

EXPERIENCES ABOUT FUSIONING 3D DIGITALIZATION TECHNIQUES FOR CULTURAL HERITAGE DOCUMENTATION IN CÁCERES WALL (SPAIN)

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ABSTRACT:

In this paper we present an experience about combining 3D digitalization techniques for cultural heritage documentation. Cáceres Wall is a big and complex construction from the XII century. Cáceres was declared a World Heritage City by UNESCO in 1986 because of the city's blend of Roman, Islamic, Northern Gothic and Italian Renaissance styles and the wall contains rich elements of all those époques. The wall captured is close to 900 meters long and contains seven towers and other complex elements. An urgent conservation and restoration program was promoted in order to prevent further damage in the wall. A complete 3D graphical record was needed to support this intervention. The main objective was to keep control of the main structures and to detect deformations of the wall and the towers. This was the reason why laser scanner, photogrammetry and direct measurement methods were used. On the same side, the 3D documentation of the Cáceres wall was recorded also for virtual tourism. Thus, this 3D model was made by photo texturing. The fusion of laser scanner and photogrammetry, creating a uniquely accurate 3D model, was necessary because in some sites the photogrammetry was the best technique to capture it and in other ones the laser scanner was the optimal. In this paper it is described how we have combined both techniques to conserve the accuracy and the phototexture in all the 3D models. Orthophotos, sections and other plans were created for this project.

A time of flight and a homemade videogrammetry-laser, a photogrammetry camera, a total station and a GPS were used to obtain a complete 3D photorealistic model of the Cáceres Wall, the objective was to create an accuracy study of the wall healthy, capture little pieces found close to the wall and get a virtual trip around all the wall and towers.

1. INTRODUCTION

Cáceres is a city situated in the west of Spain, in Extremadura region. Cáceres was declared a World Heritage City by UNESCO in 1986 because of the city's blend of Roman, Islamic, Northern Gothic and Italian Renaissance styles and the wall contains rich elements of all those époques. But the wall is one of the most representative monuments of almohade military architecture in Spain. Some parts of the wall were destroyed and reconstructed in different époques, being a compendium of cultures and construction ways.

The wall captured is close to 900 meters long and it was documented within and without the wall. The morphology of the wall is very complex, overall without the wall because this area has lots of buildings leaning against the wall, making it impossible to see the wall in some segments. Within the wall, the battlements are really narrow in some areas, no more than 2 meters long and in the same sites, the wall is close to 5 meters high, thus the captured geometry of those areas is also very complex.

The main objective of this project was to obtain a complete documentation and analysis of the wall to realize a diagnostic and plan future interventions. In this way, geometry and radiometry documentation were necessary.

To achieve a complete wall recording we have used different techniques and instruments; mainly GPS, Total Station, self-metric camera and laser scanner. On the other hand, we also have used aerial ortophotos, plans and old pictures of some interiors zones.





Figure 1. Cáceres wall and towers.

2. PREVIOUS WORK

2.1 Complexity of the Cáceres wall morphology

An optimal planning ensures highly the success of the field work. Thus, this is absolutely necessary taking into account the next points:

Cáceres is a touristic city and there are quite a lot of people walking around the old town visiting the monuments. Of course, there are people also around the wall and the towers, including the people who are living in the houses close to the wall. Thus, one of the aspects to avoid is the people; trying that they do not appear in the pictures or pass during the scanning time.

Other fundamental aspect is the traffic: there are cars parked close to the wall hindering the full visibility of the wall and there are also some cars moving through the battlements making impossible the work in some narrow areas overall. But there is a capture obstacle also with it, because when there is traffic, the laser scanner captures it and do not capture the wall, having occult areas which can be important.



Figure 2. Narrow battlement of Cáceres wall.

To avoid the traffic or parked cars and the people, we took contact with the local police who have helped us to control those aspects using police fences in strategic sites to avoid the traffic, notifying the neighbourhoods not to park their cars close to the walls, etc.

