

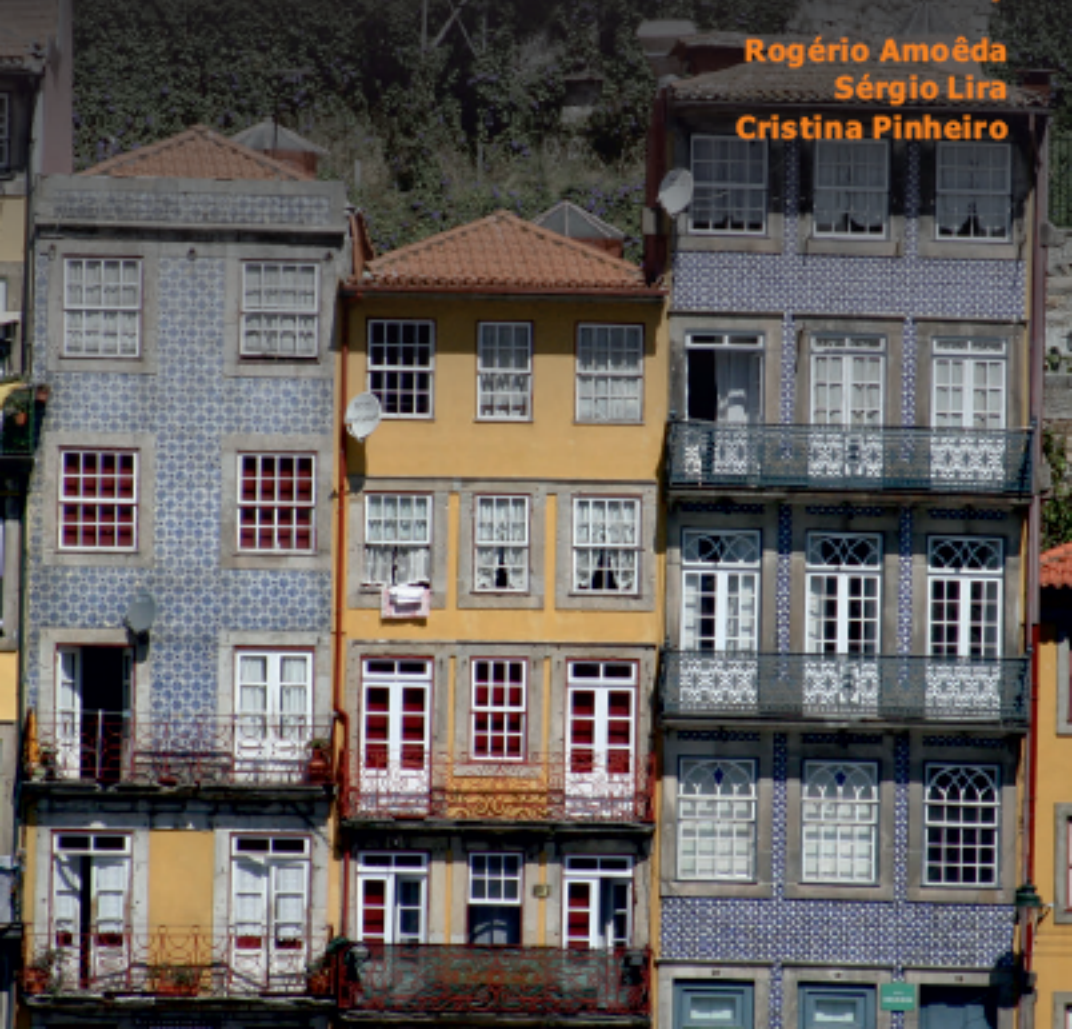
# HERITAGE 2012

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**Rogério Amoêda  
Sérgio Lira  
Cristina Pinheiro**



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# TLS and digital photogrammetry as tools for conservation assessment

L. Mateus, V. Ferreira, J. Aguiar, M. Barbosa

*Technical University of Lisbon – Faculty of Architecture, Lisbon, Portugal*

**ABSTRACT:** In this article we intend to discuss the potential and usability of the methods and tools of terrestrial laser scanning (TLS) and automatic digital photogrammetry (ADP) for the recording and production of base documentation as support to conservation analysis and intervention. These tools, TLS and ADP, can be very efficient, not only to the geometric and radiometric recording, but also as instrument for several types of analysis. It will be presented three case studies: i) “Convento de Cristo” in Tomar, ii) “Arco da Rua Augusta” in Lisbon, and iii) “Palácio de Valflores” in Loures. In these cases TLS and ADP were used as complementary tools to the recording of the built structure. TLS was also used as an instrument for anomalies detection, to measure deformations and gaps and to perform a comprehensive survey of the building. This information is being used to plan and implement conservation measures.

