GEOMETRIC DOCUMENTATION OF THE ALMOINA DOOR OF THE CATHEDRAL OF VALENCIA

E. K. Stathopoulou [a], J. L. Lerma [b,*], A. Georgopoulos [a]

[a] Laboratory of Photogrammetry, National Technical University of Athens – drag@central.ntua.gr
[b] Department of Cartographic Engineering, Geodesy and Photogrammetry, Universidad Politécnica de Valencia. Cº de Vera, s/n. 46022 Valencia – jllerma@cgf.upv.es

KEY WORDS: Cultural Heritage, Documentation, Terrestrial laser scanner, 3D Modeling, Texture

ABSTRACT:

Photo-realistic 3D modeling is a process that during the recent years is gaining ground in monument documentation, visualization and dissemination. The combination of a variety of data acquisition technologies, with photogrammetric processing and computer graphic methods has certainly been fruitful. Low-resolution 3D models are frequently used for information dissemination about monuments, e.g., via web-pages in the form of a VRML model. However, the creation, publication and interaction with high resolution photo-realistic 3D models are still rather challenging and require cumbersome tasks. It is certain that a high-quality photo-realistic 3D model, produced to guarantee a given level of accuracy, is a valuable tool for applications involving restoration, preservation and monitoring of monuments. This paper describes the various steps carried out to geometrically document a highly detailed object, the Romanesque door of the Cathedral of Valencia, by a terrestrial laser scanner. The fieldwork and processing stages are described in detail, with special emphasis on the practical difficulties. The final result, the 3D rendered model, is evaluated for its quality and usefulness.

1. INTRODUCTION

It is obvious, that the thorough study of monuments is an obligation of our era. During the recent years archaeological excavations became common practice. Especially over the very recent decades, international bodies and related agencies have passed resolutions concerning the obligation for protection, conservation and restoration of monuments.

The geometric documentation records the present of monuments, as they have been shaped in the course of time. The geometric documentation provides the necessary background for the studies of the past, as well as the plans for the future. Therefore, it may be defined as the action of acquiring, processing, presenting and recording the necessary data for the determination of the position and the actual existing form, shape and size of a monument in the three dimensional space at a particular moment in time. The value of international documentation is presented in The Athens Charter (ICOMOS, 1931).

The geometric recording of a monument is only one, but essential part of the general documentation process dealing with cultural heritage. After the acquisition and development steps, the results are a series of products, usually at large scales, which fully document the geometrical properties of the monument in 2D and in 3D (Georgopoulos et al, 2005).

Due to the spectacular technological advances, especially in the very last years, the collection of the required metric data for a full documentation of a monument is simplified. Furthermore, the development of the computer vision field enables the 3D visualizations of the monuments in a virtual world (Georgopoulos and Ioannides, 2005).

Terrestrial laser scanning allows the quick acquisition of dense point clouds. After processing a 3D model can be produced as well. These results combined with photogrammetric procedures, such as the production of orthophotos, cross-sections, top and elevation plans, represent the complexity of the monuments in standard metric documents.

The aim of this specific study is the full geometric documentation of a small part of a historic monument, the Almoina Door (Fig. 1) of the Cathedral of Valencia (Catedral de Valencia, 2007). For that purpose, contemporary photogrammetric tools based on terrestrial laser scanning and single images are combined to yield highly detailed photo-realistic models.

a)

b)

Figure 1: The Almoina door: a) Front view, b) Detail of the capitals

The Almoina Door (Fig. 1) is one of the three entrances to the Cathedral of Valencia, each one representing different styles, Romanesque, Gothic and Baroque. The magnificent Romanesque door is located on the southeastern side of the church and faces towards the Almoina Square. It has been historically dated to the 13th century A.D. and consists of a combination of arches and pillars. On the capitals, images from the Bible, Genesis, and Exodus are portrayed. On the arches, there are sculptures of saints and angels, but beasts and monsters are contrastingly portrayed as well. Moreover, fourteen male and female sculptured heads of the first inhabitants are placed above the arches. Over the door, in the upper side of the wall, there is a high window, with pillars on the left and right side, on top of which three arches are formed. The total size of the area of study reaches 17 m in width and 19 m in height.

2. METHODOLOGY

2.1 Equipment

The scanning of the monument was accomplished by using the terrestrial laser scanner *Leica ScanStation 2* (Leica, 2007, Fig. 2). It is a pulse-based time of flight scanner with a maximum range of 300 m. Its nominal accuracy is 6 mm at 50 m and can record up to 50,000 points/sec. The field of view of the scanner is 360° x 270°. It includes a digital video camera of low resolution. Its physical dimensions are 265 mm x 370 mm x 510 mm and it weighs 18.50 kg. It comes with the proprietary software *Cyclone* for processing.