Overall, in one part of the wall denominated “Los Pozos” there are so many trees next to the wall, which were a big obstacle for capturing this entire wall according the architecture requirements. But the policy of construct parks around the monuments makes optimal documentation in many monuments very difficult, at least, in Spain.

About the exterior parts of the wall, there are buildings leaning against the wall. Even to see the exterior face of the wall, in the most part of it, we have gone in the patios of the private houses and we have scanned, taken pictures and measurements from this. We have to think that the towers are in the exterior part of the wall, thus from seven towers, just one is almost free of buildings together it. The rest of the towers have buildings around them, even, some of them are habited by the neighbourhoods using their interior for tea-rooms, for example.

2.2 Light conditions

Respect of the natural colour of the wall in the documentation was one of the most important tasks in this work. For this reason, the sun-shadows projection in the wall was one of the most difficult problems to resolve. As was said before, the battlements were quite narrow and there were shadows in some parts of the wall during almost all the day. Just in one hour in the beginning and in the finish of the day the sun was occult and the wall colour was homogeneous. As it will be explained in the next point, we used laser scanner with the integrated camera, but it was not enough to obtain optimal colour results. That is one reason why we took several pictures with a hand held semi-metric camera in the hours when the sun was occult. Otherwise, the ortophotos would have parts with sun and shadows, being a problem to interpret the materials and its pathologies.

2.3 Election of the optimal technique.

Taking into account all the anterior conditions, we chose the best techniques and instruments to realize the wall

documentation. We can easily imagine that the situation of the wall is not easy to capture. We preferred to use laser scanner for a global geometry capture of the entire wall, even the exterior parts, and use digital photogrammetry to capture all the parts that the laser scanner could not capture, overall the colour, which was explained in the anterior point 2.2.

A laser scanner HDS 3000 of Leica geo-systems was used. This laser scanner permits scanning 360° of horizontal angle and 270° of vertical angle. It has an optimal range until 100 meters and an accuracy point of 6 mm. This laser scanner works by pulse time of flight principle and we thought it was the optimal one for those reasons:

1° the capacity of capture angles was necessary to record the tall parts of the wall in the narrow battlements. It was also useful to capture the interior rooms of the towers.

2° some of the exterior parts of the wall were complicated to align because they were isolated parts due to the buildings. For this reason, we scanned some areas of the exterior part from the top of the buildings or towers which permit us to connect different parts of the exterior. That is why the range of 100 meters was most useful for this project.

3° there are other laser scanners which work by phase difference principle and use an infrared beam. This kind of laser scanner would be dangerous to use in this project provided the tourist, although the police tried to keep them away from the wall, but it is not always possible. Besides, this kind of laser scanner does not have so much range like the pulse time of flight principle ones.

2.4 When LS and when photogrammetry?

We need to refer here to the architecture requirements. The necessary accuracy in all the wall documentation was in maximum. Vertical sections of the entire wall and towers were needed to know the potential risks. The bad conditions of the wall do not let to realize this operation using any technique which do not have guarantee of good accuracy.

On the other hand the interior and the exterior parts of the wall need to be highly aligned to study the thickness of the wall and the towers which permits to know the stability join with the vertical deviation or deformation.

Thus, we used laser scanner for the main geometry capture and a highly accuracy polygonal with total station to control the alignment of the laser scanner data. We should take into account that there is no way to align exterior with the interior along almost 900 meters except just in one site called *Postigo de Santa Ana*. This site is an old narrow entrance to the old town which connects both parts.

We used digital photogrammetry to complete the range data. On one hand, we took photographs with a calibrated digital camera Canon EOS 400D to capture the colour of the wall in good light conditions. Then we referenced those pictures using as control points, common points between the points cloud of the laser scanner and the photogrammetry pictures. In this way we created a 3D model by images.

