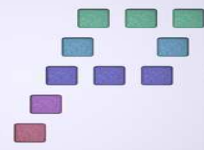


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**PFC**



**Gestión del Patrimonio Cultural  
Nuevas Tecnologías**

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**Year:**

May 2007

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**Method/Team**

Classic Topography / Laser scanner

**TITULO:** Survey of "Castillo de Villavellid" realized with traditional techniques and with laser scanner 3D system.



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## 1. INTRODUCTION

### 1.1. Objectives

The objective of the project was to carry out the survey of castle of Villavellid by using various techniques and to draw up a detailed plan of the work to the scale 1/200 as well as a plan of the surroundings in the scale 1/500.

The measurements were made with different equipments: total station (classic topography), GPS and laser scanner LS 880 of FARO.

This work consisted of the integration of techniques of data acquisition for the analysis and the study of the possibility of application of these same techniques for the patrimonial elements survey. This work was carried out in collaboration with Hafency University of Hamburg Department of Geomatics and Restauradores Sin Fronteras association.

### 1.2. Localisation

The castle is 65 kilometres far from Valladolid, between Tierra de Campos and Montes Torozos.

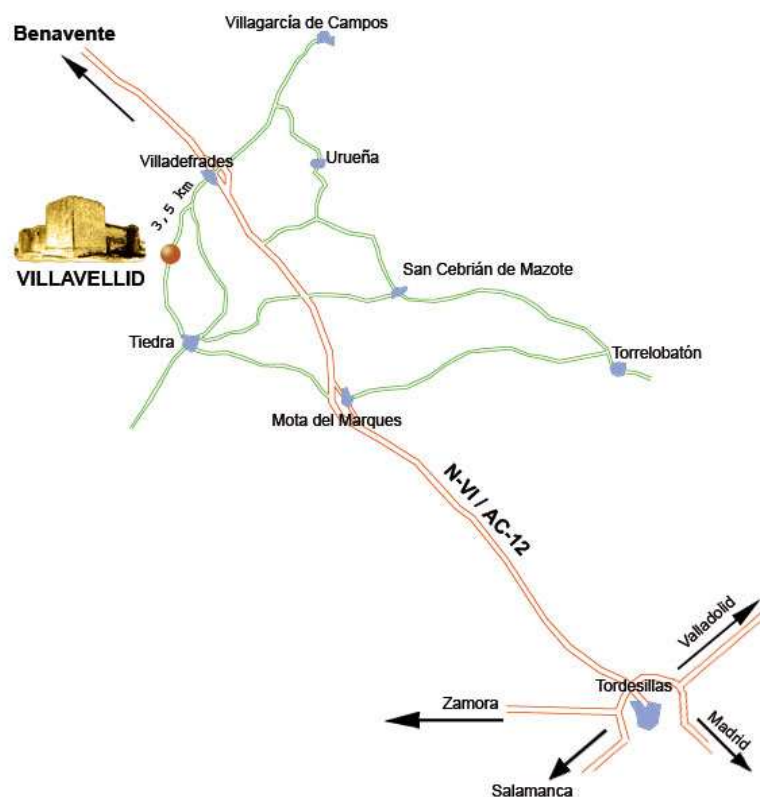


Fig. 1: Localisation of Villavellid castle

### 1.3. History

The castle of Villavellid 65 kilometres far from Valladolid, next to the village of Villavellid. Its position makes him a sentinel of the area.

