Actas del Primer Congreso Internacional
de Buenas Prácticas en Patrimonio Mundial:

# Arqueología

Mahón, Menorca, Islas Baleares, España 9-13 de abril de 2012

Proceedings of the First International Conference
on Best Practices in World Heritage:

# Archaeology

Mahon, Minorca, Balearic Islands, Spain 9-13 April 2012

Alicia Castillo (Ed.)

Editora Complutense

## Organiza

## Patrocina

## Colabora

ICOMOS ESPAÑA
ICOMOS ICAHM. INTERNATIONAL COMMITTEE ON ARCHAEOLOGICAL HERITAGE MANAGEMENT

**Edita:** Universidad Complutense de Madrid

**Diseña:** Imprenta Taller Imagen, s.l.
**ISBN:** 978-84-695-6782-1
**Depósito Legal:** SG.155/2011

## Comité organizador:

### Directoras científicas:

- Alicia Castillo, Investigadora Postdoctoral - Profesora del Departamento de Prehistoria. Universidad Complutense de Madrid
- Mª Ángeles Querol, Catedrática del Departamento de Prehistoria. Universidad Complutense de Madrid

### Secretaria científica:

- Isabel Salto-Weis. Profesora Titular del Departamento de Lingüística Aplicada. Universidad Politécnica de Madrid

### *Representantes del Instituto Menorquín de Estudios:*

- Margarita Orfila Pons. Catedrática del Departamento de Prehistoria y Arqueología. Universidad de Granada
- Clemen García, Institut Menorquí d'Estudis

### *Representantes del Consell de Menorca:*

- María Nieves Baíllo Vadell, Consejera de Cultura, Patrimoni i Educació del Consell Insular de Menorca
- Simón Gornés. Técnico arqueólogo.
- Joana Gual Cerdó. Técnica arqueóloga

### *Representante del Pla de Dinamització del Producte Turístic de Menorca:*

- David Vidal, gerente

## Comité de Honor:

- Bauzá Díaz, José Ramón. Presidente del Govern de les Illes Balears
- Tadeo Florit, Santiago. Presidente del Consell Insular de Menorca
- Carrillo Menéndez, José. Rector de la Universidad Complutense de Madrid
- Bokova, Irina. Directora General de la United Nations Educational, Scientific and Cultural Organization (UNESCO)
- Prieto de Pedro, Jesús. Director General de Bellas Artes y Bienes Culturales del Ministerio de Cultura
- Ricard, Denis. Secretario General de la Organización de las Ciudades del Patrimonio Mundial (OCPM)
- Mayor Zaragoza, Federico. Ex director General de la UNESCO
- Araoz, Gustavo M. Presidente del Consejo Internacional de Monumentos y Sitios (ICOMOS)
- Suárez-Inclán Ducassi, Rosa María. Presidenta del Comité Español del Consejo Internacional de Monumentos y Sitios (ICOMOS)

## Comité científico:

- Albert, Marie Therese. Dr. Professor and Holder of UNESCO Chair. Brandenburg University of Technology, Cottbus, Germany
- Arsuaga, Juan Luís. Dr. Codirector del yacimiento de Atapuerca. Catedrático de Paleontología de la Universidad Complutense de Madrid, España
- Barceló, Juan Antonio. Dr. Profesor de Prehistoria. Universitat Autónoma de Barcelona, España.
- Bordoni, Luciana. Patrimonio Culturale. Italian National Agency for new technologies, energy and the environment (ENEA- FIM), Italy
- Comer, Douglas C. Dr, RPA Principal, Cultural Site Research and Management, Inc. (CSRM), Co-president ICHAM. USA
- Criado Boado, Felipe. Dr. Director del Instituto de Ciencias de Patrimonio, Incipit, CSIC, España.
- Doglioni, Francesco. Dr. Architect. Professor. Università IUAV di Venezia, Italy
- Fernández Cacho, Silvia. Dra. Jefa del Centro de Documentación y Estudios, Instituto Andaluz de Patrimonio Histórico, Sevilla
- Gándara, Manuel. Dr. Arqueólogo. Profesor-Investigador, Posgrado en Arqueología, ENAH/INAH, México
- Gavua, Kodzo Dr. Professor.Department of Archaeology and Heritage Studies, University of Ghana
- Inaba, Nobuko. Director/Professor, World Heritage Studies, Graduate School of Comprehensive Human Sciences University of Tsukuba, Japan
- Lasheras, José Antonio. Dr. Director del Museo Nacional y Centro de Investigación de Altamira. Ministerio de Cultura, España
- Lilley, Ian. Dr. Professor FSA. Aboriginal and Torres Strait Islander Studies Unit,The University of Queensland, Brisbane, Australia
- Martinho Baptista, Antonio. Pré-Historiador de Arte. Parque arqueológico do Vale do Côa. Secretaria de Estado da Cultura. Portugal
- Mateos, Pedro. Dr. Científico Titular CSIC. Director del Instituto Arqueológico de Mérida, España.
- Mora Alonso-Muñoyerro, Susana. Dra. Profesora de la Escuela Técnica Superior de Arquitectura. Universidad Politécnica de Madrid, España

- Murillo, Juan. Dr. Arqueólogo. Director Gerencia de Urbanismo del Ayuntamiento de Córdoba, España
- Musiba, Charles. Dr. University of Denver, Colorado, USA. Co-founder of the Tanzania Field School in Anthropology
- Rodríguez Alomá, Patricia. Arquitecta. Doctora en Ciencias Técnicas, Directora de Plan Maestro. Oficina del Historiador de la ciudad de La Habana, Cuba
- Santana Quintero, Mario. Dr. Rymond Lemaire Centre for Conservation, university of Leuven (Belgium)-President ICOMOS scientific committee on heritage documentation (CIPA)
- Shady Solís, Ruth. Dra. Aqueóloga. Antropóloga. Catedrática. Universidad Mayor de San Marcos (Perú). Directora del Projecte Especial Caral-Supe
- Silverman, Helaine. Dr. Professor, Department of Anthropology, University of Illinois. Director, CHAMP (Collaborative for Cultural Heritage and Museum Practices), USA
- Sivan, Renée. Museologist. Chief curator of the Tower of David Museum - Jerusalem Israel. Heritage Presentation Specialist
- Villafranca Jiménez, María del Mar. Directora del Patronato de la Alhambra y el Generalife, Granada, España
- Willems, Willem. Dr. Dean, Professor of Archaeological Heritage Management Leiden University (UL), Leiden, the Netherlands. Co-President of ICAHM