## 1 INTRODUCTION

Architectural conservation interventions should be based on a careful assessment of the values underlying the built object (Feifer 1989; Brandi 2006). To recognize those values an extensive analysis should be undertaken. That analysis should follow a systematic approach linking several fields of knowledge (architecture, conservation, archaeology, history, geology, and many others).

Regardless of what kind of analysis model one want to perform, it is necessary to gather and manage data about the structure. Part of that data can be collected with recording methods. Those methods can be classified as direct methods and indirect methods (Blake, 2010; Boehler & Heinz, 1999).

In this paper we intend to demonstrate that the application of the indirect methods, namely terrestrial laser scanning (TLS) and automatic digital photogrammetry (ADP) based on structure from motion (SFM), can be efficiently used as means to record architectural structures and support state of conservation analysis.

## 2 BACKGROUND ON TERRESTRIAL LASER SCANNING AND DIGITAL PHOTOGRAMMETRY APPLICATIONS

In the early days of analog and analytic photogrammetry, this technique was mainly used to depict the geometric configuration of the recorded objects. The digital era

brought an all new potential of development and fields of applications. Analog images were replaced with digital images processed by computer what meant that the semantic information from images could be more easily associated with the photogrammetric deliverables. Nevertheless, photogrammetric processing used to be a cumbersome task. When TLS of topographical scale appeared in the nineties of the xxth century, many people advocated the end of photogrammetry since it enabled a much faster way of recording the geometry of the built structures. Additionally, radiometric information can be associated with point cloud data. This radiometric information can come from digital imagery or from the spectral response of materials to the used laser wavelength. In this case one refers to intensity images. This is due to the fact that TLS is an active technology.

Digital photogrammetry is a passive technology. This means that the photogrammetric recording is based on the acquisition of the environmental radiation.

Recent developments of computer science enabled the automation of the photogrammetric processing, for instance with the structure from motion (SFM) approach, making it as faster as TLS processing, or even faster, but in an almost unattended way. SFM means that the three dimensional structure of image acquisition, including camera parameters estimation, can be automatically recovered from a data set of images with small base distance in between the images.

Usual deliverables of photogrammetry and TLS are two dimensional drawings or ortho-images that the conservation professionals use as base for material identification and characterization, for anomalies recording, and to document the conservation measures. It is being recognized that the use of intensity images of TLS can open a new application opportunity for the material and conservation analysis of the built architecture (Docci & Docci, 2005) and in our opinion TLS and ADP should be faced as complementary techniques to produce a more comprehensive documentation in the context of conservation.

### 3 THE CASE STUDIES

It will be presented three case studies: i) “Convento de Cristo” in Tomar, ii) “Arco da Rua Augusta” in Lisbon, and iii) “Palácio de Valflores” in Loures. In the first case, TLS and ADP were used as complementary tools to the recording of the built structure and reflectance images of TLS were used as an instrument for anomalies detection. Anomalies could be detected from image interpretation and image processing. Image processing of TLS reflectance images is possible if more than one instrument, with different laser wavelengths, is used. The principle is that materials respond in different ways when exposed to radiation of different wavelengths. In the second case, TLS was used to perform a comprehensive survey of the building, including the sculptural elements. This survey enabled several analyses from the study of stereotomy (stone cut) to the understanding of the conceptual geometry behind the design of the building. Reliable geometric documentation enabled testing and verification of different conceptual conjectures that were significant for conservation planning. In the third case, the building is a pre ruin and TLS was used to measure the amount of deformation of structural walls and the amount of loss of filling mortars. This information is being used to plan and implement conservation measures.