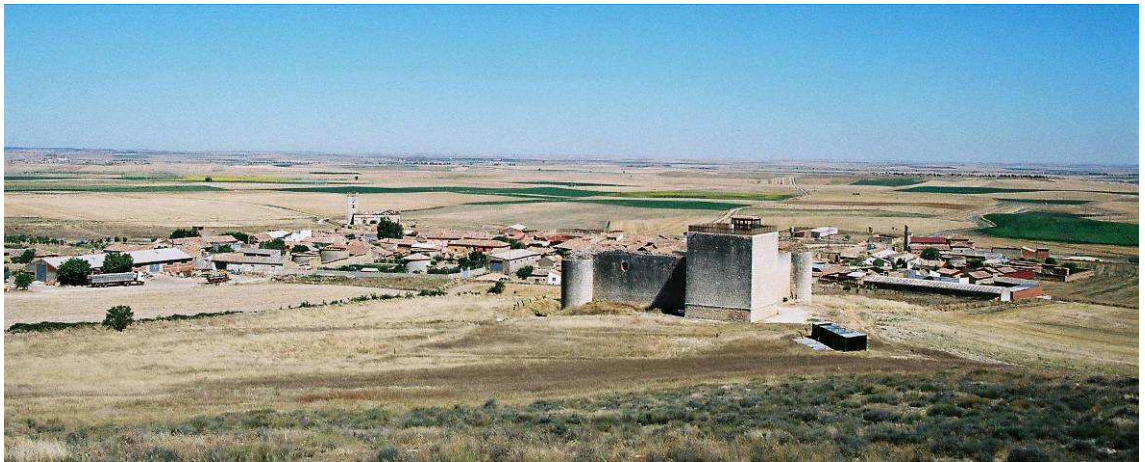


Fig. 2: Villavellid Castle view

The castle is characterized by sober and discreet architecture divested of visible ornamental motive. The association in charge of the project intends to carry out a historic research work on the castle but also of all the area where are also numerous castles.

## 2. GPS NETWORK

A set of points was beforehand staked out by GPS with the fast static observation method. First of all, several points were stationed around the site. These points belong to the REGENTE network which is the official network. This network establishes the primary network. From the primary network, we made the setting-up of a second network established by points more close to the site. This secondary network constitutes the secondary network of the site and is calculated from points constituting the primary network. To carry out this work, the team used three GPS Leica 500 whose technical characteristics are the following ones:

- Phase measurements L1.12
- Post-processing accuracy: 5mm+0,5ppm.
- Real time accuracy: 10mm+2ppm.



### 2.1. Primary network

To make the primary network, a GPS was stationed on the point 34165 - Montemata of the REGENTE network, and two GPS were parked each on a point of the primary network: Ref1 and Ref2.

The Leica Ski-Pro program was used to calculate the transformation of the coordinates in the WGS84 and ED50 geodesic systems. To make this transformation, four points known in both systems were stationed: four points of the REGENTE network, the closest to the site. The maximum residue of this transformation on a point was 10cm in planimetry and 2cm in height.

## 2.2. Secondary network

The interest of the secondary network is to have near the site a set of points known in the wished geodesic system. These points will serve as basic points for the observation and the calculation of the network of the reference points which we need for the laser scanner survey.

The secondary network is constituted by nine points outside of the castle and of five points inside. Points which are outside are positioned at 30 metres approximately of the walls of the castle. The observation of these points is made with GPS, the point used is Ref2.

All the basic lines between Ref2 and the points of the secondary network are calculated. The transformation of the points of the secondary network in the geodesic system ED-50 is then applied.

The calculation of certain basic lines for points inside the castle raised some problems. A increase of the network was thus carried out by using traditional technics. This phase is explained in detail afterward.

Coordinates adjusted of the points of the secondary network situated outside of the castle had a better accuracy than that required in the project specifications. This accuracy is 13mm.

## 3. SECONDARY NETWORK RAISE

The objective of this phase is to densify the secondary network by endowing with coordinates the points of this network which we couldn't observed with GPS. The observations are then made with a total station (classic topography).

The total station used is a station Leica TCRA 1105. This allows us to realize distance measurements without prism. Instrument characteristics are explained below.



Angles measurement deviation	1.5 mgon
Distance measurement deviation	
With prism reflector	$\pm ( 2\text{mm} + 2\text{ppm} )$
Without prism reflector	$\pm ( 3\text{mm} + 2\text{ppm} )$
Focus	30x
Automatic corrections	Vertical indice error Collimation error
Axis compensator	
Levelling sensibility	
Spheric bull	$6 \sqrt{2}$ mm
Display accuracy	1"

Other equipments used are :

- meter.
- Wood and steal Tripods.
- Bases Leica with bull.
- Staff with prisms reflectors Leica.

The observations of increase of the secondary network were made from the same station, by using the points of the primary network for orientation.

This technique was also applied for the increase of the secondary network outside of the castle. The new basic points were situated on ideal sites to observe the network of reference points with the best possible angle. Since these basic points, it is possible to observe the reference points of every piece of wall.

These new stations (eight all in all) were observed in the same way as that situated inside. For each, aims were made towards at least three points of the secondary network.

All the calculations and the adjustments were made in a local system of coordinates. The increase of the secondary network as well as the calculations of the network of reference points were used to the fastening of the works of laser scanner. Indeed, this equipment can only work in a local system of coordinates and without projection. The coordinates of the points of the secondary network on which are connected the works of laser scanner will be the object of a transformation in the local system to proceed to an adjustment by mean squares.

#### 4. REFERENCE POINTS NETWORK

The shape and the dimensions of the signals of reference points are appropriate for the scanner laser employed. The equipment FARO LS 880 HE and the IT applications which

accompany it define the type of signal of the aim. These marks are paper marks fixed to walls or white spheres which settle thanks to magnets on metallic elements.