# Terrestrial Laser Scanning and Digital Photogrammetry as Tools for the Archaeological Recording – The Case of Convento de Cristo

## *Escaneado láser terrestre y fotogrametría digital como herramientas para el registro arqueológico, el caso del Convento de Cristo*

L. Mateus (1), V. Ferreira (1), J. Aguiar (1), A. Dias (2)
(1) TU of Lisbon – Faculty of Architecture, Alto da Ajuda (lmmateus, victor, jaguiar)@fa.utl.pt
(2) IGESPAR, Palácio Nacional da Ajuda – Lisboa, acdias@igespar.pt

**Abstract**
The "Convento de Cristo", located in the city of Tomar, represents the best that has been produced in the history of Portuguese architecture. This monumental site, built between the 12th and 17th century, includes a Templar castle and a convent of the Order of Christ, and is classified as World Heritage by UNESCO since 1983.
In this paper we intend to discuss the potential and usability of the methods and tools of digital photogrammetry and terrestrial laser scanning (TLS) to the recording and production of base documentation as support to heritage interventions. A set of documentary case studies accomplished in this monumental site will be presented.
In these case studies documentation for stratigraphical analysis prior to Rehabilitation and Restoration planning design, was produced regarding the knowledge of the historical and cultural evolution of the site. The archaeological recording was done at the level of deposits and walls. In the same context, documentation as support to Conservation interventions was also produced.
The following approaches were used: i) rectified photography as a low-cost and very practical method, ii) automatic three dimensional reconstruction from multiple images with the state-of-the-art structure-from-motion (SFM) software VSFM (Visual SFM), followed by a dense reconstruction with the multi-view-stereo software CMVS+PMVS, in a approach that minimized the processing time, maintaining quality of output, iii) TLS as a tool for geometric and radiometric survey, iv) image interpretation and processing of TLS reflectance images as a tool for the differentiation of materials and constructive systems and assessment of the conservation state. Three dimensional data enabled spatial comparison between the phases of excavation.
The complimentary potential between the techniques of TLS and automatic photogrammetry was demonstrated by using low altitude aerial images (taken with helium balloon with remotely controlled digital camera) allowing a more comprehensive documentation, in particular in those situations where TLS presents limitations (higher parts of buildings).
Interpretation and processing of TLS reflectance images was demonstrated to be a valid tool for the inquiry of the architectural object that allows one to extract relevant information both for Archaeology and Conservation. It was possible to distinguish between several types of joints (even to perceive early interventions done with cement mortars), to detect several constructive patterns through the analysis of the stone cuts, to calculate a vegetation index, and to differentiate between organic and inorganic materials.

**Key words:** Terrestrial laser scanning, automatic photogrammetry, stratigraphic analysis, recording

**Resumen**
El Convento de Cristo, situado en la ciudad de Tomar, representa el mejor ejemplo en la historia de la arquitectura portuguesa, de un conjunto monumental construido entre los siglos XII y XVII que incluye un castillo templario y un convento de la Orden de Cristo. Está declarado Patrimonio Mundial desde 1983. En este artículo nos proponemos analizar el potencial y la utilidad de los métodos y herramientas de fotogrametría digital y el escaneo



Actas del Primer Congreso Internacional de Buenas Prácticas en Patrimonio Mundial:Arqueología 400-412

ISBN: 978-84-695-6782-1

láser terrestre (ELT) para la elaboración y producción de documentos que son la base de las intervenciones en el Patrimonio, así como su apoyo.
Los estudios que se presentarán consisten en la documentación para el análisis estratigráfico previo a la rehabilitación y al proyecto de restauración, en relación con el conocimiento de la evolución histórica y cultural del lugar, en el registro arqueológico que se realiza a nivel de los depósitos y de las paredes, y en la documentación de apoyo a las intervenciones de conservación.
Se utilizaron los siguientes métodos de registro: i) la fotografía rectificada como un método de bajo costo y muy práctico, ii) reconstrucción tridimensional automática a partir de varias imágenes con el software VSFM, seguido por una reconstrucción densa con el software PMVS, en un enfoque que minimiza el tiempo de procesamiento, manteniendo la calidad de los productos documentales, iii) ELT como una herramienta para el levantamiento geométrico y radiométrico, iv) la interpretación y procesamiento de imágenes de reflectancia del ELT. Los datos tridimensionales permitirán una comparación espacial entre las fases de excavación. La complementariedad entre las técnicas de la fotogrametría automática y del ELT se demostró mediante el uso de imágenes aéreas de baja altitud (tomadas con un globo) que permitirán una documentación más completa, en particular en aquellas situaciones en las que el ELT presenta limitaciones (en altura).
La interpretación y procesamiento de imágenes de reflectancia del ELT, ha demostrado ser una herramienta válida para la investigación del objeto arquitectónico, que permite extraer información relevante tanto para la Arqueología como para la Conservación. Es posible distinguir entre varios tipos de juntas (incluso percibir las intervenciones tempranas realizadas con mortero de cemento), para detectar varios patrones constructivos, a través del análisis de los cortes de piedra, para calcular un índice de vegetación, y para diferenciar entre materiales orgánicos e inorgánicos.

**Palabras clave:** Escaneado láser terrestre, fotogrametría automática, análisis estratigráfico, registro

## 1. Introduction

According to the ICOMOS "Charter for the protection and management of the archaeological heritage" [1] the knowledge of archaeological heritage should be based on the principle of systematic recording. Additionally it recommends that non destructive techniques should be used whenever it is possible. On the other hand, the recognition of value on a structure also relies on the documentation about it. And that documentation should be reliable and trustful. In other words, and according to the Nara [2] document, it should be clear the relation between information and the real object. In our opinion, the use of indirect methods of documentation [3] [4] can be part of a strategy that could lead us to those purposes since they enable a comprehensive recording of the structures, in a preliminary stage, without interpretation. This does not mean that interpretation should not exist. In fact it has to exist.

