CLOSE RANGE PHOTOGRAMMETRY AND TERRESTRIAL LASER SCANNING: HIGH RESOLUTION TEXTURIZED 3D MODEL OF THE CHAPEL OF THE KINGS IN THE PALENCIA CATHEDRAL AS A CASE STUDY

Francisco JORDÁ[1], Santiago NAVARRO[2], Antonio PÉREZ[1], Rocío CACHERO[1], David LÓPEZ[1], José L. LERMA[2]

[1] Metria Digital, S.L. Parque Tecnológico de Asturias, Ed. CEEI. 33428 Llanera, Asturias, Spain

(fjorda, aperez, rcachero, dlopez)@metria.es

[2] Dpto. Ing. Cartográfica, Geodesia y Fotogrametría. Universidad Politécnica de Valencia.

Cº de Vera, s/n. Edificio 7i. 46022 Valencia, Spain

sannata@topo.upv.es, jllerma@cgf.upv.es

Keywords: close-range photogrammetry, terrestrial laser scanning, documentation, reconstruction, true-orthoimage, dense surface model, heritage, analysis, gothic-style

Abstract

Nowadays close-range photogrammetry and terrestrial laser scanning have been shown to be effective and accurate techniques for the three-dimensional documentation of complex buildings and sites. The combination of both techniques with others like topography or manual measurement tools also offers the user the potential and flexibility necessary to perform an exhaustive documentation of any monumental real estate. This paper describes the surveying process carried out inside a gothic-style cathedral, using, on the one hand, photogrammetry and laser scanning separately and, on the other, both techniques combined to obtain high resolution texturized 3D models, true-orthoimages and plans. Finally an exhaustive comparison of all the results is shown.

The Chapel of the Kings is located at the Ambulatory of Palencia Cathedral, a Gothic building with renaissance, baroque and neoclassical decorative elements. The floor plan of the chapel is hexagonal, with an approximate dimensions of 4,5 meters in length by 3,5 meters in width and 13 meters in height, and it is covered by a starred vault. The main decoration in the chapel is the polychromatic plaster work that covers both the vault and the walls, with no empty spaces. The predominant colours of the plaster are blue, white and ochre.

The generation of accurate digital surface models and photo-realistic outputs is performed by means of Orthoware®, an image-based software tool designed for non-specialist users. This tool also allows the combination of close-range photogrammetry data and large sets of terrestrial laser scanning data. The results have been used to systematically improve architectural understanding. In this sense true-orthoimages are shown to be an optimum product for heritage documentation as both the high resolution 3D model and the photorealistic texturized model are merged into one document.

1. INTRODUCTION

1.1 Background

During the last years multiple applications and projects for heritage documentation have been performed using laser scanner techniques, close-range photogrammetry, combination of both and other techniques, and discussions about which is the best choice for this work have been ongoing, facing the different methodologies and tools [1].

The rehabilitation project of The Chapel of the Kings started at the end of year 2006, completing its documentation in January 2007. At that time there was no unified software in the market that allows to read laser scanner data, perform the DSM, carry out the photogrammetric project and apply high definition textures from images on the DSM. Nevertheless commercial applications existed for the execution of each step separately but with the difficulty of the transformation between formats. Therefore we decided to use our own software for orientation and texture application onto a DSM.

In year 2010 Metria Digital started to commercialize the Orthoware® software, merging multiple software modules developed by the Company and applied on our project production through years enabling us to perform all the operations described above. This is why the Chapel of the Kings project was performed again, in order to compare these results with those obtained in 2007, bearing in mind that the ultimate goal of documentation work was the generation of true orthophotographs [9].

This paper has a double aim; on the one hand to show how close-range photogrammetry, topography and laser scanner data can be combined to create high quality results to serve to the technicians for analysis and facing readings for the heritage restoration. On the other, to present the results of the same work but using only close-range photogrammetry by using Orthoware to generate a high density point cloud based only on digital photographs.