To give coordinates to spheres, they are replaced during the measurement by miniprisms among which the centres coincide with those of the spheres. To attribute coordinates to the paper marks, we measure their centre.



Fig. 3a: Miniprism



Fig. 3b: Sphere

These marks were positioned in the bottom of the castle and halfway up the bulwarks, in a way that they cover the surface which is going to be scanned. Spheres were fixed in the top of the tower and to metallic elements around the scanner and around the castle, around such way as the equipment laser scanner can capture points in coordinates known on all its scans.

The observations were made by making an orientation from the points of the secondary network and since the stations resulting from the increase of the network. The points of observation were chosen in a way that their position provide a good angle of intersection with points.

We made the network's calculation and we apply a transformation including three translations and three rotations to transform coordinates adjusted in the original system.

For the internal secondary network, this transformation is not applied. The original coordinates of the bases of the secondary network result from observations GPS and these last ones do not guarantee us to be in the same system as that of the outside network. The work is thus made separately in both sets of coordinates during the various phases of the project.

## 5. GROUND SURVEY

A survey is made around the castle to know the topography of the area. The survey is made by using classic topography means in all the zone close to the castle because bulwarks prevent a good cover by satellite. The rest of the zone is made with GPS by applying the method RTK.

## 6. LASER SCANNER SURVEY

To carry out this project the FARO company lends us the laser scanner equipment FARO LS 880 HEY.

For the castle's survey, it is necessary to position the scanner on various places around this one, so as to obtain a complete scan of the castle. The scanner is at a distance of the castle included between 20 and 30 metres. The density of the cloud of points is about a point all 3 to 5 mm in total resolution.

Several zones of study are defined to make the scan of the castle:

- A zone for every outside section of wall. Every piece is scanned since several sites, and with different resolutions.
- The inside of the square. It was possible to make a complete scan of the square with a scanning of 360 °, but the computer system, itself, could not manage the resultant files. The place was thus divided into several angular sectors to realize every scan with an optimal resolution.
- The top of bulwarks and main tower.
- The inside of the tower so as to make simpler its structure modelling.

The best moment to make the scan of the various zones of study is determined in function of the orientation of the zone with regard to the sun. Indeed, on the walls the most exposed to the sun, the resultant images in black and white of the scan appear with alteration. Later, it was verified at the office that the heat had altered the measure.

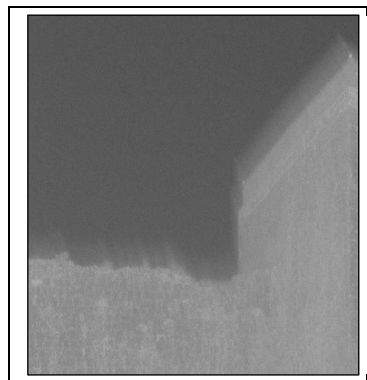


Fig. 4: Black and white image of south wall with alteration.

The observations were realized in this order:

- 360 ° horizontal scanning low resolution of 360 ° with taking of photos.
- Selection of the angular window which interests us for a high resolution.



- Change of the site of station for the scan of the same zone to have a different point of view.

During the campaign, a total of 55 scans was made. We were able to note how the speed of acquisition decrease considerably with a requirement of better resolution.

### 6.1. Data processing

The data processing acquired with the laser scanner is made with the associated program FARO Scene 3.0. We proceed then to the scanner files control.

Paper marks and white spheres were endowed with coordinates for the calculation of the network of reference points. In each of the clouds of scanned points, it was necessary to determine the position of the centre of all the reference marks in the instrumental system. The program determines the position of every leading type in a interactive way.

Once the zone of the cloud of points was selected, that where is the reference mark, we analyse the position of the points the brightness of which contrasts with a dark bottom, this to define the centre in the case of the marks of paper. In the case of the measurement of the centre of spheres, we analyse the position of all the points of the sphere to calculate the centre of this last one.

Once reference marks measurement ended, we import the coordinates of the network of reference points and we proceed to the control of all scanner files. In every scan, the scanner situation is determined with the one who fits to best the reference marks measured in the local system with coordinates imported by objects in the global system. In this transformation, we calculate the coordinates of the scanner (x,y,z) and its orientation remains defined with three angles. This control system requires at least three reference points, or a reference plan and two points. The quality of this adjustment can be determined by measuring the distance between reference points in the local system and in the global system. We do not take into account the adjustments which have a distance superior to 20mm.

As soon as all the clouds of points are in the same global system of coordinates, we can make the modelling of the object studied. The FARO Scene program allows the modelling and the extraction of certain geometric forms. However he does not allow to export them in the format suited to the program which was used on the reconstruction of the three-dimensional digital model and on its display. It was thus decided to export directly the clouds of points to model the object of study.