The archaeology of architecture must be understood as part of a broader process of knowledge that has as ultimate goal the definition and implementation of conservation measures. One can state that the understanding of the built structure can be achieved with a systematic approach encompassing analysis models. And stratigraphical analysis is one of those models. Other models are iconic analysis, distributive analysis, material and constructive analysis, state of conservation analysis, and structural analysis [5].

Being World Heritage, it must be assured that fundamental values are not put into question. But it should also be assured that proper conditions are given to people that wish to visit the monument and wish to know more about it.

Currently, there are several areas in the convent that are not accessible to the public. Some of those areas are not accessible for security reasons and others are not accessible because the visiting circuit is not compatible with that access. In order to improve those conditions it was decided by IGES-



ISBN: 978-84-695-6782-1

PAR (Portuguese Institute for the Management of Architectural and Archaeological Heritage) to improve the visiting circuit of the monument as well as the accessibility conditions. For that reason, stratigraphic analysis of the areas under intervention was mandatory.

## 2. The Templar Castle and the"Convento de Cristo"

The first king of Portugal, D. Afonso Henriques donates the "Ceras" Castle and a vast territory to the Order of the Temple (or Order of the Templar Knights) in 1159. Master Gualdim Pais (Portuguese master of the Templars), chose an elevation looking to the Tomar river, presently know as Nabão, situated 15 Km north of Tagus river, to build the new Portuguese headquarters for the Order of the Temple. The geomorphology of the hill, with good platforms to establish a military structure, controlling fertile lands, with a plentiful water supply and traces of old settlements, namely in the left bank of the Nabão river, where a "civitas de Sellium" and several Muslim remains, identified on the present historical centre of Tomar, must have contributed to that choice. The construction of Tomar Castle started in 1160.

The analysis of the Tomar castle and the entire walled perimeter allows us to say that the area of the Templar Castle was an entirely medieval creation, an establishment from scratch [6]. Eventually it could have had previous occupations, namely in the Castle area, that was never subject of archaeological excavations. However, all the military structure seems to correspond to a well thought-out programme, delineated and whose military architecture planning has been executed all at once, stating the significance of the Order of the Temple and aiming at populating and defending a border territory [7].

The Tomar Castle was organized in three spaces separated by walls:

- The "Alcáçova" (citadel) delimited to the east by the castle and to the west by the Romanesque church, better known as "Charola". This area was reserved to the Order.
- The central courtyard, where the surrounding population gathered in case of attack or siege.
- The "Almedina" residential area corresponded to the village within the walls.

In the 15th century, under the administration of "Infante D. Henrique", the "Alcáçova" will suffer changes with the construction of new buildings that improve life in the convent. Besides the "Charola", the "Claustro do Cemitério" (cemitery cloister) is built, followed by the "Claustro da Lavagem" (washing cloister), S. Jorge chapel and the "Paços Henriquinos" (Henry the Navigator manor house). In the south side, these constructions make use of the wall that separated the main courtyard from the "Alcáçova".

In the 16th century, King D. Manuel orders the inhabitants of the inner walls village to leave, making the walled perimeter reserved access to the Order of Christ. He expands the "Charola" to the west, with the construction of a huge nave and starts the construction of the "Casa do Capítulo" (chapter house) that will never be finished. He renovates and widens the "Paços Henriquinos". The west side of the wall was destroyed to enable the construction of the "Nave Manuelina".

As the castle loses its military relevance, new buildings will appear, related to the life in the convent and the prestige of the King.

With the king D. João II, the so called "Convento Novo" (new convent) was built - five new cloisters and the "Necessárias" building (toilets building). In the 17th century, the aqueduct and the monks infirmary are built, completing the built complex that we call today "Convento de Cristo", being a medieval military structure, to which new


Actas del Primer Congreso Internacional de Buenas Prácticas en Patrimonio Mundial:Arqueología 400-412

ISBN: 978-84-695-6782-1

conventual constructions were attached and added to the west and north. In figure 1 these areas of "Convento de Cristo" are depicted.

The "Convento de Cristo" is a monument that was occupied for a long period of time, at least from the 12th century to the 17th century, showing growth of the building complex to the west and north, with the maximum use of the top of the hill and the half hillside (south and west sides). For that to happen it was necessary to level the terrain irregularities, trough different methods, available at the time, for instance: the construction of two buildings with two levels, taking advantage of the slope, with huge landfills and with the construction of a crypto portico.

Besides this growth in the horizontal, several buildings suffered changes - ruptures, demolitions, additions that oblige us to record thoroughly the walls to interconnect this wall stratigraphy to the deposits stratigraphy.

### 3. Recording methods overview

Traditionally the archaeological record is done with direct survey techniques. Usually a grid is materialized in the site related to a previously defined coordinate system. Measurements are taken and recorded on paper in order to depict the site stone by stone. This means that the work in the field is more intrusive and takes long periods of time with many operators. It also means that there are options about the discretization of the object that have to be decided in the field. This approach is both valid for the planimetric and altimetric recording.

With the use of a total station it is possible to consider the grid only virtually. This