Figure 2: HDS ScanStation 2 during the data acquisition

2.2 Field Work

In order to enable indirect target-to-target registration (Lerma et al, 2008), five Leica HDS retroreflective targets were placed around the perimeter of the object.
The targets were measured with a Topcon 7003i total station from one position. Furthermore, around 60 detailed points were also measured geodetically in order to control the quality of the photogrammetric processing. In addition to the laser scanning, some general stereo-pairs and details were taken with a CANON 1Ds Mark III with a 50 mm Sigma lens. Moreover, some general and detailed pictures were also taken by the CANON PowerShot G11 (3648x2736 pixels) in order to fully texture the 3D model. Both cameras have the ability to give raw as well as jpeg files. The total size of the photo files reached 7,5 GB.
The scanning of the object was performed from five different scanning positions (Fig. 3), measuring 3 to 5 HDS targets from each position (Kraus, 2004). The average point cloud overlap was about 40%. The dual-axes compensator of the laser scanner was always on.

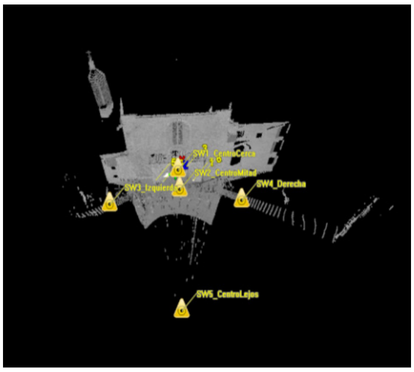

Figure 3: The scanning positions

The distance of the object to the scanner for each scanning clearly differs. However, an equal scanning resolution of 5 mm was set. The field work lasted a total of 8 hours, in which 6.500.000 points were acquired, many of which were obviously retrieved outside the object of interest. The size of the scanning files (imp files) reached 500 MB.

2.3 Processing

2.3.1 Registration of the point cloud: The registration of the five point clouds was accomplished with the *Cyclone* software. First, the point clouds were registered to the HDS targets and later georeferenced (with the help of the total station measured targets) to the local reference system. This was considered the most suitable method of registration in order to minimize the errors. One of the five targets was not distinguished adequately in all of the scans and consequently affected negatively the least squares solution. For this reason it was excluded from the solution. After careful registration, the error reached 0.003 m. The points that were outside of the object of interest were also removed.

2.3.2 Modeling: Modeling serves to create a three dimensional model of the object. This process was accomplished through the software package *3DReshaper* (Technodigit, 2009a). Firstly, the data sets which were provided from *Cyclone* (point clouds) were imported into *3DReshaper*. The extraction of data in the pts format has the benefit of placing each scan in a different layer so that the data can be managed more easily. Eight different point clouds were retrieved, consisting of about 5.550.000 points.
The creation of the 3D model follows 4 stages: firstly, filtering the point clouds, secondly, creating the surface; thirdly, smoothing the surface, and finally, cleaning the surface and hole filling.

Stage 1: Filtering the point clouds
Filtering of all the point clouds was applied first, discarding points creating "noise". Points above a distance threshold were removed. After the filtering processing about 5.440.000 points were left, i.e. 2% of the points were removed.
Stage 2: Creating the surface
The software provides the ability of automatic surface meshing (in Triangulated Irregular Network format) from point clouds in a relatively small time frame. However, it was preferable to create many smaller surfaces. In this way a better representation of details and easier data handling was achieved. The software also gives the option to create meshes while simultaneously removing the noise. It also enables the user to form meshes without removing noise. In this case it was preferable to create the meshes using all the points, since the noisy points were

removed earlier with the filtering command. As a result, through the combination of the layers of the point clouds which were introduced at the beginning, around 90 new layers were formed by separating and merging them (Fig. 4). Some of the layers contained just a small number of points.

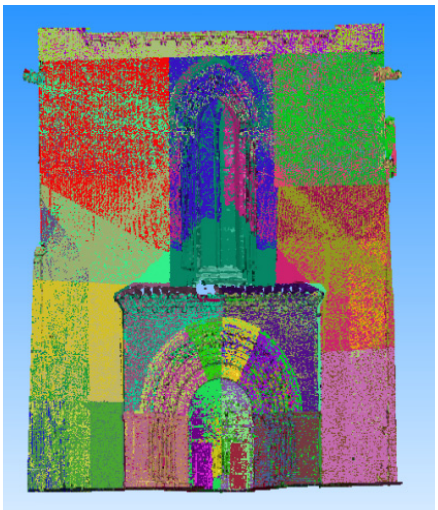

Figure 4: Coloured point clouds after registration

The meshes were formed in TIN format from the software's automatic command, combining all the point clouds which displayed the same part of the object. Through this process 18 meshes were created, with around 10.500.000 triangles formed.
In the smooth areas of the object such as the parts of the stone wall, the results satisfied the demands for accuracy. It represented with great level of detail the shapes and alterations of the object. On the contrary, in the areas with relief such as the areas with many details (arches, pillars, heads, etc.), the created mesh contains much more noise, as well as incorrect triangles, gaps, etc (Fig. 5).
The area just above the vertical axis of the scanner is a special case since the created mesh contains many circular gaps.
On the wooden part of the door (entrance to the Cathedral) a large amount of noise was noticed, which was possibly due to the absorption of the laser beam onto the dark wooden surface.