### 3.1 “Convento de Cristo”

“Convento de Cristo”, in Tomar - Portugal, is classified as world heritage by UNESCO since 1983.

In order to prepare the base documentation for restoration and rehabilitation works, two neighbouring areas in the monument were surveyed, during 2009, with two different laser systems: 1) a Phase Shift Laser Scanner (ZF Imager 5006) with a red laser of 683nm wavelength, and ii) Time of Flight Laser Scanner (Optech Ilris3D) with an infra-red laser, 1500 nm wavelength.

The point cloud data generated was first used to produce planimetric and altimetric deliverables for intervention planning.

It was then observed that in the overlapping area of both surveys the quality of intensity images (fig. 1), corresponding to walls, was very different and that different wavelengths corresponded to different features depicted.

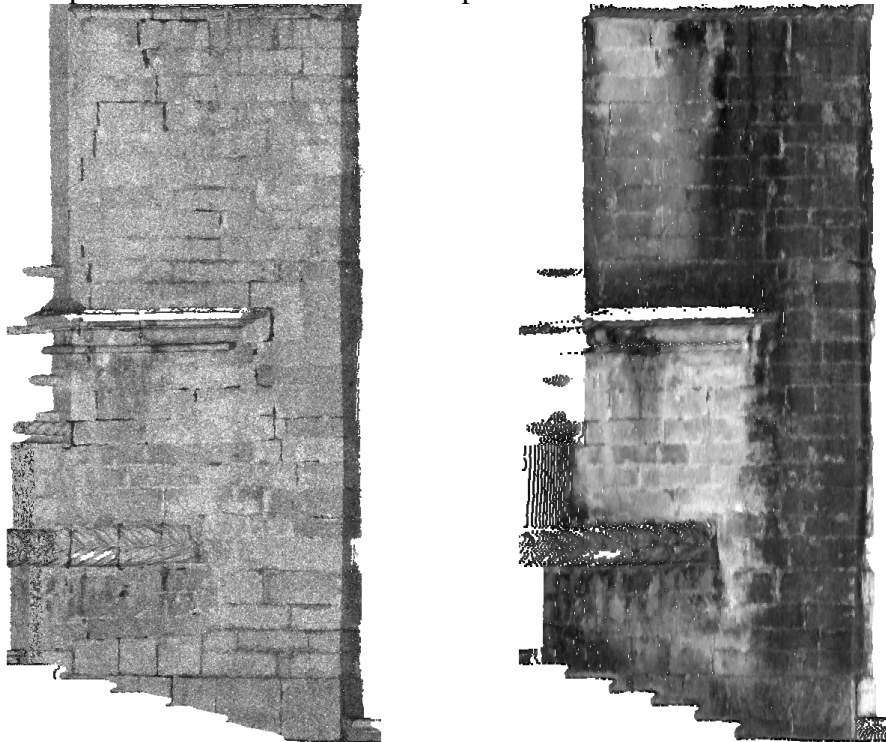


Figure 1. Left: near infra red image. Right: red image.

For instance, the infrared image was able to put in evidence early interventions with cement mortars in masonry joints, and the red image was more close to the visual perception of the surface.

The ortho images, with the recorded intensity (reflectance) of both wavelengths was exported and processed. Since we had images with red and infrared information, we processed it with same method used in remote sensing for calculating NDVI (Normalized Difference Vegetation Index) from satellite images (Lillesand et al., 2004). As this is a way of detecting the chlorophyll content in plants, it provided, in this case, a way of detecting biological colonization, in the wall. The results are presented in figure 2.

We further performed a principal components analysis with both images (figure 3). This was done by processing variances and co-variances of the original images.

These images can, in some way, concatenate and put in evidence a set of characteristics of the original images. First principal component image was able to show what areas of

the surface are cleaner and second principal component image was able to differentiate organic and inorganic materials.

The innovative factor in this approach was the fact of using intensity data from the TLS, that has a very narrow band (the satellite images have bands that cover a wider range of the spectrum), and still obtaining a usable result, that detected the biological activity on the wall, and that was confirmed locally by a specialist.

We further tested and compared the performance of ADP and TLS. A set of 543 images of “Janela Manuelina” was automatically processed to generate a very dense point cloud model (about ten times more dense than the corresponding TLS model) mapped with the radiometric information of the images (figure 4).