The Palencia Cathedral (Figure 1) is located in the Spanish city of the same name, in the Autonomous community of Castilla y León. It is a Gothic-style building with visigothic, romanesque, renaissance, baroque and neoclassical decorative elements. It is approximately 130 meters in length by 50 meters in width and 30 meters in height in the apse.

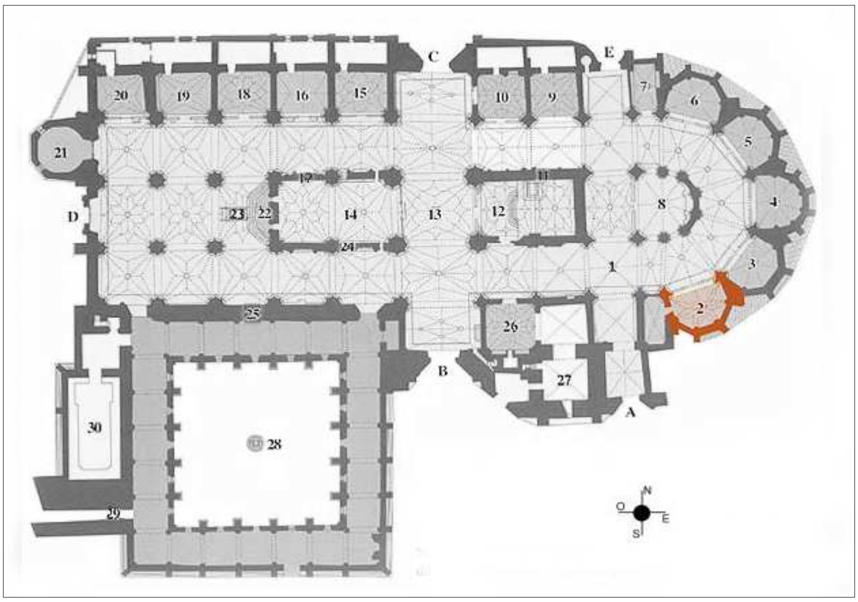

Figure 1: Ground plan of the Palencia Cathedral. Tha Chapel of the Kings is highlighted in red color.

The Chapel of San Pedro is also known as The Chapel of the Kings, by the plaster reliefs decorating it. It was built in the XIV century and reformed in the XVI century, and it is located in the first place of the ambulatory. Its plant is hexagonal and is covered by a groin vault [12]. Its dimensions are approximate 3.5 meter in width by 4.5 meter in length and 13 meter in height [8]. It has a polychrome plaster ornamentation that covers the walls and dome, being the predominant colours blue, white and ocher. In the dome can be seen the images of a series of prophets inside medallions, accompanied by coat of arms, grotesques and angelfish. The alterpiece of the Chapel is a renaissance work, with the figure of San Pedro in the main niche.

1.2 Orthoware capabilities

Orthoware is an innovative software specifically designed for documentation of historical and cultural heritage, easy to use by non-photogrammetrists automating to a large extent all the routine tasks so much so that the user need only evaluate the results and make decisions. It provides a fast and easy startup, evolving progressively towards the results with the accuracy and detail required [9, 10].

The detection and marking of hundreds of homologous marks in the working images is carried out automatically by using various computer vision algorithms to calculate the relative orientation of the cameras with small user intervention [3]. Subsequently, the internal parameters of each of the images used are accurately recalculated using a self-calibration process [9].

The densification of the model is performed by calculating a detailed disparity map using correlation. This map provides the small corrections to produce millions of new homologies. Having seen the disparity map, the user can decide which areas are considered to have been modeled in compliance with defined requirements for precision and detail, and, with those that do not, input a new point to refine the initial reference surface in an iterative process.

In this way, the user need only outline the areas of interest and correct the areas where the correlation fails, which can easily be detected visually. To obtain the correct position of each pixel Orthoware uses mathematical models such as Least Squares Matching (LSM) and Multi Photo Geometrical Constrained (MPGC) [4, 5, 6, 11].