On the other hand, we used digital photogrammetry to capture the data which the laser scanner could not capture. Those parts were the most difficult ones to record because of its location: narrow patios, hidden corners, etc. In all those sites, we always

tried to reference them with range data, close to those places. We took some pictures of those zones from different perspectives to obtain enough angles for stereo matching process. Like in the anterior case, we create a geo-referenced 3D model using also images.



Figure 3. Ortophoto from LS and Photogrammetry.

2.5 Short range laser scanner

To achieve a complete documentation we used short range data for some sculptures and less important pieces. We also made a laser scanner with video metric characteristics which we calibrated and used in this project.

First we scanned some pieces related with the history of the wall and the old city with the smartSCAN3d of Breuckmann. This laser scanner has 700 mm of range and 2 µm of minimal resolution. The middle accuracy is 30 µm. Overall, this laser scanner has photorealistic characteristic. This laser has 100 W halogen of light source and two digital colour CCD cameras of 1384 x 1036 pixels each one. This laser scanner works recognizing light projection on the object, once the laser was calibrated using a targets table.

About the homemade laser scanner that we construct in the Research laboratory of *GAVLE: Documentación Gráfica del Patrimonio Company*, it has 0.5 millimetres of accuracy although it depends of the angle and the resolution is highly variable. The laser scanner consist of a line beam photodiode with 532 nm, 5mW and adjustable focus, a camera with Carl Zeiss optics, and a High detail video resolution of 960 x 720 pixels. The system contains also two tripods, one for the laser and another one for the camera, and a targets table to calibrate it before scanning. The calibration targets consist of two tables positioning with an angle of 90°. The camera captures this image and the user has to introduce the scale. This laser scanner has also photorealistic characteristics. The scanning process consists of positioning the object between the calibrated table and the camera and laser sensor. The camera cannot be moved; only the laser will be moved scanning the object slowly and without light. While the camera is recording all the process and computing the angle of the laser beam respect the calibration table, obtaining a points cloud with X, Y, Z. Then, with optimal light conditions, a camera will produce a snapshot to photo-projection on the 3D model.



(mm)	D1	D2	D3	D4
Calibrated distance	41.771	16.697	46.117	46.169
Home made laser scanner distance	41.730	16.651	46.153	46.182
differences	0.041	0.018	0.036	0.013

Table 1. Simple calibration result of the homemade laser scanner.

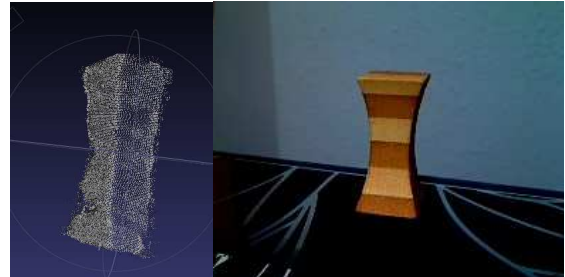


Figure 4. San Jorge Sculpture documented with SmartSCAN3d.

The homemade laser scanner was calibrated to know the real deviations. To achieve a good calibration a simple object was used and measured. The object was carefully measured using a calibre with an accuracy of 0.05 mm. The object was calibrated several times in some concrete distances and averaged the results. The same was done for the interior targets of the object.

Finally, the object was scanned and the results were compared as it is shown in the next table:



Figure 5. Ceres Goodness sculpture.



Figure 6. Ceres goodness 3d LS model.

3. 3D CAPTURING PROCESS

Once the previous work was described, the field work was done more easily. Without a good previous work, the project will not be available, at least in the time that it was realized.

3.1 Scanning Cáceres wall

Firstly, we began to scan the interior part of the wall, always helped by the police who prevented the presence of the people and the cars. The laser scanner was positioned in the planned sites, modifying of its depending of the results that we could see in the notebook.

Scanning the wall

As it can be imagined, the narrow segments needed more stations than the others. We always took care about the colour of the camera scans, although the sun-shadow projections

existed in this part during almost all the day due to the orientation of the south.