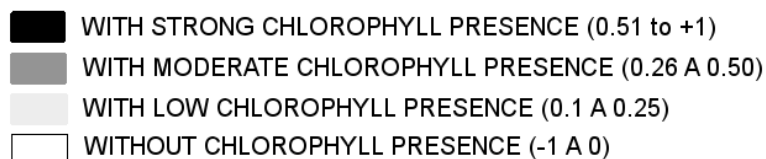
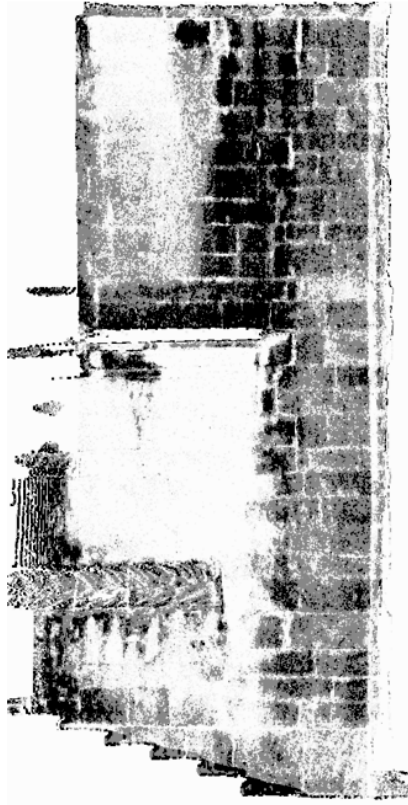


Figure 2. NDVI reclassified in four classes.



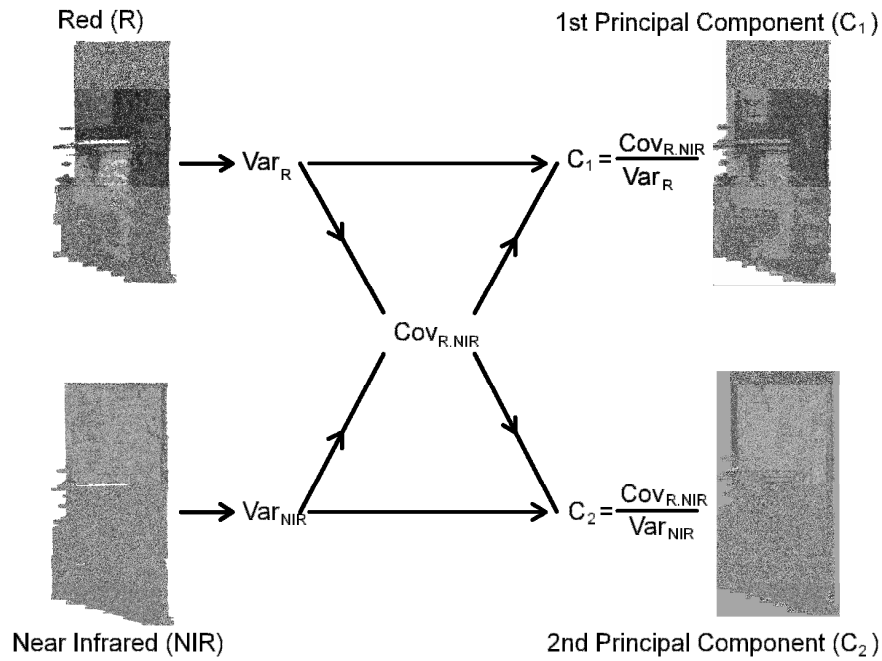


Figure 3. Left: First principal component. Right: Second principal component.



Figure 4. Details of the photogrammetric survey.

Comparing both models showed that identical metric performance can be obtained with both systems with the advantage that, in ADP, the association of radiometric information to the geometric model is part of the same process.

### 3.2 “Arco da Rua Augusta”

This second case occurred in late 2010 and early 2011.

The “Arco da Rua Augusta” is a portuguese national monument, located in Lisbon, built in the XIX century. Since there was no precise survey of the “Arco” to serve as the basis

for developing conservation planning and for future memory, a very detailed survey was needed, and TLS was chosen as the main survey tool.