A key concept of this software tool is the design of a new graphical user interface that enables high interactivity to perform corrections in real time through development in GPU (Graphic Processing Unit) using the OpenGL and DirectX graphics libraries.

2. WORKFLOW

As mentioned before, two different process were carried out to obtain the same documentation, the true-orthophotogrpahs of the Chapel and his dome.

The first process was to join the laser data (Figure 3) and include high resolution textures. 11 scans were performed using a Faro LS 880HE laser scanner with a point density of 1 point/cm2. The relation between the different scans was carried out through spheres and targets. Also, to provide color to the point cloud with the aim of improving the representation, a Nikon F60 camera with a 6 Mpx resolution was installed on the laser scanner. Faro Scene®, RapidForm® and Polyworks® were the software applications used to get the DSM with a 0.3 cm grid step.

To perform the photogrammetric project a FujiFilm FinePix S2 SLR camera was used (2/3” format, 6 Mpx resolution and a 18mm calibrated lens), and some targets, calibrated spheres and singular points of the facings as control points (Figure 2) were measured with a Leica TCR 1103 total station. A selection of 22 photographs of the 591 of all those taken in the field work were used in the photogrammetric project, resulting a RMS of 0.008 m. and a 84% medium coverage of the images.

The joint of the photogrammetric data and laser data was performed using the control points. In this way the reference system of the DSM and the photogrammetric project was the same in both cases. Then the texture obtained from the images of the photogrammetric project was projected on the DSM carried out from the laser scanner point cloud. This data joint was performed with own software modules.

Figure 2: Control points distribution

The second process was to generate the true-orthophotographs just only from the images. The densification of the model was performed by means of some dense matching techniques implemented in Orthoware. The number of images used in the project was 52, the RMS 0.005 m and a 95% image covarage. A point cloud with a density of 9 points/cm2 was generated to perform the DSM with a 0.3 cm grid step.

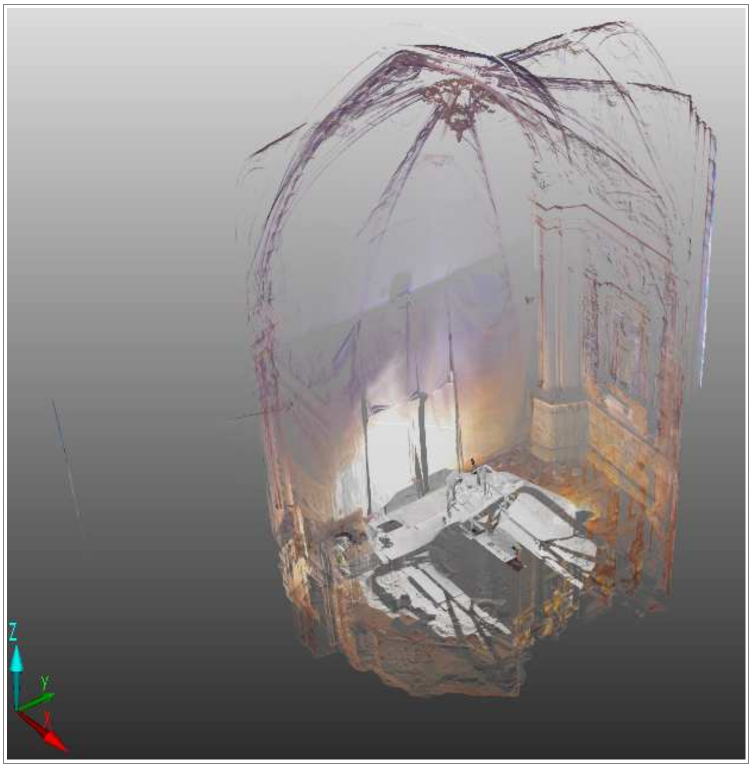

Figure 3: Laser Scanner point clud distribution

3. RESULTS

3.1 True orthoimages

The true orthoimage of the chapel (Figure 4) covers its five face elevations and the vault. The orthoimage was generated with a scale of 1:40, an accuracy of 8mm and a 150 ppi resolution.

