research results by rendering, videos, VR (Virtual Reality), AR (Augmented Reality) applications or 3D printing for public display, which contributes to the local population engagement with the site.

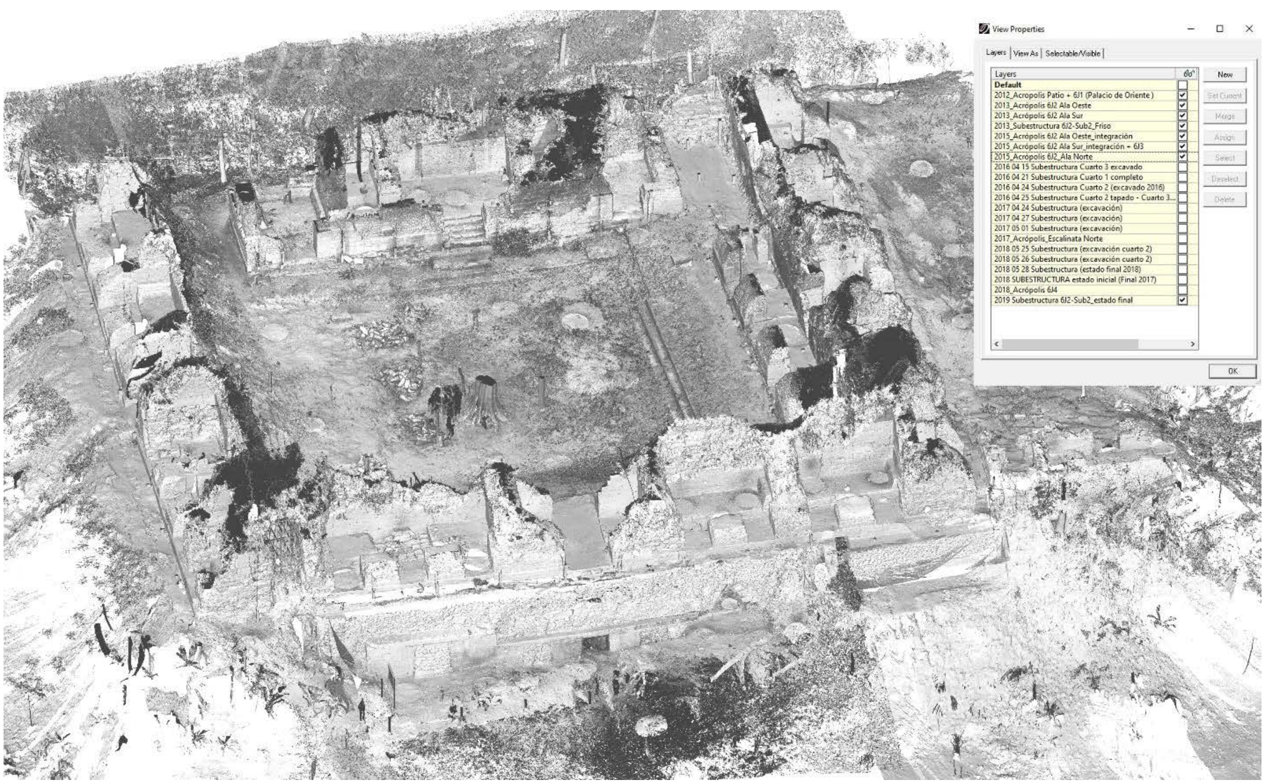

Figure 12. View of the architectural digital database of the excavation.

One of the most innovative outputs of this laser scanning database was the creation of a physical model of the Acropolis through 3D printing, which was installed as a didactical resource at the site's visitor center. For this purpose, we developed a reverse modeling workflow to create a virtual replica of the Acropolis optimized for 3D printing, i.e. without any holes or boundaries and consisting of a sufficiently limited number of polygons to be printed with Fused Deposition Modeling (FDM) technology while ensuring high geometric fidelity at the selected printing scale[5] (Fig. 13).

This reality-based 3D model not only improves the understanding of the architecture of La Blanca and shares the results of the research project, but also contributes to the valorization of this heritage. The 3D printed model is used as a dissemination resource for visitors (Fig. 14), who can obtain information about both the site and the excavation project. Through the model it is possible to find correspondences with the images shown on the panels, as well as providing a better understanding of this architectural complex. The model is also used as an educational resource for local schools, which often take children to the site for field practice on the history of Maya civilization. It is a useful tool to sensitize the younger generations to the preservation and appreciation of their cultural heritage. Furthermore, it also represents an enhancement of the didactic resources available to local tour guides, who use it as a tool to explain the unique architectural features of the Acropolis and the ongoing excavation project to tourist visitors.