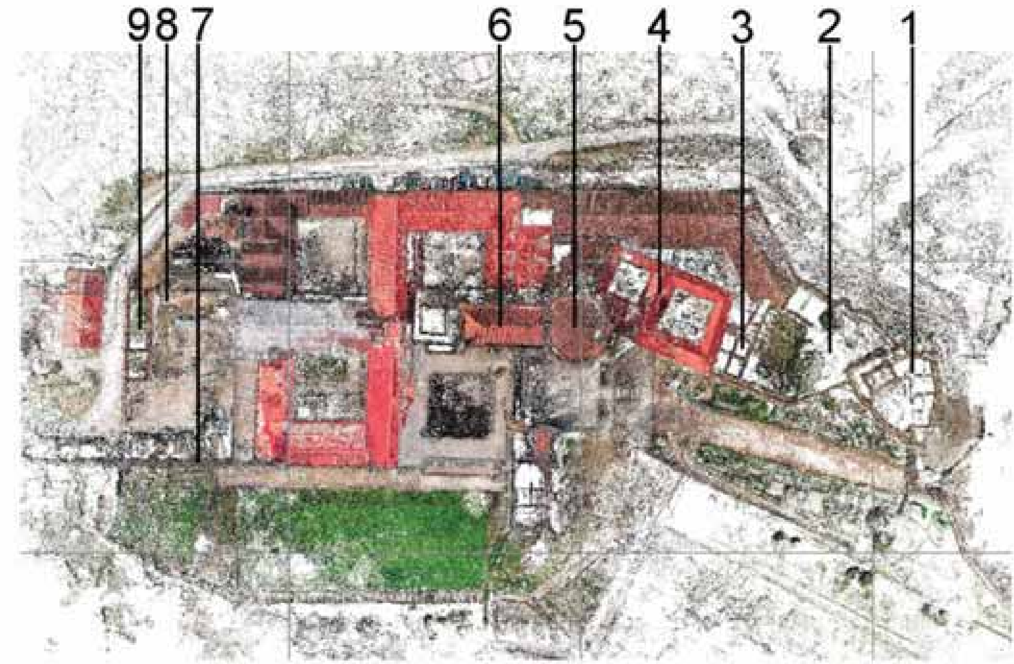


Figure 1. Planimetric view of "Convento de Cristo" automatically processed with 1154 images. (1) Templar Castle, (2) "Alcáçova", (3) "Paços Henriquinos", (4) "Claustro da Lavagem" e "Claustro do Cemitério", (5) "Charola", (6) "Nave Manuelina", (7) Aqueduct of "Pegões", (8) "Necessárias" in "Pátio dos Carrascos", (9) agricultural house.



ISBN: 978-84-695-6782-1

means that after the moment that the coordinate frame is set, measurements can be done directly from the view point of the instrument. This is less intrusive but it is still very time consuming, and individual measurements for each point have to be done.

With indirect methods of recording large amounts of data are recorded in the field and information selection occurs in the office. Digital photogrammetry and Terrestrial Laser Scanning (TLS) are such methods. The difference between these is that photogrammetry is passive and image based and TLS is active and range based [8].

A TLS scanning system uses an internal source of laser radiation that is used to measure distances from the device to the object with a very high rate and almost in real time [9]. Since it has its own source of energy, a TLS system can be used even at night. To enhance the semantic quality of gathered data, radiometric information from images can be associated with point cloud data.

One can divide photogrammetry into 2D (two dimensional) and 3D (three dimensional). In the first case images are only manipulated in two dimensions. It is the case of rectified images and photo-mosaics. In the second case images are used to reconstruct the three dimensional geometry of the objects represented in the images. The photogrammetric work-flow consists on camera calibration, relative orientation, external orientation and geometry reconstruction. Until recent times these steps were done manually (with tools like Photomodeler) or semi-automatically (with tools like Image Master). But today it is possible to perform

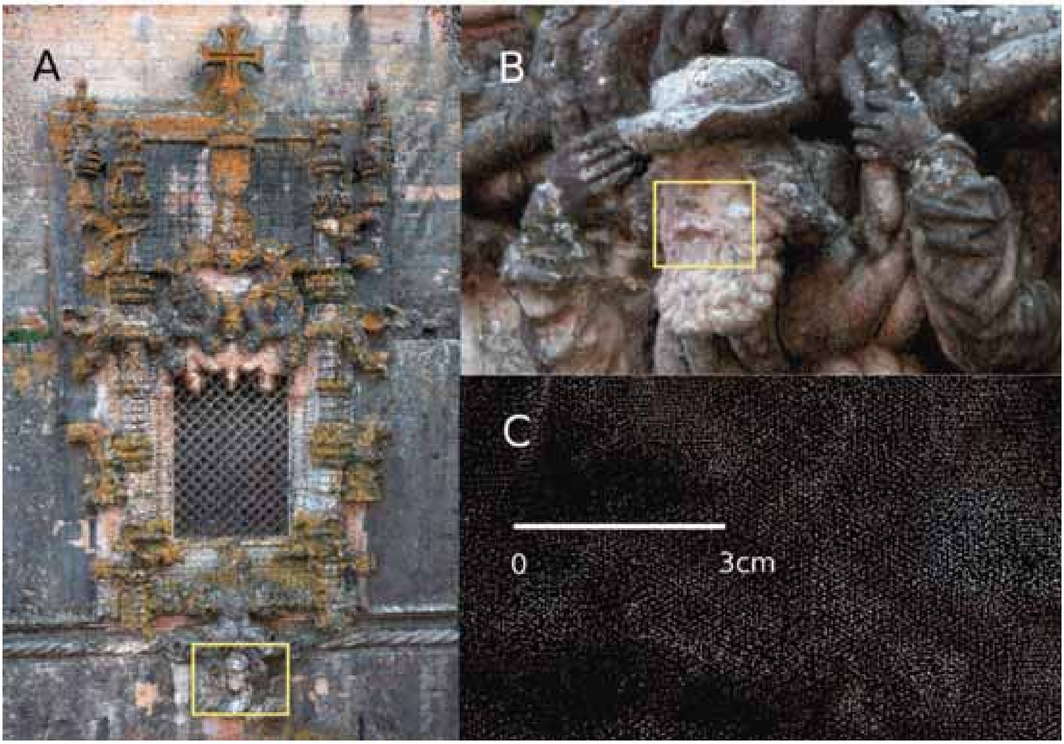


Figure 2. Detailed view of point cloud data from “Janela Manuelina” in “Convento de Cristo” processed with 543 images.



Actas del Primer Congreso Internacional de Buenas Prácticas en Patrimonio Mundial:Arqueología 400-412

ISBN: 978-84-695-6782-1

all those steps in a full automatic way, for instance with the Structure from Motion (SFM) and Multi-view Stereo (MVS) methodologies (with tools like VisualSFM [10] and PMVS/CMVS [11]) being able to deal easily with several hundred images simultaneously. We refer to this form of photogrammetry as Automatic Digital Photogrammetry (ADP) although this is not a common designation. This possibility really represents a new field of opportunities for the archaeological recording.