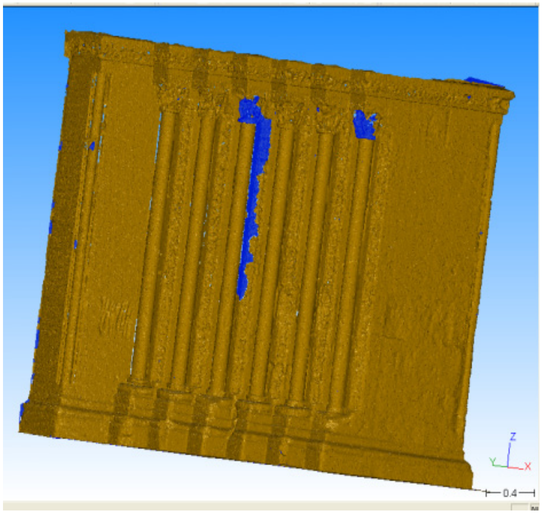

Figure 5: Mesh with lots of sharp edges

Stage 3: Smoothing the surface
Smoothing followed the generation of the meshes since they contained many sharp edges, and wrong triangles (because of the noise). It was conducted carefully in order to avoid erasing of important details for the documentation. The surface smoothing is a very useful function in *3DReshaper*, which modifies the triangle organization so that they "follow" the mesh curves. Generally, the main issue is to find the best compromise between noise measurement elimination and preservation of the maximum of details (Technodigit, 2009b). After some trials, the proper combination of parameters was found (Fig. 6).

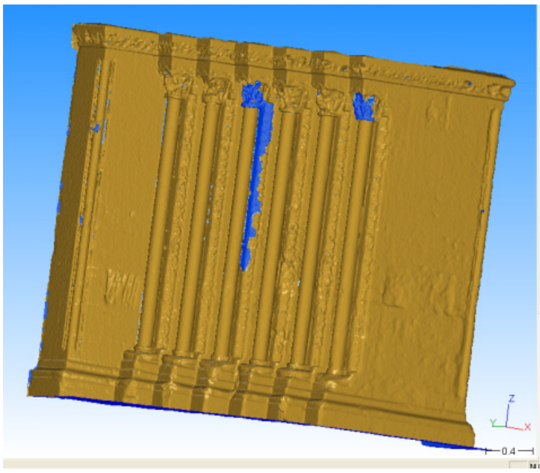

Figure 6: Smoothed mesh

Stage 4: Cleaning the surface and hole filling
The results after the smoothing were satisfactory but there were still some triangles which were clearly incorrect, since they did not belong to the mesh. These areas were noted especially where the object becomes complex. These triangles were removed manually, by a cleaning command. Also, there were many gaps due to the position of certain points (very high and with acute angles). In these areas it was impossible to extract information. The process of covering the gaps was carried out either automatically, with a special command of the program which creates an amount of triangles in any gap indicated by the user, or manually where the automatic command did not yield satisfactory result. In areas where the gaps are too big, bridges were created between the points in order to decrease the size of each gap and later implement automatic filling. At this stage another smoothing command was also locally used to correct the areas with irregular triangles (Fig. 7).

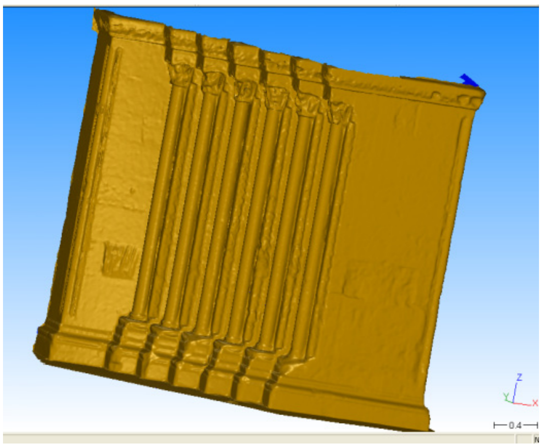

Figure 7: Mesh after cleaning and hole filling

Next, all the meshes were united as one, filling in certain gaps which possibly were formed among them. Simultaneously, the mesh was reduced to decrease the volume of the mesh files to make the data more manageable.