With this process, it is possible to reduce the number of points if they are in excessive number. To do it, we export points by filtering them through a grid where we take only a point by compartment of the grid. The filter which applies to the selection which is going to be exported, eliminates the erroneous points. These erroneous points are isolated points or points which reflected not enough energy and which could result from a fault of measurement.

The export of the cloud of points is made in the format PTC. With this format, the application with which we work then, Autocad-PointCloud, can handle the cloud of points by making cuts and sections, intersection of plans, etc.... It can also reduce the size of files which is interesting. A cloud of two million points engenders a file DXF of 196 MB where as the size of the same object in file PTC is only of 61MB.

## 7. TRIDIMENSIONAL MODELLING

The survey of the castle of Villavellid, of the shape and the dimensions of the construction and its environment gave place to the use of various topographic technics. It was decided that the best representation would be a three-dimensional digital model. We can then obtain from this one all the necessary graphs, the plans of floor or sections. We proceeded to the creation of a digital terrain model ( MDT) for the surface of the zone surveyed by GPS and total station, and the tridimensional model for the castle.

### 7.1. Castle modelling

For the castle modelling, we exported scan in file PTC by using the FARO scene application associated with the equipment laser scanner. Then we load these files PTC, one by one in the application PointCloud. It was necessary to move clouds of points inside the place. Indeed, these points were positioned in another global system that of their reference points, as explained more forward. This movement was made by adjusting the common zones between the clouds of points of the inside and of the outside.

The vertical surfaces of bulwarks were created as surface of network defined by four sides, by selecting the lower axis, the superior outline and two lines which united both. For some irregular details, as the windows and the superior limit in ruin of bulwarks, we proceeded to the digitalization of 3D polylines by uniting its points.

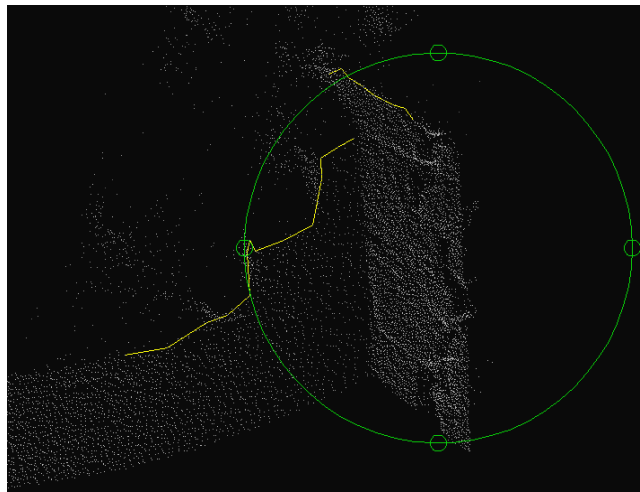


Fig. 5: 3D polyline digitalization

The surfaces of bulwarks in ruin were modelled by different manners. At first lines were digitized on stones of both extremities of every wall, and have created a surface defined by its sides. The result was not satisfactory.