The survey was split into the following steps: i) choice of most suitable system, ii) definition of the equipment positions during the survey, according to the processing methodology, iii) setting the point cloud density according to the desired level of detail for documentation, iv) estimating the execution time of the fieldwork. This planning was partially made in the field in order to include and predict constraints and obstacles, or perceive possibilities that may enhance the system. In this survey we captured about 176 point clouds, 42 of them using the telescopic platform lift.



ARCO DA RUA AUGUSTA  
- Alçado Sul -

0 1 5 10 20m

Figure 5. Elevation of the main façade.



These point clouds allowed the next stage of the process, a first approach construction of the 3d Model of the object. After the capture and the removal of spurious data, point clouds were oriented relative to a common reference system. Lastly the model was oriented with the help of control points from a topographic survey.

The point cloud model is a first product of TLS. From this other products may be generated, in particular the traditional 2D drawings (figure 5).

Briefly, to produce a drawn part it is necessary to: i) orientate section planes/ 3D model projection, ii) export sections produced by these planes, iii) exports images resulting from the projection of the point clouds on those planes, iv) edit the images to generate an ortho image, and v) import sections and ortho image in CAD Software and proceed to the graphic restitution.

The 2D drawings are still the support of choice among architects for the development of their project action. Yet they have some limitations, for example when used in processes for measuring spatial development with complex shapes.

Nevertheless, two dimensional data has shown to be very important to understand the conceptual geometric nature of the structure since it replicated what can be considered as the conceptual and operative framework of the architect, the multiple views system derived from descriptive geometry. From that layout it was possible to place a hypothesis on the geometric rules and from the three dimensional data it was possible to prove that the hypothesis was correct (figure 6).

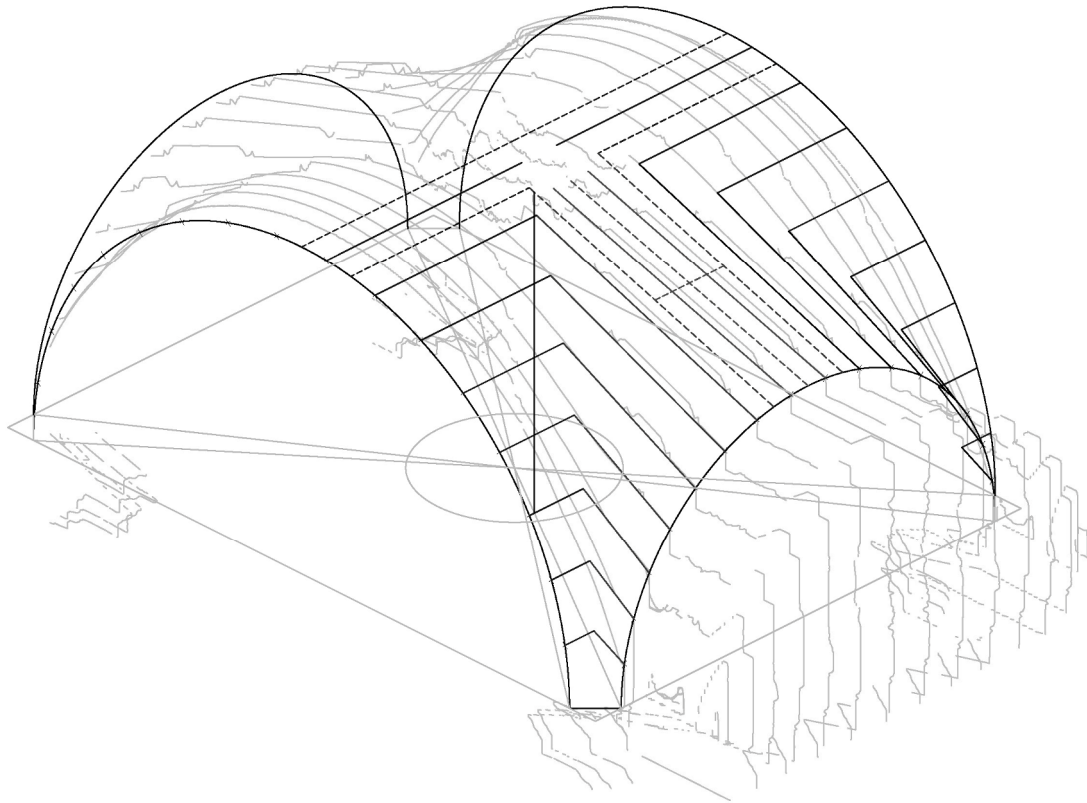


Figure 6. Comparison of the theoretical model with the surveyed data.