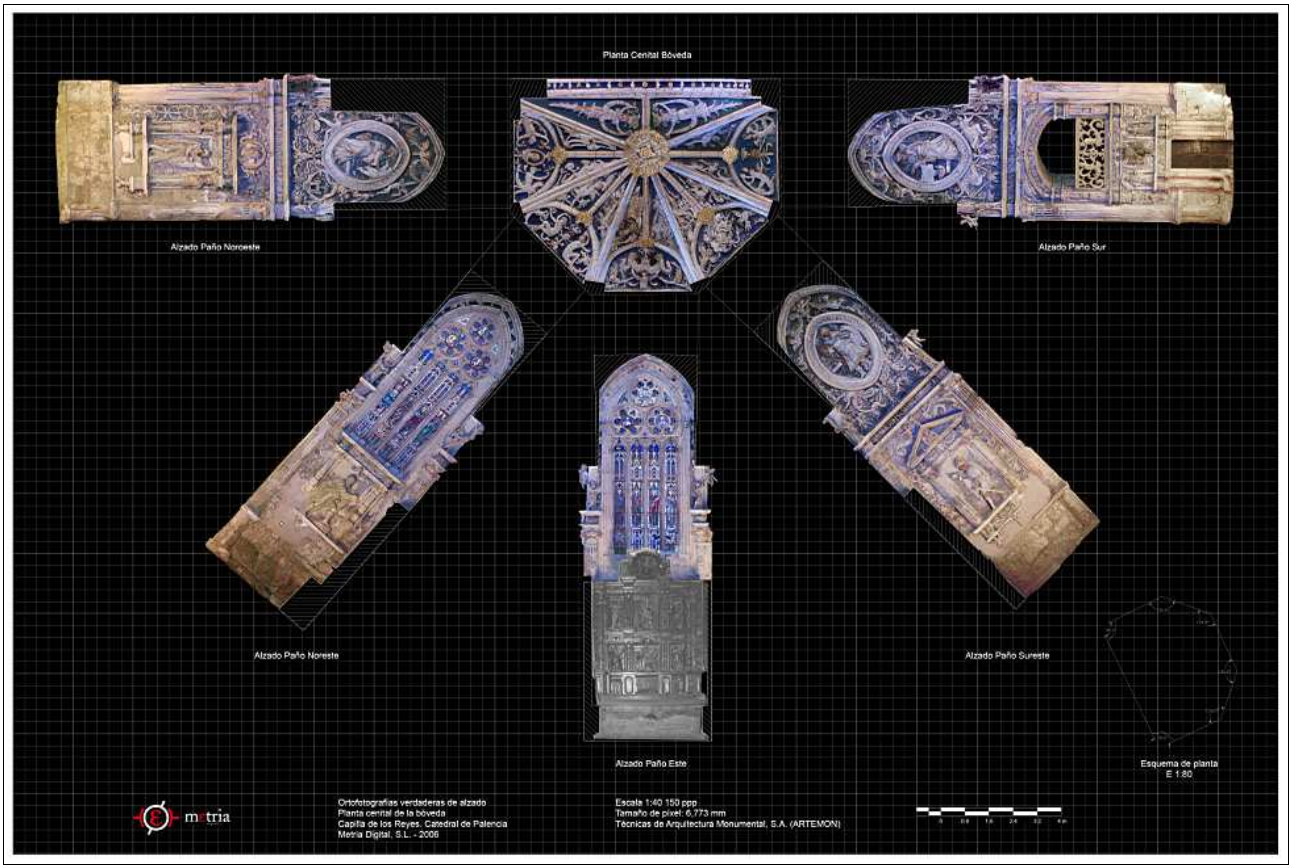

Figure 4: True orthoimages of the faces and the vault

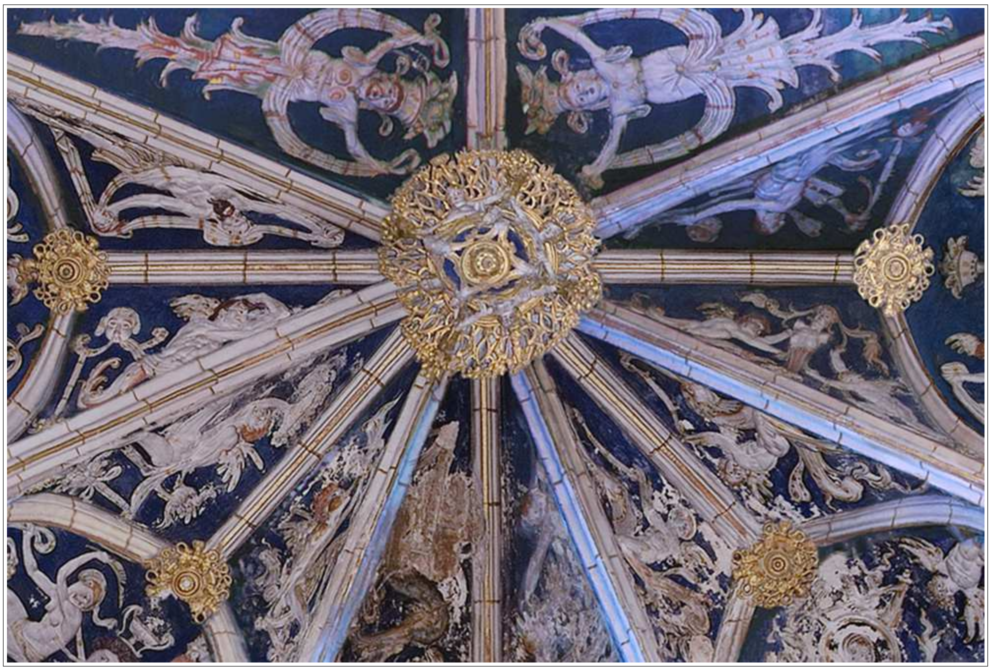

Figure 5: True-orthoimage detail of the vault

3.2 Comparison of results

In order to know the differences between the point cloud obtained with laser scanner (Figure 6) and that performed using Orthoware (Figure 7), the