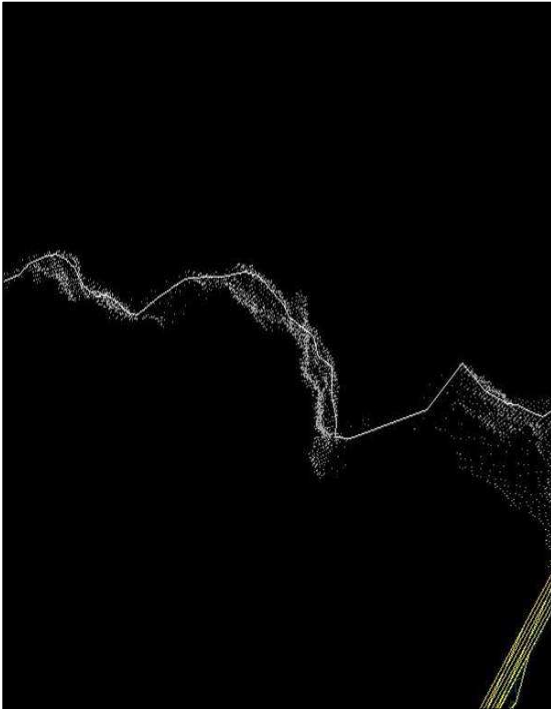


Fig. 6a: Digitalisation on rocks

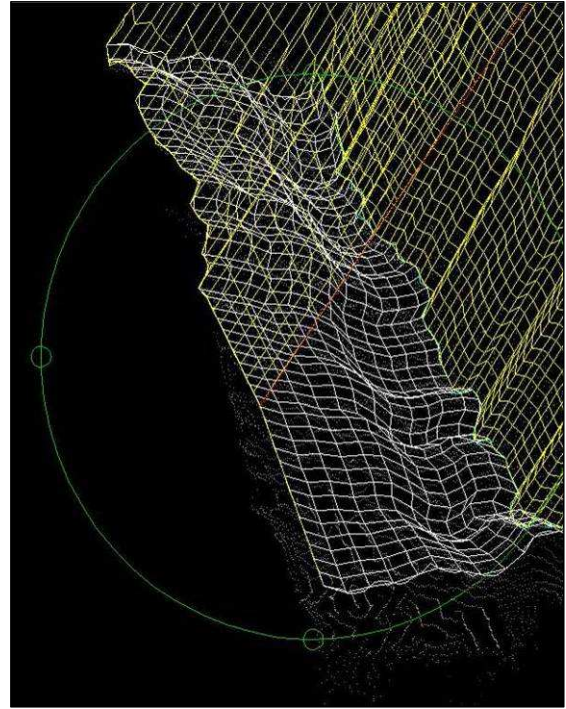


Fig. 6b: Surfaces

We opted for generating a digital terrain model with a triangular irregular network TIN, by extracting with Autocad the points which defined these surfaces. Then, we exported points towards the application Cartomap 5.6 where the digital terrain models were created and surfaces were exported in 3D faces. When surfaces had a slope close to the vertical line, we did not obtain a good result. That's why, these vertical parts were separated from the remained surface. They underwent a rotation in the space to place them in a horizontal plan to apply them the triangulation. Once obtained, the three-dimensional surfaces, the inverse rotation was applied to them to put them back in their original plan. They were added then to others surfaces. Once imported the surfaces of the three-dimensional model of the castle, it was necessary to make a manual edition of the model to correct errors and to make correspond the edges of surfaces to the edges of bulwarks.

For certain elements as the beams of the roof of the hall or the inside of the tower, we measured the necessary distances to build every element directly in the files of the scanner. We select both points forming the extremities of the distance to be measured and the distance appears on the screen. Then, we build the element and place it in the cloud of points. It is a hard and slow work, which difficulty is the spatial analysis of the various elements and their identification inside the cloud of points. The edition of certain elements can last hours. A lot of time, it was necessary to have a look to photos to be able to interpret suitably the cloud of points.

The inside of the tower was modelled during the last sessions of scans realized with the laser scanner equipment. In this way, it was possible to include it in a virtual visit tour. For this reconstruction, the point of departure is the quotation of the first floor, measured with total station since the network of the inside of the square. We built in planimetry a square prism of 7m of base (measured in the cloud of points) and placed in a parallel way in surfaces from the outside of the tower. By taking for base this prism,

we built the various elements, also by helping with measures of the height of staircases in four floors which compose the tower.

When all the structures of the castle were built, they were separated each in their layer to facilitate the application of materials and textures in the phase of display of the complete digital model.

## 7.2. Digital terrain modelling

To complete the digital model, we elaborated the digital terrain model near the castle, by using the Cartomap 5.6 program. We imported in this application points and lines of break of the ground. We created the digital model with these data. Since Cartomap 5.6 we exported the surface of the ground generated in the file DWG of the digital model of the castle.

Both integrated models bring all the necessary information to obtain the graphic files of this project: plans, heights and more some virtual visit tour and recording of the three-dimensional model with textures.

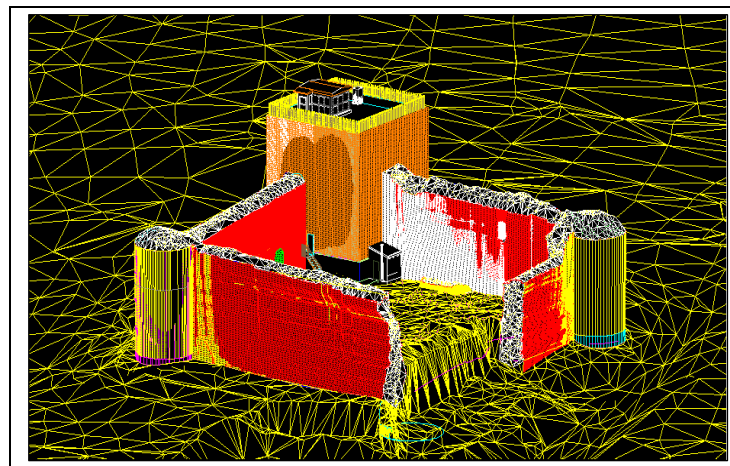


Fig. 6: Castle model

## 7.3. Model display

Once ended the construction of the digital model of the castle and its neighbourhood, we edited the model to be suitably presented to the user. This phase was realized with the program AutodeskVIZ on 2005. The various objects and the surfaces, in 3D format, were exported from the digital model.