The result of TLS and ADP recording are point clouds. The point clouds of ADP have the advantage that radiometric information from images is inherently associated to the calculated points during the processing. With TLS, even if the systems have cameras incorporated, there are always two distinct moments to consider: i) geometry acquisition, and ii) color acquisition. Nevertheless, colour mapping can be done automatically.

The advantage of TLS and ADP is that they shorten those repetitive steps (point picking by the operator both in field and in office) what means that, at the end, more time is available for the important task, the analysis of the built structure.

It is interesting to underline that ADP is more versatile than TLS because it can cover a very large range of object and scene sizes, and with the same system one can document both large scale (figure 1) and small scale (figure 2) objects.

## 4. The documented areas of "CONVENTO DE CRISTO"

Mainly, there were two areas under analysis: i) "Paços Henriquinos" (figure 3A) where a new reception is being planned, and ii) "Pátio dos Carrascos" (figure 3B) where the future circuit of visitation will end.

In both areas a TLS survey was accomplished prior to excavations. The main purpose of that survey was to document the present state and to serve as basis for the production of the elements for design planning. From that survey, plans, elevations and sections were produced. One of the first uses of those elements consisted on the planning of excavations.

### 4.1. "Pátio dos Carrascos"

The "Pátio dos Carrascos" is located in the west limit of the convent. It is a big courtyard that was related to the agricultural life. To the north, it is limited by the building of "Necessárias", to the east by the cloister of "Corvos", to the south by the aqueduct of "Pegões", and to the west by a ruin of an agricultural house of the 19th century (figure 1 and figure 3B).

The purpose of the stratigraphical analysis in this area is to end the visiting circuit


Figure 3. "Paços Henriquinos" (A) and "Pátio dos Carrascos" (B)



ISBN: 978-84-695-6782-1

here and to restore the 19th century ruin, installing a small restaurant there, and a esplanade in the courtyard, where the visitors can enjoy the end of their visit. But to make sure that no relevant value is lost, proper documentation and investigation was required, namely about the surfaces that are directly affected by the architectural planning intentions.

Documentation for the stratigraphical analysis was produced with photogrammetric techniques since TLS equipment was not available at all times.

The walls that are almost flat could be properly recorded with rectified imagery and photo-mosaics, as it can be seen in figure 4, having topographic data as control information.

For the planimetric recording, rectified imagery was not very suited because there were no flat surfaces. So in this case we followed the SFM/MVS approach. We collected 176 images with 8Mp. All the images were processed, in a fully automatic way, with the software VisualSFM and PMVS/CMVS.

The first software estimates the camera calibration parameters and solves relative orientation between images. The result of these steps is a sparse point cloud model. The total amount of time consumed in this operation was about 26 minutes. Then the second software performs a dense point cloud reconstruction, also in a completely automatic way. The operator only has to choose the appropriate parameters. The parameters will have influence on the point cloud density, the level of reconstruction, and the time consumed. With the chosen parameters the dense reconstruction took about five hours to be completed. The result was a dense point cloud model with approximately 8 million points over an area of 110 square meters (7 points per square centimetre). The image of figure 5 corresponds to an ortho-image extracted from the point cloud data and its respective stratigraphical analysis.

This model was put to scale with topographic control points.

In the south façade of “Necessárias” we had evidence, given by negative and posi-

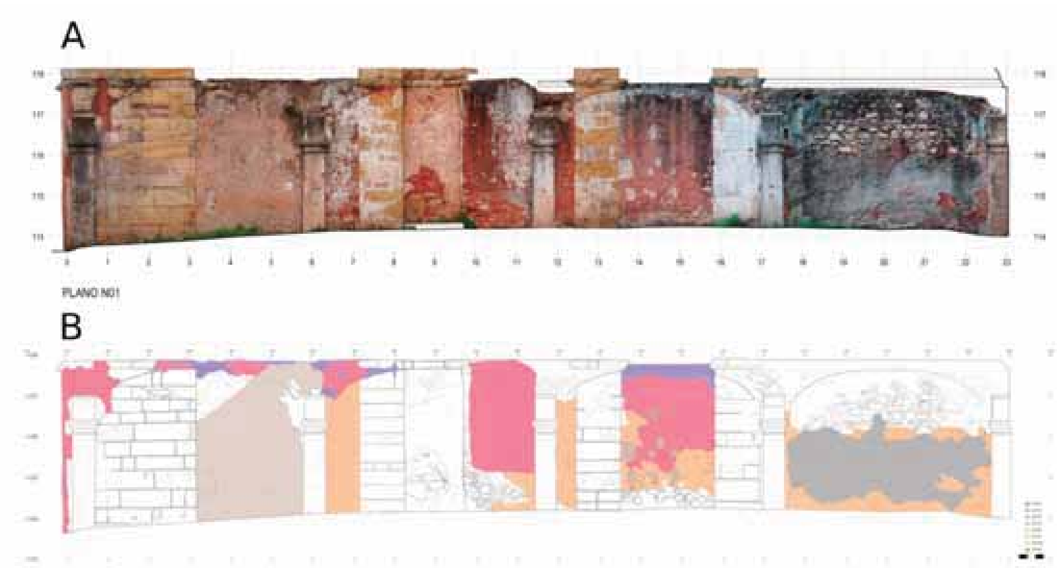


Figure 4. Photo mosaics of the south wall of “Necessárias” (A) and its stratigraphical analysis (B).