comparison of the two DSM was carried out (Figure 8) using the same reference system.

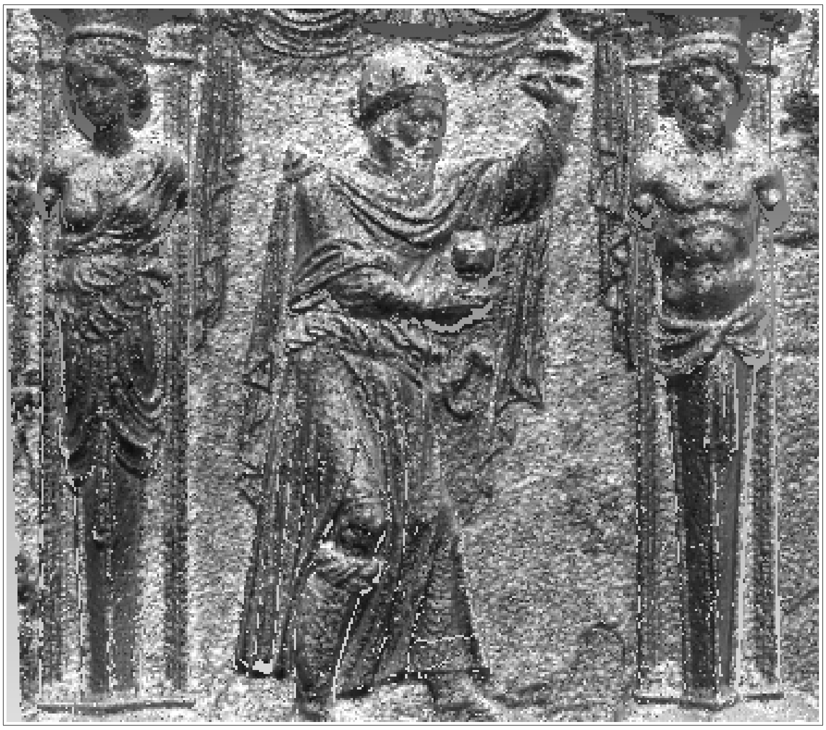

Figure 6: Image of point cloud obtained with laser scanner

Figure 7: Image of point cloud obtained with Orthoware

The comparison of the results (Figure 8) shows that both models match in a 99% according to the required accuracy (1 cm).