2.3.3 Texturing: The last stage of processing consisted of texturing. This process was also accomplished with the software package *3DReshaper*. The software gives the choice of texture mapping, in which an image is introduced onto the object (preferably not of very high resolution due to the data volume). After the user has measured at least 3 conjugate points between the model and the image, a perspective transformation is automatically estimated and the image is adjusted onto the model (Fig. 8). The parameters of interior and exterior orientation can be introduced if they are known. They can also be estimated if at least 6 conjugate points are measured.
This processing is simple and easy, despite the fact that photos on which the interpolation is applied should be chosen very carefully. In most of the cases, especially in the regions with many details, texturing required more than one photo due to the lack of information on occluded areas. So, two or more photos from different perspectives were used.

a)

b)

Figure 8: a) Mesh after texturing, b) Close-up view of the capitals

It was also necessary to adjust the radiometric values and the color of the photos, because they were taken in different lighting conditions. For this procedure, *Adobe Photoshop CS5 Software was used.* The photos used were in jpeg format (smaller files, easily handled).
The filtered (cleaned) point cloud files can be exported in ascii or binary formats such as rsh type (the software's own format), stl, mdl, obj, vrml, etc.

3. CONCLUSION

The use of the described contemporary methodology gives satisfactory products, despite the fact that the terrestrial laser scanner used was a priori not the most appropriate for the fine details existing e.g. in the arches and capitals. On the other hand, the exhaustive metric documentation that might have required the data acquisition with two laser scanners, one triangulation-based for short ranges and one pulse-based used for mid-range distances, has been overcome with efficient meshing in 3D and the textures coming from the images.
The problems that the users should cope with are mainly referred to the large data amount which has to be handled by the computer and the applied software. These kinds of projects require powerful computers with fast processors and graphic cards. Indicatively, it is referred that for the mesh creation from a point cloud with 450,000 points approximately, 2-3 minutes was required and for smoothing, about 5-6 minutes with a 3.4GHz Pentium D processor. But the most lengthy process was the mesh cleaning and the hole filling. This task was done manually, due to the inability at present to perform by automatic means (with enough reliability) the afore-mentioned tasks. In fact, 3 to 10 hours approximately were needed for each mesh, depending on the complexity of the surface.
Clearly, the geometrical documentation should not include only the formation of the 3D model. The conventional photogrammetric procedures are still irreplaceable and necessary. It is important to emphasize the need of using photogrammetric approaches to capture data, provide control and ensure geometrically correct models (Tsakiri et al. 2003). For the full geometric documentation of the monument, orthophoto mosaics are still required to display the actual conservation state of the monument.

REFERENCES

Catedral de Valencia, 2007. http://www.catedraldevalencia.es/en/arte_paseo-por-los-exteriores.php (accessed 12 Mar. 2010).

Georgopoulos, A., Ioannidis, Ch., 2005. 3D visualization by integrating multisource data for the Geometric Recording of Minumenta. In: *Proceedings of the International Workshop on Recording, Modeling and Visualization of Cultural Heritage.* Ascona, 22-27 May 2005.

Georgopoulos, A., Makris, G.N., Dermentzopoulos, A., An Alternative Method For Large Scale Orthophoto Production. In: *CIPA 2005 XX International Symposium,* Torino, 26 September-01 October 2005.

ICOMOS, 1931. The Athens Charter for the Restoration of Historic Monuments. http://www.icomos.org/athens_charter.html (accessed 20 Jun. 2010).

Kraus, K., 2004. *Photogrammetrie Band 1, Geometrische Informationen aus Photographien und Laserscanneraufnahmen. Walter de Gruyter Verlag*, Berlin, 2004. 7. Auflage.

Leica ScanStation2, 2007.
http://hds.leica-geosystems.com/en/Leica-ScanStation-2_62189.htm (accessed 20 Jun. 2010).

Lerma Garcia, J.L, Van Genechten, B., Heine, E., Santana Quintero, M. (eds), 2008: *Theory and practice on Terrestrial Laser Scanning. Training material based on practical applications*. Universidad Politécnica de Valencia, Spain. 261 p.

Technodigit, 2009a. Discover 3DReshaper in several clicks. http://www.3dreshaper.com/en1/En_3dreshaper.htm (accessed 12 Mar. 2010).

Technodigit, 2009b. Using 3DReshaper to prevent measurement noise and orange skin effect.
http://www.3dreshaper.cpm/en1/En_Noise.htm (accessed 26 Apr. 2010).

Tsakiri, M., Ioannidis, Ch., Carty, A., 2003. Laser scanning issues for geometrical recording of a complex statue. In: *Proc. of the 6th Conference 'Optical 3-D Measurement Techniques'*, Zurich, Switzerland, 22-25 September 2003.