As we planned, the most complex area to scan was the exterior part due the buildings leaning against the wall. Some of those segments were simply impossible to capture and it was necessary to go into the houses and scan into the patios and windows, from superior battlements situated on the wall or from the tower terrace. All the sites were ok if we could see the wall from there.

Scanning the towers

Seven towers, interiors and exterior were scanned. The difficulty to scan those towers was even higher than with the wall. We can say this was the most difficult part of the project.

One of the difficulties has been repeated during this entire article; the buildings close to the towers. By the way, through those same buildings there was a unique way to access of the towers in almost all the cases. We carried out all the instruments with us through the houses and we carried them up to the terrace. In one of the cases, there was only a metal stair to access there with the

Figure 7. Ortophoto of the interior part of the wall.

instruments, batteries, note book, etc.

The terraces were good places to scan the exterior parts of the wall but to do it we put the laser on the merlon. This site was useful for us to capture part of this same terrace and align this one together with the rest of the wall.

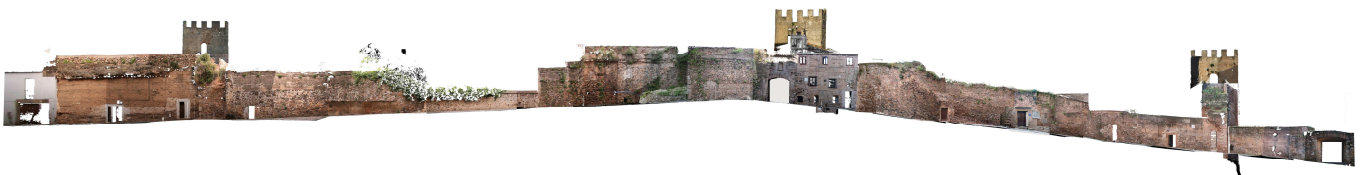
We did not use any targets in the scanning process. We only used common points to align the different scans and the total station was used to measure common points and to correct the alignment.

Scanning interiors sites

The patios and the interior rooms of the towers were scanned positioning the scanner on the floor and not using the tripod. This method permits to scan larger area even obtaining data of the floor. This part is very important because the level of the building, floor and roofs, respect the wall will decide future policy decisions about the wall rehabilitation-restoration.

Scanning sculptures and little pieces

We used three laser scanners to capture different pieces in



relation with the wall. One of them was the SmartSCAN of Breuckmann, the second one was a homemade LS which was described in the part 2.5 (both short range LS), and the last one the HDS3000 of Leica geosystem (middle-long LS) which was

used to scan a big sculpture of the Ceres' Goddess situated close to the exterior part of the wall.

3.2 Photogrammetry capture

As we explained in the previous work, the photogrammetry was used to complete the range data. The 18 mm objective was always used which was previously calibrated by Shape capture laboratory.

Close to 1000 pictures were taken for this project. The most part of them were taken from 7:00 AM to 8:00 AM in the morning to avoid sun projections on the wall. But the pictures of the exterior part of the wall were taken when we could do it, appearing some shadows in some of the ortophotos; remember the difficulties we had to go in the houses of the neighbourhoods.

The control points of the most 3D models created by digital photogrammetry were obtained of the range data. In the rest of cases, a total station was used for this purpose.

The cases when we used photogrammetry were described in the point 2.4.

3.3 GPS and Total Station capture

25 points were positioning on the floor using a Leica GPS900. Those points were necessary to get all the data in a Global coordinate system European Datum 1950.

Those points were used to create a polygonal along and around the entire wall. Those geo-referenced points permitted to measure points of the wall and towers. Singular points like corners, stones, etc were used for this purpose.

4. POSTPROCESS

All the data was processed and fused to obtain optimal final results. We used range data to capture the geometry mainly. It means the colour could not be captured due to the sun projection of the wall, creating a heterogeneous wall colour which does not permit an optimal interpretation of the wall materials.