Actas del Primer Congreso Internacional de Buenas Prácticas en Patrimonio Mundial:Arqueología 400-412

ISBN: 978-84-695-6782-1

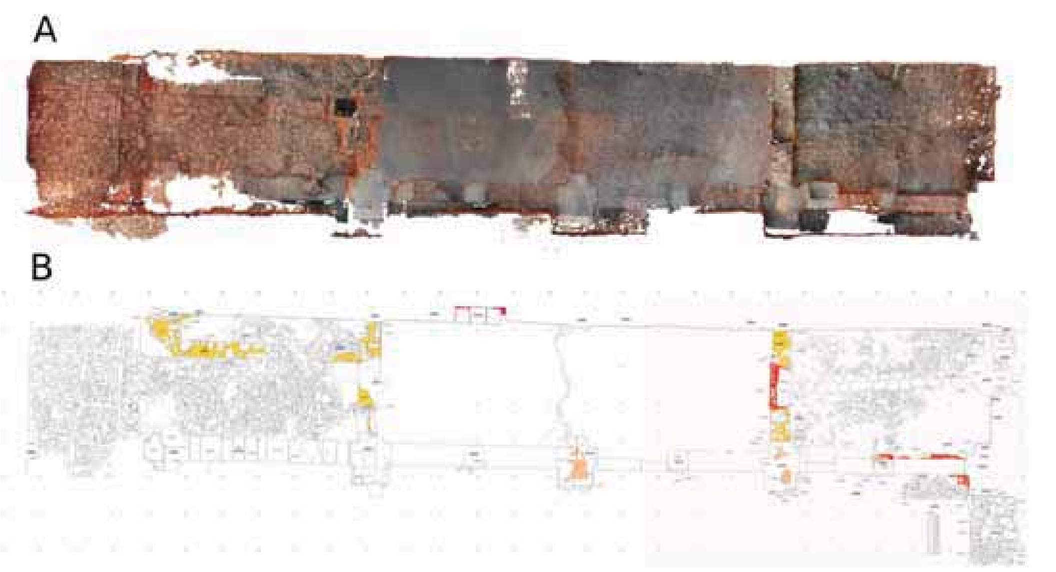


Figure 5. Point cloud ortho-image of the “Pátio dos Carrascos” (A) and its stratigraphical analysis (B)

tive elements, of a former arcade that was built against the wall at ground level. Beyond the material evidence we had access to an ancient photography where the arcade could be identified. And at the east top of the arcade of “Necessárias”, it was possible to identify a walled door.

Direct observation of the structure and other graphic sources gave us information about one or two arcades that connected the cloister of “Necessárias” to something that has been integrated into the house in ruins. We were interested to find if there were any remains of the arcades at south and to know what their state of conservation was. It was important to record all data about the walls and to relate that with any archaeological remains that could be uncovered. All the information was essential to inform the architectural planning about the restaurant and the esplanade. Stratigraphical units were defined over the drawings using a sequential numbering.

This kind of analysis is only possible with a detailed representation of the walls. To produce that with a traditional approach would be a cumbersome task and it wouldn’t be easy without scaffolding. Rectified imagery allowed us to draw with all the detail required.

With respect to the pavement, the followed approach (ADP) resulted in a much faster way of documenting. Additionally, it was possible to spend less money recording.

It was possible to identify the south side of the arcade as well as the original pavement. It was also possible to understand how, during the 20th century, the arcade was partitioned in order to be used as support to the agricultural activities and as a stable. The deposits that were removed, the archaeological structures and the interfaces were identified as stratigraphical units. This recording enabled us to understand the relation between the wall stratigraphical units and the pavement strathigraphical units and, at the end, to point out the chronology of the structure.

Briefly we can say that in the 17th century there was a circulation area between



ISBN: 978-84-695-6782-1

the corridor of "Necessárias"/"Micha" cloister and the "Pátio dos Carrascos". This circulation was assured by the above referred walled door and another walled door found at the house in ruins. Probably the arcade was built as an enhancement of "Pátio dos Carrascos" resulting from the construction of the aqueduct in the 17th century.

The architectural planning has recovered that original circulation sense between several spaces of the convent integrating them in the visiting circuit, and kept the metric of the arcade by proposing a pergola that covers the pavement of the corridor (figure 6).

**4.2. "Paços Henriquinos"**

Nowadays "Paços Henriquinos" are in ruins. Parts of those ruins were used as a bar of a military hospital that was installed in the convent.

During the 20th century it was intended to build a hotel over those ruins. Pursuing that goal, excavations were done in 1985 and 1997. There were found archaeological deposits dated to Roman, Suebi, Mozarabic, Medieval and modern occupation. From the findings we highlight a pavement, whose central tray is in brick, and laterals are in limestone. They were identified as Islamic or Mozarabic [12]. This pavement appears in the continuity of "Porta dos Arcos", Romanesque door that connected "Pátio Central" (the main courtyard) to "Alcáçova" (the citadel). These archaeological excavations were done in all the area of "Paços do Infante", with the exception of the area that was occupied by the old military bar and an annex. Fortunately, the hotel was never built and the ruins remained intact.

Recently, there were plans to make the reception/entrance of the monument in the "Paços Henriquinos" area. This area is exactly between the Castle, that presently is not open to the public, and the Gothic cloisters that are at the beginning of the visiting circuit ("Claustro da Lavagem" and "Claustro do Cemitério"). The option of making the reception in this area had the following purposes: in the first place, restoring the ruins, consolidating it, and in second place, rehabilitating the area corresponding to the military bar area, making the reception there, and starting the visiting circuit there. In a near future this reception would be also the connection to the Castle.

The area we wanted to work on was, therefore, a construction of the 20th century that appeared to lean on part of "Paços do Infante" constructions. It was a dark, enclo-

Figure 6. Rendering of the architectural proposal for "Pátio dos Carrascos"



Actas del Primer Congreso Internacional de Buenas Prácticas en Patrimonio Mundial:Arqueología 400-412

ISBN: 978-84-695-6782-1

sed area, built in two levels, at different heights. After the topographic and architectural survey with TLS, it was necessary to demolish the bar, i. e. the equipment, walls and pavement coverings. Laborious task, since cement and reinforced concrete had been generously used.

After removing the wall cladding a record was made with photography (figure 7) aimed to produce rectified images later on, allowing us to define the stratigraphical units. Subsequently, the archaeological excavation was done. The clear identification of walls built in the 60 of the 20th century, and after 1918, in very well know context, allowed its demolition, making the 15th century façades visible.

After the excavation was complete, another photographic survey was done. This time, images were used to produce a dense point cloud model with the method of ADP. This model was put into scale and into place with control data from the TLS survey since there were overlapping areas between the two epochs of recording than remained unchanged.

In figure 8 it is possible to observe the results.