One of the most relevant outcomes of this was the understanding that the building represents the most relevant technical and scientific knowledge of the time of its construction, and that brought more accurate knowledge regarding this structure and its stereotomy.

### 3.3 “Palácio de Valflores”

“Palácio de Valflores”, and respective farm, located in Loures (Portugal), is a unique example of portuguese civil architecture of the XVIth century. In the last forty years it has been used as an agricultural warehouse and corral. Recently the municipality bought the property and is planning an intervention. The main building has no roofs and presents severe deformations.

A TLS survey of the building was accomplished in order to generate graphic data for the restoration and rehabilitation planning.

The first level of approach to the understanding of structural behaviour is to analyse the visual evidence presented by the object, for instance, the apparent deformations and cracks. These visual evidences can be verified, corroborated and measured by processing the point cloud data. One way of measuring the amount of deformation is through depth maps. For each façade we placed reference plans and measured the distance from the point cloud to those reference plans and plotted those distances with a colour based code (figure 7).

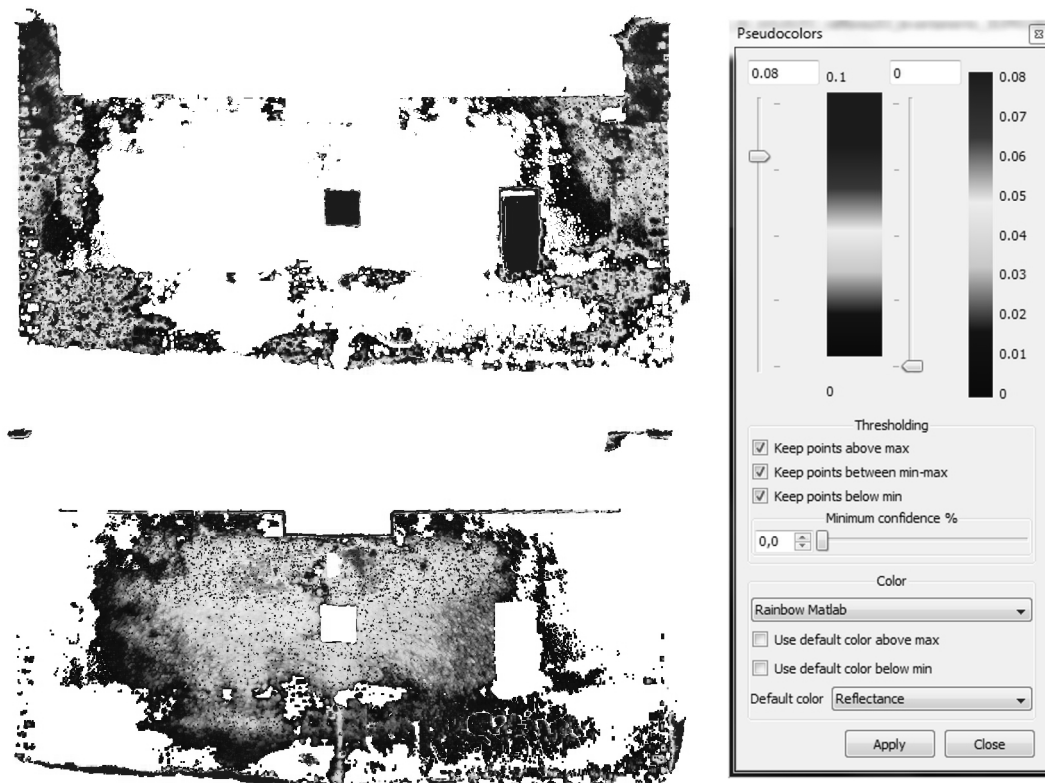


Figure 7. Deformation analysis with depth maps. Upper image: depth behind the reference plan. Lower image: depth in front of the reference plan.