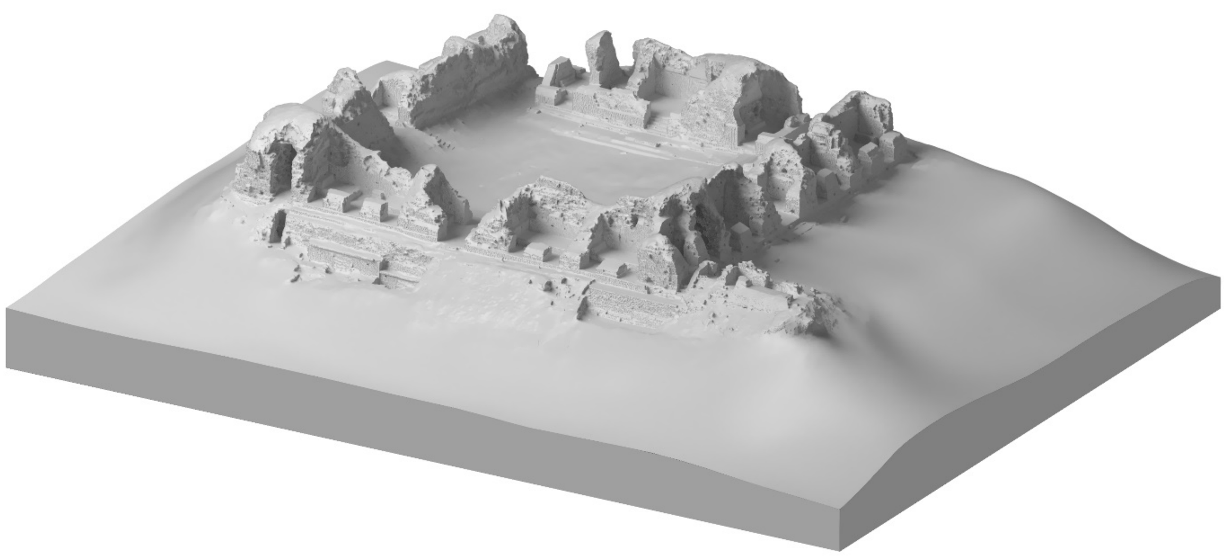

Figure 13. 3D model of the Acropolis obtained by reverse modeling.

[5] Methodology and procedures for obtaining this printable model were shared and discussed at the *HERITAGE2020 International Conference on Vernacular Architecture in World Heritage Sites. Risks and New Technologies* [Montuori et al. 2020]

Figure 14. 3D printed model of the Acropolis installed in the La Blanca Visitor Centre as a resource for dissemination, 2017.

5. DISCUSSION AND CONCLUSIONS

The main purpose of documentation is to keep a record of all the actions and studies conducted on cultural heritage, a legacy that must be transmitted to future generations. Digital techniques offer the opportunity to achieve digital copies of objects with a high level of detail and accuracy, and allow to obtain numerous graphic outputs highly useful for research, conservation, management, and dissemination. However, this increasingly large three-dimensional documentation must be structured to ensure that the data can be accessed and used over time, avoiding loss or deterioration.

The importance of recording plays also a key role in the promotion of the economic value of cultural heritage. For this purpose, it is necessary to create digital databases and inventories, which need to be correctly managed, as well as make them publicly available. Thus, only the correct management and dissemination of the information related to cultural heritage turns into its adequate identification, interpretation, and preservation [Lourenço et al. 2010].

In the field of archaeological heritage, protection and conservation actions must be based upon its fullest possible knowledge, so that survey plays a major role [ICAHM 1990]. In the special case of Maya sites, whose research is carried out through long-term archaeological excavations and often in challenging conditions, it is of great importance to follow a rigorous methodology of documentation. In addition, it becomes essential to develop an efficient system for storing and managing the large amount of data obtained, which enables its agile and systematic consultation and exploitation.

The architectural digital database of La Blanca allows the investigation of the remains right after excavation, a factor in which lies to a great extent their historical and scientific value [ICOMOS 2017]. It becomes an updatable digital data repository and represent a very rich source of documentation of this architecture at risk, which can be further used for research, conservation, and management purposes, as well as for developing dissemination strategies for both the general and specialized public. It also ensures the long-term stability and accessibility of the digital records.

This 3D model offers the possibility of visualizing all the architecture results of the excavation at the same time, regardless of whether the remains are visible or had to be reburied to ensure their preservation. Combining datasets from several field seasons in a single repository allows for a more accurate planning of the excavation of the missing –or yet unknown– parts of the architectural remains in subsequent campaigns, as well as working at different scales and levels of detail. Furthermore, in an architectural complex with several construction phases such as the Acropolis of La Blanca, it is particularly important to have the digital buildings models in the same reference system in order to study the geometric relationships between the superimposed buildings and analyze how the Maya builders conducted this practice of reuse and build on the built.

The range-based documentation of the buildings is complemented by a photogrammetry survey to also obtain the chromatic data of the buildings. This is especially important when there are stucco or mural painting remains. These image-based models are processed, scaled and aligned to the general database reference system after each field season, and then safely stored to be ready-to-use.

The methods and procedures presented here are applicable to other archaeological contexts, especially fragile sites and endangered architecture where digitation contributes an important record.

Finally, we would like to emphasize the importance of research and documentation of Maya architecture, not only for its high cultural value, but also for the great possibilities it offers as an engine for the economic and social development of the surrounding communities, the main heirs of this legacy.

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