### Lights and materials assignation

A material is applied to every object to check attributes such as the colour, the brightness, the opaqueness and the relief, for example. These values used with the lights applied to the scene have to give an impression of reality at the spectators.

By studying the characteristics of the represented element, as well as the conditions of the environment which surround it, we tried to simulate these situations in our model. For the creation of the materials, we resorted to the numerous photos of the castle. We selected photos taken perpendicularly on the surface and they were edited with Corel PHOTOPAINT 10 to be able to use them as boss on objects. We also used materials defined by the program for objects determined as the wood, the metal or the crystal.

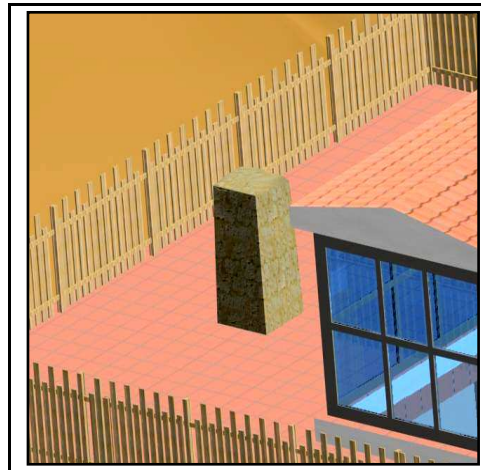


Fig. 7: Materials reconstruction

To give a visible relief to surfaces as bulwarks, tiles... The program allows the application of a bitmap of relief. In this map, the white pixels show all the intensity of the effect of relief on the surface to which they apply. The black pixels do nothing, whereas the grey pixels affect in one of 236 intermediate levels. These maps of relief were obtained by modifying the same forms used on the material but by increasing the contrast and by extracting edges:



Fig. 7a: Material view



Fig. 7b: Relief image

After numerous tries, we configured a system of lights consisted by a diurnal light (corresponding on January 30th in 15:40) and a set of lights of illuminate grey areas.

For the bottom of the model, we opted for an image of clear sky. The resultant image on the edges of the digital model of the ground was not a very good. We thus tried to improve the result by incorporating a digital model of the more vast ground resulting from the National Topographic Map in the 1:25000. But the size of the resultant files in the first attempts was too big for its manipulation. These improvements did not succeed. The final model limited itself to the zone raised in the radiation, although it supposed the vision of the heavenly bottom below the ground.

### Films and model images

We generated a series of images of representative different zones of the model. This phase was made by the "renderizador" of the application, which generates objects, materials, illumination and effects to obtain strong images. An animated sequence was generated by the same program by creating a tour of the castle with a camera.

We show after a series of representative images of the final model at different time of the day:



Fig. 8: Aerial view

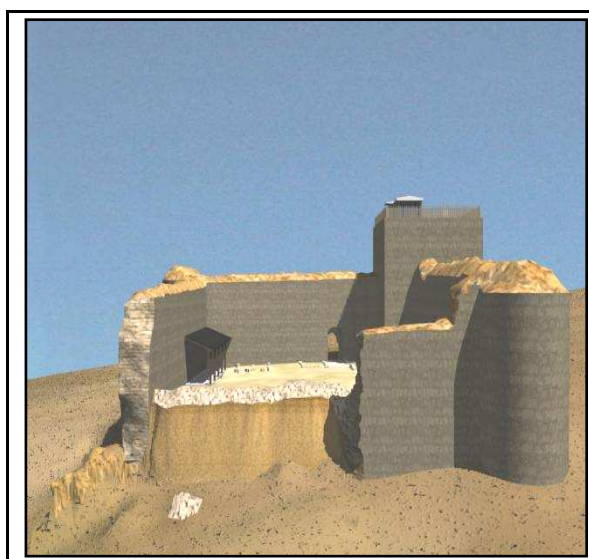


Fig. 9: West wall view



Fig. 10: Patio view



Fig. 11: Patio view

## 8. CARTOGRAPHY DESIGN AND EDITION

In this last phase of the project, we make the cartography of the castle and its environment. The necessary data for the elaboration of this cartography have for origin the previous phases of capture and the data processing:

- Survey of the surroundings with GPS.
- Survey of the circle of acquaintances close to the castle with total station.
- Survey of the walls of the castle with the laser scanner.

From the first two phases, we obtained a cloud of points on which were digitized lines of break and the rest of the elements of the cartography: punctual and linear objects.