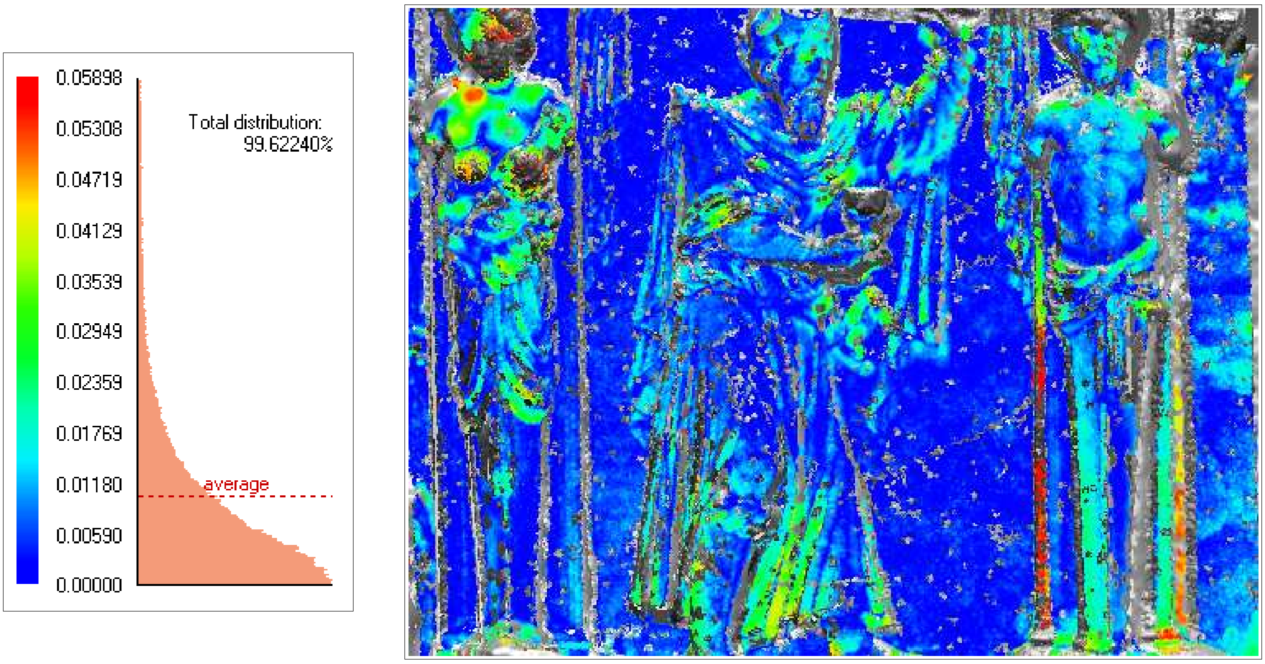

Figure 8: DSM comparison and resulting histogram

4. DISCUSSION

Using some conventional commercial software, close-range photogrammetry can not create 3D models automatically. In contrast, close-range photogrammetry presents a high accuracy and flexibility methodology without being an invasive technique, allowing to obtain a selective data acquisition from any area or region of the object [2].

On the other hand, laser scanners allow the massive data collection of point clouds, but this technique only gets the 3D position without other additional information, like the radiometry data. It is possible to solve this deficiency adding a digital camera on the device, but this is an imprecise, discrete and no selective information [7].

The combination of both methods can solve the limitations that each has separately, ensuring the geometric control of the project with topographic measurements. In this way we get a high quality three-dimensional model with high resolution texture obtained using close-range photogrammetry techniques. Orthoware can merge the results obtained using laser scanning and close-range photogrammetry. It can also create high-density DSM data based only on close-range photogrammetry, as proved in this paper.