Excavating this area allowed the identification of an inner courtyard, to which looked the west and north façades of the “Paços do Infante” and the east façade of “Claustro da Lavagem”. By comparing the stratigraphical analysis of the walls and sediments, pre-existing structures where identified, some affected and destroyed by the later constructions, other integrated and reused in the more recent constructions. Another part of the stone pavement found in 1985 was uncovered. The archaeological structures found are dated from the time of the templar citadel, with the changes introduced with the construction of “Paços Henriquinos” in the 15th century and posterior readjustments in the 16th, 17th and 19th centuries. In 1918, a decision was made to enclose one of the arches and to cut the circulation area connecting the “Porta dos Arcos” to the Castle, so it was possible to use the new “enclosed” space as support for the Military Hospital.

### 4.3. The use of TLS spectral images

The fact that TLS is an active technology means that intensity values can be recorded and associated to point cloud data. Those intensity values are related with the albedo of

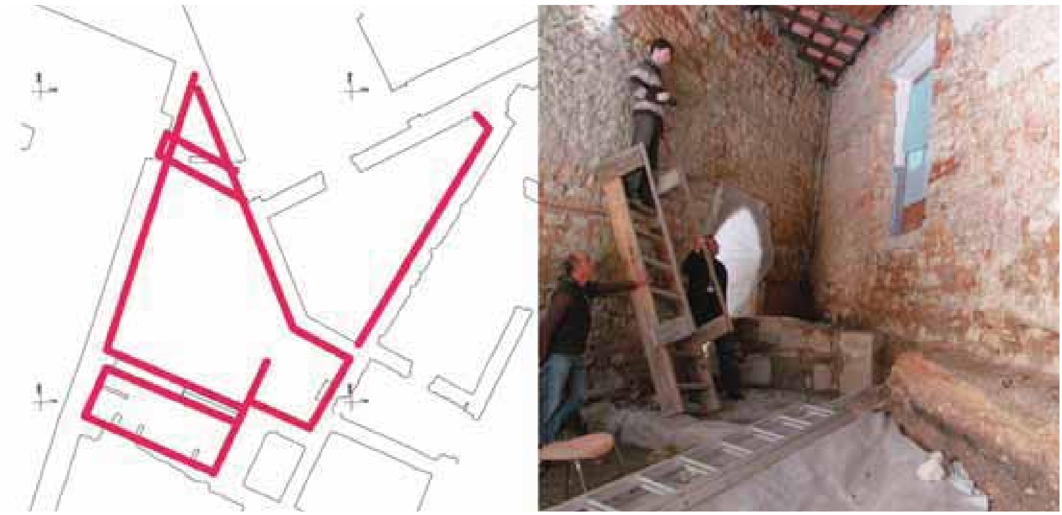

Figure 7. The photographic survey to produce rectified imagery during excavations



ISBN: 978-84-695-6782-1

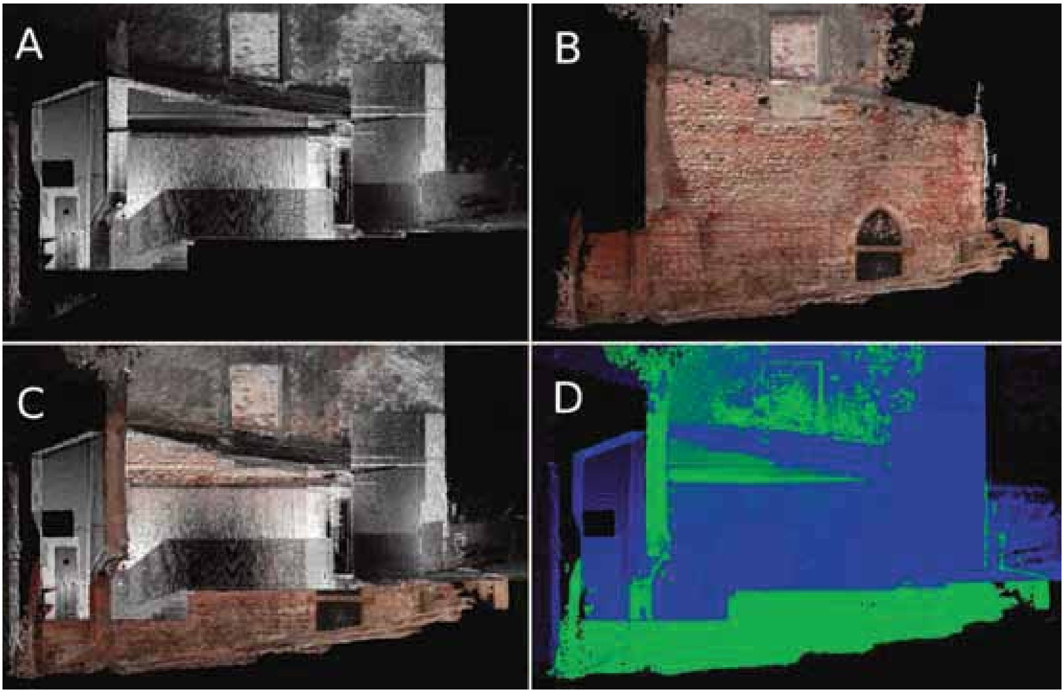


Figure 8. Overlapping (C and D) of TLS survey (A) and ADP survey (B)

the surfaces with respect to the laser wavelength used. Different wavelengths mean different spectral responses from the surfaces. And those responses can give us information about the surface features (figure 9).

We can observe that there are some features easily depicted in some images that one can hardly perceive by visual inspection. For instance, it is easy to see cement joints in infrared images or to detect some constructive patterns that one can date from a certain period. This experience was done in a wall of "Nave Manuelina" a 16th century construction next to "Charola".

## 5. Conclusions

With this work we showed that ADP and TLS can be used as complimentary tools for the archaeological recording.

ADP is more versatile than TLS since it relies on simpler hardware requirements, a simple camera, that can be available all time, and a workstation. The same camera is suited for large scale and small scale recording. Being fully automated it can be easily used to keep an updated record of the site under excavation and allows the archaeologist to be more time on field to analyse what is important, the built structure. ADP point cloud reconstructions are very dense and they allow us to generate ortho-images from it with no extra processing. The archaeologist can then identify the relevant features for the stratigraphical analysis.