With the last phase, we obtained the digital model and from this one, we extracted the lower line of every wall which defines an outline of the construction in floors, to which the other elements got by the scanner were also added and represented on the digital three-dimensional model, as the columns of the hall.

### 8.1. Plans design

We proceeded to the curvature of the triangulation and to the sweetening of the engendered contour lines.

In the zones of difficult access, the results obtained from the triangulation did not represent well the reality. The purpose was to obtain contour lines in the following way. In the cloud of points resulting from the scanner laser, horizontal cuts were realized at the corresponding heights with contour lines. On these sections, we digitized the lines which united points of equal height.

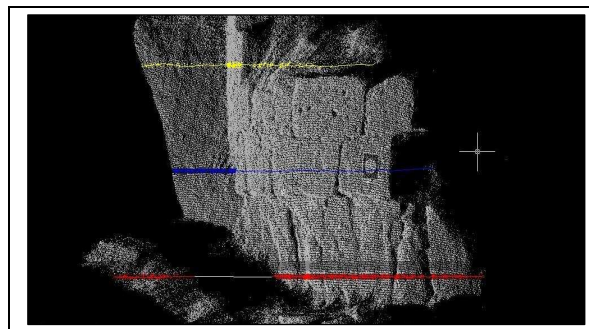


Fig. 12: Horizontals sections

For these maps, the ground relief is represented with contour lines of equidistance 1 m for the plan of scale 1:500 and of 0,5m for the scale 1:200. This equidistance defines well enough the hillside where the castle leans; more auxiliary curves of lesser equidistance were inserted into these flat zones which needed a better definition.



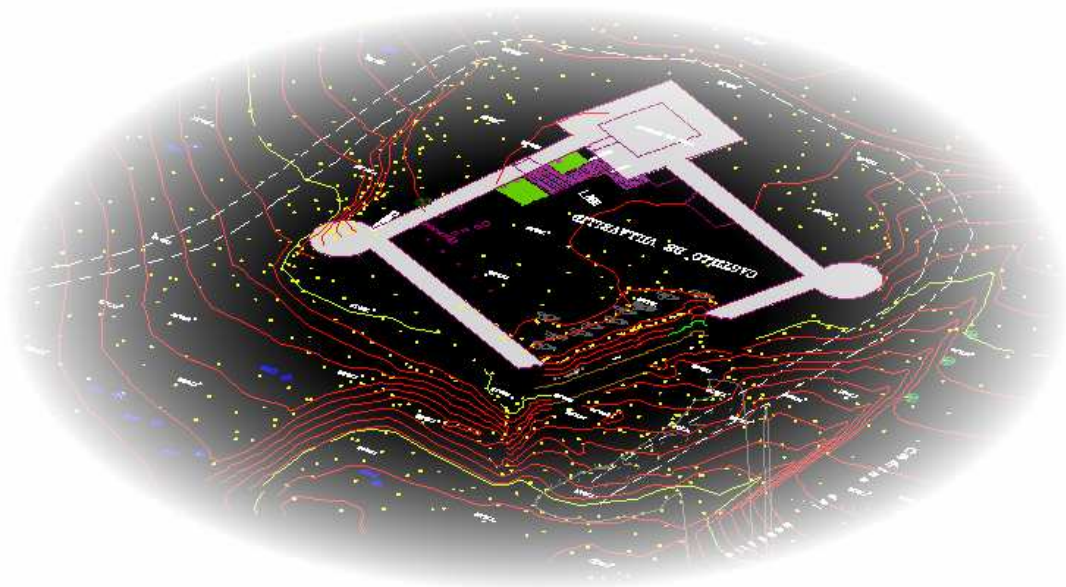


Fig. 13: Resultant image plan

## 9. CONCLUSIONS

The use of the GPS facilitates the survey and the link with a reference system of coordinates, however problems of mask of the signal GPS, shows that the use of the total station is still necessary.

For the works which zone of study is small, as this project, it would have been possible to use methods of classic topography to observe and to calculate all the network and reaching the required precision.

The problems detected in the scanning and the processing of the resultants files, show the importance of the grading and the check of instruments and software.

The difficulty in the use of laser scanner is that informatics supports nowadays can't manage high data files. This problem makes us work sometime in a lower resolution. We had to delete a great number of points to work in an easier way.

To model a cloud of points is very difficult for an inexperienced operator. It was very useful to use the photos of the castle which we had realized. The improvements of the software of the laser scanner with algorithms of recognition of structures and adjustment of surfaces to geometrical elements will improve time of modelling. The relation between the time past on the ground and that spent to the office is a report of 1 for 5 (6 days of field / 28 days of office). This report is usual, the average being between 1/5 and 1/10. It is necessary to remind that the operators were beginners.