The accuracy and quality of the point cloud obtained by laser scanner depends on the surface of the object and the accuracy of the laser device itself. Using Orthoware close-range photogrammetry the factors that define the quality of the point cloud can be summarized: quality of the images and its coverage, and the accuracy of the scaling measurements used in the photogrammetric project.

The differences between laser and photogrammetric models are attributed to the noise introduced by both models at the time of its generation. In the photogrammetric model, noise can be caused by the accuracy of the extrinsic and intrinsic parameters of the cameras used and the error of correlation techniques identifying homologous points. About the laser model, the noise is due to own error data of the capture system and data post-processing.

5. CONCLUSIONS

Laser scanning and close-range photogrammetry are suitable techniques for the heritage documentation, obtaining the best results when combining both techniques solving the limitations that each has separately. Moreover a new field of action is opened with infinite applications.

Orthoware is a suitable software for the performance of photogrammetric projects that can import data from other capture devices, as well as an image-based tool able to carry out three-dimensional reconstruction with high resolution textures. Its dense matching algorithms can generate point clouds and high density meshes only from photographs, opening new posibilities to close-range photogrammetry as a tool for massive data capture.

The accuracy of point cloud obtained with Orthoware software depends on the quality of the working images and on the quality of the photogrammetric project.

6. REFERENCES

[1] Almagro A., Almagro Vidal A., 2007. *Traditional Drawings Versus New Representation Techniques.* In: The ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Athens, Greece, Vol. XXXVI-5/C53, pp. 52-57.

[2] Avşar, E. Ö., Duran Z., Akyol O., Toz, G., 2008. *Modeling of the Temple of Apollo Smintheus Using Photogrammetry and Virtual Realty.* In: The ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Beijing, China, Vol. XXXVII, Part B5, Commission V, pp. 357-360.

[3] Bay, H., Tuytelaars, T., Van Gool, L., 2006. “SURF: Speeded Up Robust Features”. ECCV2006. Lecture Notes in Computer Science, A. Leonardis, H. Bischof, and A. Pinz, Eds., vol. 3951. Springer, 2006, pp. 404-417.

[4] Gruen A. 1985. Adaptive Least Squares Correlation: A Powerful Image Matching Technique. South African Journal of Photogrammetry, Remote Sensing and Cartography. Vol.14, pp 175-187.

[5] Gruen, A., Baltsavias, E., 1986. Adaptive least squares correlations with geometrical constraints. Proc. of SPIE, Vol. 595, pp. 72-82.

[6] Gruen, A.W. and Baltsavias, E.P., 1988. Geometrically constrained multiphoto matching. Photogramm. Eng. Remote Sensing 54 5, pp. 633–641.

[7] Lerma, J.L., 2002. Fotogrametría Moderna: Analítica y Digital. Universidad Politécnica de Valencia, p. 449.

[8] Navascués, P., Sarthou, C., Catedrales de España. Espasa Calpe 1996. ISBN 84-239-7645-9

[9] Pérez, A., Cachero, R., Navarro, S., Jordá, F., López, D., Lerma, J.L., Martos, A., 2011. Digital Reconstruction of the Church of San Ildefonso in Zamora (Spain) using Orthoware. In: The ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Trento 2011 (3D-Arch'2011). Vol. XXXVIII-5/W16.

[10] Pérez, A., Lerma, J.L., Martos, A., Jordá, F., Ramos, M., Navarro, S., 2007. Generación automática de ortofotografías verdaderas en Arquitectura. In: Séptima Semana Geomática de Barcelona, España.

[11] Remondino, F., Menn, F., 2008. Image-Based Surface Measurement for Close-Range Heritage Documentation. In: The ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Beijing, China, Vol. XXXVII, Part B5, Commission V, pp. 199-206.

[12] Sancho, A. La Catedral de Palencia: guía breve. León: Edilesa, 2005. ISBN 84-8012-515-2