Additionally, the point cloud model with depth maps applied as texture can be dynamically explored and visualized. That enables a global perception about the level of deformation of the built structure what enhances the recognition of deformation patterns in the structure as a whole (figure 8).

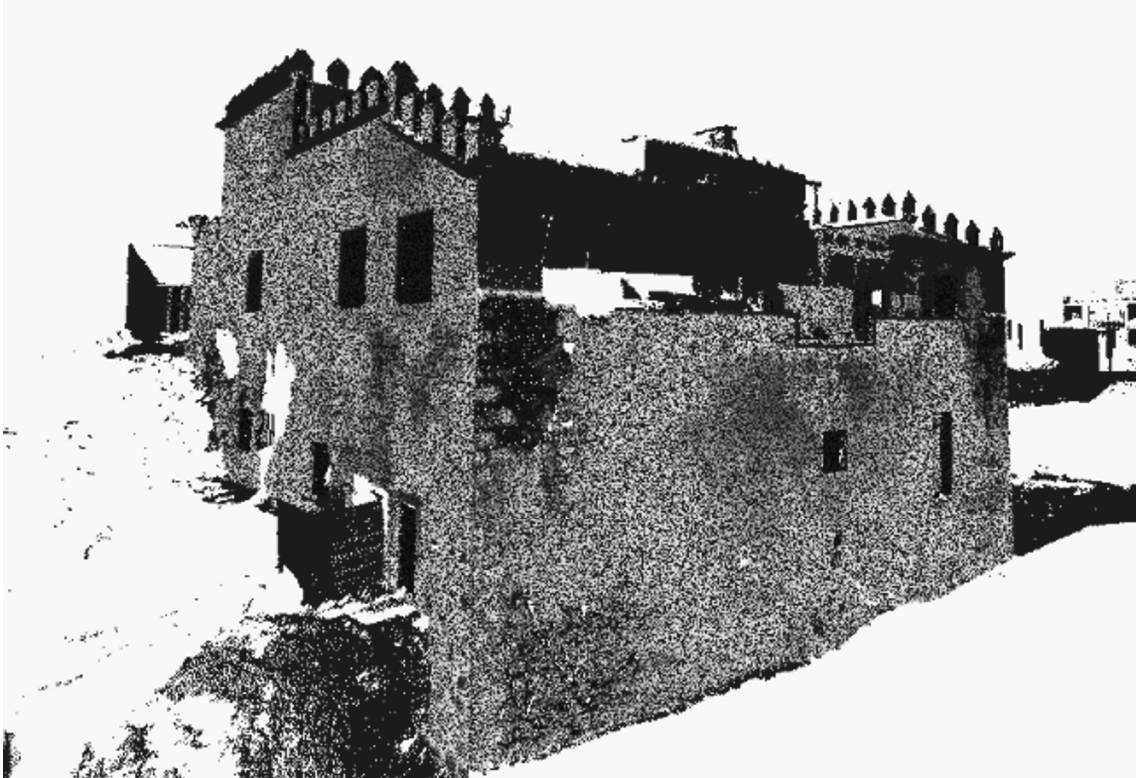


Figure 8. Three dimensional mapping of depth maps into point clouds.

#### 4 CONCLUSIONS

With the first case study we demonstrated that the potential of TLS goes far behind from the simple geometric survey of the built structure. Image interpretation and image analysis with intensity images from TLS have proved to be interesting and effective tools for conservation assessment. It was also showed that ADP can be used to produce very rich and detailed information with a high level of semantic value.

With the second case study we demonstrated that by analysing two dimensional representations that resulted from a very detailed and accurate three dimensional recording, it was possible to identify an ultimate value of the building as an expression of the scientific and cultural level underlying the epoch of construction.

With the third case study we showed that visual inspection of the building can be potentiated with a comprehensive three dimensional survey. With this kind of documentation it is possible to dynamically inquire the three dimensional model and to identify anomaly patterns that one could not identify other way.

But it is also necessary to have in mind that the technologies presented only allowed do record and document that subset of phenomena that appear at the surface of the objects. In conservation other kind of data is required to. So, the correct documentation strategy has to encompass other tools and techniques.

## 5 ENDNOTES

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