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[http://aulaweb.topografía.upm.es/webaula/privado/alum\\_asignat\\_recursos\\_actualiza\\_d\\_escargas.asp?documento=tema\\_2\\_Incertidumbre\\_Observaciones\\_topográficas](http://aulaweb.topografía.upm.es/webaula/privado/alum_asignat_recursos_actualiza_d_escargas.asp?documento=tema_2_Incertidumbre_Observaciones_topográficas)

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3DS Max 6

### Acknowledgment

To the student Manuel Barrio Martínez and all the supervisors and students who made possible the project and this report.

## **ANNEXE I**

### **Reference point report example**

### REFERENCE POINT REPORT

**Name:** E1

**Number:** 1003

**Kind of signal:** Iron stalk coated with mortar.

**Coordinates UTM** sistem ED-50, with orthometric height with sea zero reference

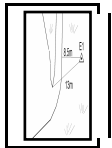
**X:** 310775.267 m

**Y:** 4618072.517 m

**H:** 781.478 m

**Description :** This mark is east of the castle, on a field. Since the castle it is necessary to follow the road of exit, in approximately 3 metres there is a mark of cherry red paint; by continuing towards the right in approximately 8,5 metres, we find the summit marked with the paint.

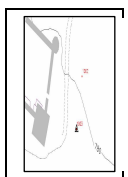
**Sketch :**



**Photography :**



**Place :**



## **ANNEXE II**

## **BUDGET**

## BUDGET

ACTIVIDADES		días	Equipo Humano				Instrumental		Material	Transporte	Dietas		C. Indirectos		COSTE TOTAL POR ACTIVIDAD
			ITT	Auxiliar	C. Unit.	C. Total	C. Unit.	C. Total	C. Total	C. Total	C. Unit.	C. Total	C. Unit.	C. Total	
Fase Previa	Preparación de equipos	1	1	150	150	345	345	3.5				17	17		
				150 €		345 €	3.5 €	0		0		17 €		516 €	
GPS	Desplazamiento	1	1	1	225	225			55	54	108	17	17		
	Señalización y observación	1	1	1	225	225	345	345	61.35	15	54	108	17	17	
	Levantamiento RTK	1	1	1	225	225	345	345		15	54	108	17	17	
	Cálculo	1	1		150	150	19	19				17	17		
				825 €		709 €	61.35 €	85 €		324 €		68 €		2 072 €	
Levantamiento del castillo	Desplazamiento	1	2	1	375	375			110	54	162	17	17		
	Preparación de equipos	1	2	1	375	375	244	244		30	54	162	17	17	
	Señalización y observación redes	4	1	1	225	900	90	360	150	30	54	108	17	68	
	Radiación en cercanías	1	1	1	225	225	97	97		30	54	108	17	17	
	Observación con láser escáner	5	1		150	750	154	770			54	54			
				2 625 €		1 471 €	150 €	200 €		594 €		119 €		5 159 €	
Cálculo de redes	Conocimiento programa	1	1		120	120	19	19				17	17		
	Obtención de coordenadas	5	1		120	600	19	95				17	85		
				720 €		114 €	0	0		0		102 €		936 €	
Tratamiento datos escáner	Conocimiento del programa	4	1		120	480	19	76				17	68		
	Proceso de las nubes de puntos	4	1		120	480	19	76				17	68		
				960 €		152 €	0	0		0		136 €		1 248 €	
Reconstrucción tridimensional	Modelo digital	20	1		120	2400	19	380				17	340		
	Asignación de texturas y salidas gráficas	22	1		120	2640	19	418				17	374		
				5 040 €		798 €	0	0		0		714 €		6 552 €	
Edición cartografía	Diseño de los planos	9	1		120	1080	19	171				17	153		
	Impresión	2	1		120	240	49	98	60			17	34		
				1 320 €		269 €	60 €	0		0		187 €		1 836 €	
Memoria del proyecto	Redacción e impresión	18	1		120	2160	20	360	166.8			17	306		
				4 560 €		760 €	166.8 €	0		0		646 €		6 133 €	
<b>COSTES TOTALES</b>					<b>16 200 €</b>		<b>4 618 €</b>	<b>442 €</b>	<b>285 €</b>		<b>918 €</b>	<b>1 989 €</b>		<b>24 452 €</b>	
Coste del proyecto : <span style="float: right;">24 452 €</span> Beneficio del 15% : <span style="float: right;">3 667.7 €</span> I.V.A. 16% : <span style="float: right;">4 499.1 €</span>															
<b>COSTE TOTAL : 32 618.50 €</b>															

**ANEXO III**  
**Laser scanner LS 880 HE technic**  
**characteristics**