The range data was processed first cleaning it; eliminating all the points that we did not need and aligning all the scans together in a 3D global model. This global model was geo-referenced using the points measured with the total station. To ensure the accuracy of this global model we also used the measured points with the total station to check the different scan positions and rectify it, if it had some deviation. Second an optimal mesh of the point cloud was created and finally different planes were positioned to realize ortophotos and cross sections like we will see in the next points.

We used the photogrammetry for two purposes: to capture the geometry when the laser scanner could not do it and to capture the colour of the wall. In both cases, control points from the range data were used to referenced the images and then obtain ortophotos.

All the data was combined using CAD software. Different plans were positioned to the 3D model ortoproject and created ortophotos and ortoimages.

4.1 Ortophotos

Many ortophotos were obtained from all the wall and towers. All the parts of the wall and towers were represented by ortophotos, even the interior room of the towers.

The plans of projections were positioned parallel to the wall for each segment. We should take into account that the wall is not a straight line; it is closer to a polygon with multiple sides. Thus, we needed plans which follow this irregular form.

4.2 Ortoimages

The same plans from the ortophotos were used to capture the reflectance of the 3D model of the wall; creating the ortoimages.

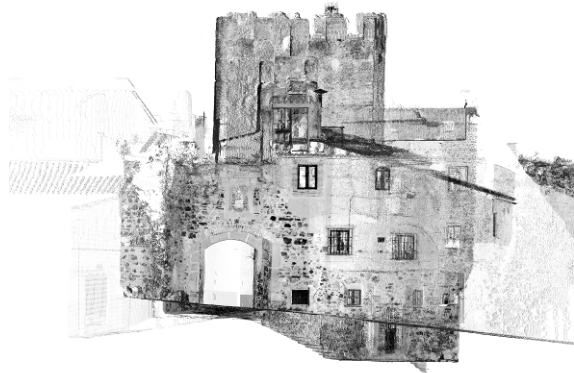


Figure 8. Ortoimage of the wall and Santa Ana tower obtained from range data.

4.3 Plans

Horizontal and oblique plans were positioned, this time to obtain the section with the 3D model. The cross sections were done at the bottom and at the top part of the wall, towers, interior rooms, etc.

Those cross sections on the range data are very realistic; you can see clearly on them the contour of the stones, merlons, etc.

4.4 Cross Sections: comparison between Laser scanner and photogrammetry applied to the deformation of the towers.

Once the range data was align, correct and meshing, several vertical cross sections were done along the wall and towers. Those sections will advice about possible deformations of the wall and calculate, together with the thickness and materials, the risk of the wall or towers to fall or collapse.

The capability to show this kind of deformation was compared between laser scanner and digital photogrammetry. A tower was measured with both techniques and the results were compared.

	Absolute Deviation (in millimeters)				
Laser scanner cyrax 3000.	4	6	2	9	7
Digital photogrammetry using Canon 400D and Shapecapture.	12	31	20	35	30

Table 2. Comparison between Laser scanner and photogrammetry applied to the deformation of the towers.

As it is shown in the figure, the results are different. On one hand, the resolution is highly better in laser scanner than in the photogrammetry. Secondly, although the accuracy of photogrammetry is better in the control points, there are too much surface without information; in this case, the photogrammetrist have to measure point with the total station in the most important and relevant part of the wall, but this one is not always easy. Because usually the deviation is quite smooth and it cannot be seen directly, you need measured instruments.

4.5 3D perspectives

The 3D perspective was an important part of the work. The perspectives helped us to understand better the situation of wall respect the buildings and measure the visual impact for the tourist.

4.6 Virtual travel

Finally, we created a virtual travel film around the entire wall. These kinds of products are more than useful for the virtual tourism. The tourists can see the forms and textures of this scene in a very realistic way.

5. CONCLUSIONS

This paper described a case of complete heritage documentation. Six instruments and different methodologies were necessary to get an optimal result.

The fusion of techniques and the knowledge about them will be absolutely necessary for choosing which one to use in each case. The objective of the work, the accuracy, the resolution and the object to be documented will decide the use of the different techniques.

6. ACKNOWLEDGEMENTS

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