The use of TLS survey was important to record the initial state of the site before the beginning of excavations. Later photographic surveys that led to rectified imagery and dense point clouds could be easily integrated in a common reference frame in order to be used to support the identification of the stratigraphical units. This showed that digital photogrammetry can be complimen-



Actas del Primer Congreso Internacional de Buenas Prácticas en Patrimonio Mundial:Arqueología 400-412

ISBN: 978-84-695-6782-1

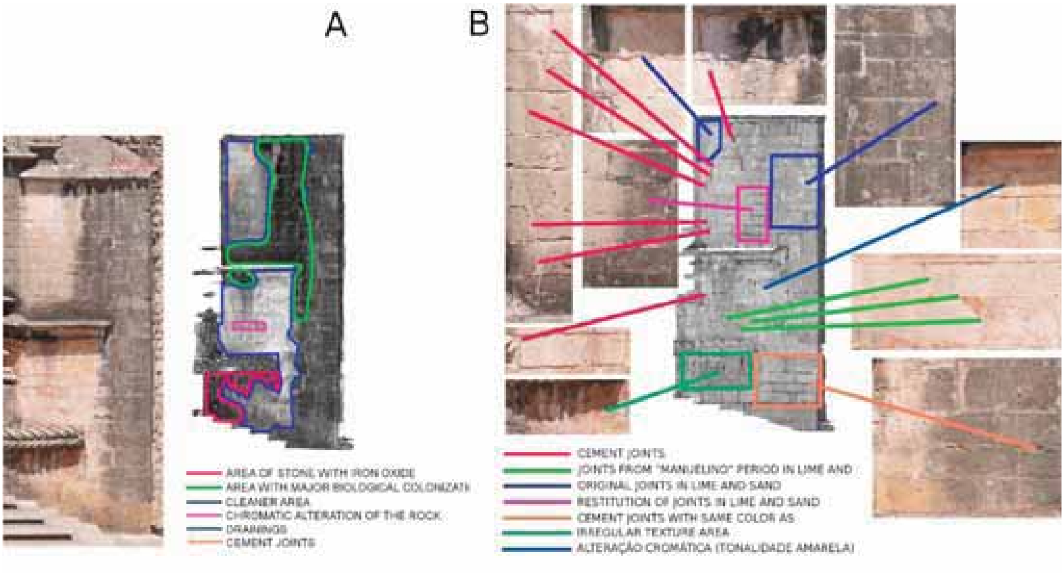


Figure 9. Comparing photographic images with TLS reflectance (grey images) red (A) and near infrared (B) images

tarily used with TLS with benefits of less time and money consumption.

Making easier the recording and documentation task, ADP allowed a very effective way of comparing different phases of excavation in a three dimensional environment.

The use of TLS reflectance images is not very common in archaeology or conservation but we find it a very promising tool for both disciplines since it can be used to identify features than cannot be easily identified by normal visual inspection.

The use of these methods requires what we can call digital literacy in order to deal with this kind of data.

**Acknowledgements**
The authors wish to thank to FCT (Foundation for Science and Technology) for funding the research where the present work was integrated, namely the research project "Contributions to Architectural Heritage Conservation: Documentary Methodology based in terrestrial digital photogrammetry and 3D laserscanning",
ref.: PTDC/AUR/66476/2006.

**References**

[1] ICOMOS. (1990): "Charter for the protection and management of the archaeological heritage" Retrieved from http://www.international.icomos.org/charters/arch_e.pdf

[2] ICOMOS. (1994): "The Nara document on authenticity" Retrieved from http://www.icomos.org/charters/nara-e.pdf

[3] Blake, B. (2010): What is the future of metric heritage documentation and its skills?. *Proceedings of the ISPRS Comission V Mid-Term Symposium.* Newcastle. UK. Retrieved from http://www.isprs.org/proceedings/XXXVIII/part5/papers/92.pdf

[4] Boehler, W & Heinz, G. (1999): Documentation, surveying, photogram-



ISBN: 978-84-695-6782-1

metry. *Proceedings of the XVII CIPA Symposium*. Olinda. Brazil. Retrieved from http://www.i3mainz.fh-mainz.de/publicat/cipa99/cipa99.pdf

[5] Feifer, C. (1989): *Il progetto di conservazione*. Milan: Franco Angeli Libri.

[6] Barroca, M.J. (1996): *A Ordem do Templo e a Arquitectura Militar Portuguesa do séc. XII*. Portugália XVII-XVIII. Porto

[7] Dias, A. C. (2012): O Castelo dos Templários e o Convento de Cristo à luz das recentes escavações arqueológicas. *Proccedings of I Colóquio Internacional Cister, os Templários e a Ordem de Cristo*. Tomar.

[8] Remondino, F. (2006): *Image-based modelling for object and human reconstruction*. PhD Thesis. Swiss Federal Institute of Technology (ETH) – Zurich. Retrieved from http://www.igpdata.ethz.ch/berichte/Blaue_Berichte_PDF/91.pdf

[9] Bryan, P. Blake, B.& Bedford, J. (2009): *Metric Survey Specifications for Cultural Heritage*. English Heritage. Retrieved from http://www.english-heritage.org.uk/publications/metric-survey-specification/

[10] Wu, C. (2011). Visual Structure From Motion (software). Retrieved from http://www.cs.washington.edu/homes/ccwu/vsfm/

[11] Furukawa, Y. & Ponce, J. (2009): Accurate, Dense and Robust Multi-view Stereopsis. *IEEE Transactions on Pattern Analysis and Machine Intelligence* (PAMI 2009). Volume: 32, issue 8. pp. 1362-1376. Retrieved form http://www.di.ens.fr/sierra/pdfs/cvpr07a.pdf

[12] Ponte, M. & Silva, P. (1989): Abordagem Arqueo-histórica dos Paços do Castelo dos Templários (sondagem 1985). *Boletim Cultural e Informativo da Câmara Municipal de Tomar 11/12*. Tomar.



Actas del Primer Congreso Internacional de Buenas Prácticas en Patrimonio Mundial:Arqueología　400-412

ISBN: 978-84-695-6782-1