

## LOW COST DIGITAL PHOTOGRAMMETRIC TECHNIQUES FOR 3D MODELIZATION IN RESTORATION WORKS. A CASE STUDY: St. DOMINGO DE SILOS' CHURCH (XIVth CENTURY, ALCALA LA REAL, SPAIN).

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### ABSTRACT

This work is about a photogrammetric record and the 3D modelization of St. Domingo de Silos' Church (XIVth century), in Alcala la Real (Jaen, Spain). The church is located in the fortress of La Mota Castle (declared National Monument in 1931) that it was a strategic stronghold during medieval times. The origin dates from the XIVth to XVIth centuries. It was the first church founded in the city of Alcala, above the rests of an old mosque. The church is gothic mudejar style, but large reconstruction was done at the end of XVIth century. At present it is a ruin near to collapse and urgent actions for the reconstruction were decided. Previous to the restoration works, different surveying and photogrammetric techniques were used for a reconstruction project, but at moderate costs with the extensive use of non metric instrumentation. The main final products, in case of planar surfaces, were mosaics of rectified photographs, although orthophotographs, stereoplotting of main walls, cross sections and DEM of the vault were also made in order to support the final restoration project. Finally, a 3D modelization was carried out. This was an accurate photo-realistic model with real textures taken from the image mosaics (made from the rectified images and the orthophotographs). The process to create the geometry of facades, walls, arcs, vault, etc. and their integration in the same model with textures was mainly done under CAD and 3D modelling programs. Also photo-realistic walkthrough movies and anaglyphic images were done in order to show the present ruin state of the church. The paper analyse the full photogrammetric project, the evaluation of the non metric instrumentation and methods used, the creation of the model and the evaluation of additional widely used 3D modelling software for more detailed parts in the general model.

### 1. INTRODUCTION

The St. Domingo de Silos' Church is located in the impressive fortress of La Mota Castle in Alcala la Real (Jaen, Southern Spain). The place was a strategic stronghold during medieval times, and subsequently occupied by the Moors in 713. Thereafter, Alcala was the scene of frequent battles between the Moors and the Christians. The origin of this church dates from the XIVth to XVIth centuries. It was the first church founded in the city of Alcala, above the rests of an old mosque, after the fortified city was conquered to the Muslim Kingdom of Granada in 1341. The church, built in XIVth century, is gothic mudejar style, but large reconstruction was done in the sacristy and tower at the end of XVIth century. It presents an asymmetrical ground plan with two large rectangular naves, the main chapel (with a strange plan, between trapezoidal and rectangular) covered by a rib vault, the sacristy and a square tower (Figure 1). Because the historical importance of this church, it was declared National Monument in 1931. The original paintings, sculptures and furnishings of the church are now dispersed in private collections, in other churches in Alcala la Real and Granada cities or lost. At present it is a ruin heavily damaged and near to collapse after injuries during the Spanish War (1936-39) and further decades of abandonment. So, local authorities have decided urgent actions for the reconstruction. Previous to the restoration works, the monument has been documented by means of photogrammetric and surveying techniques (UJA, 2003). Since the financial cost of the photogrammetric survey had to be kept low, extensive use of non metric and semi-metric instrumentation and mosaics of digital rectified images were used.

The main parts of this work have been done with a digital reflex non metric camera (Canon D30). This camera has been successfully tested for use in low cost applications for low and medium precision surveys in archaeology, architecture and cultural heritage (Mata et al 2004).

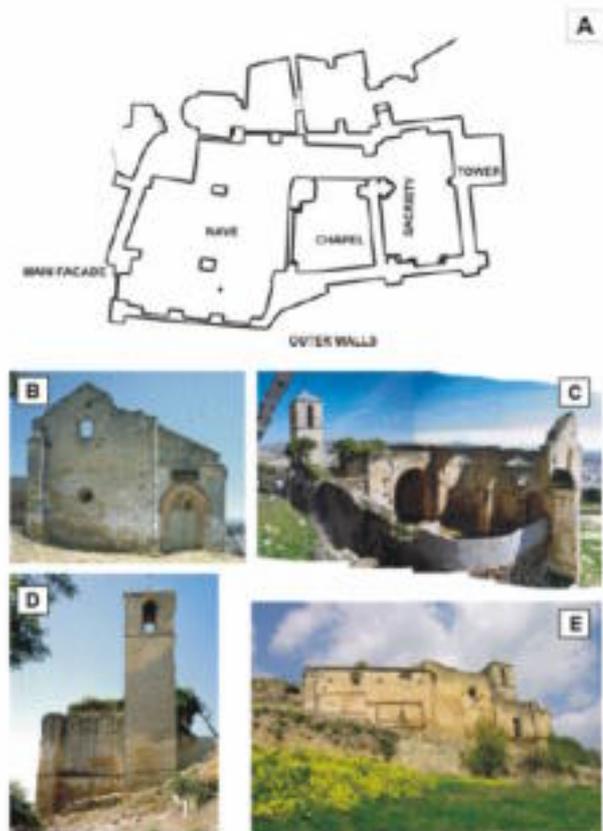


Figure 1. A: Ground plan of Santo Domingo de Silos' Church; B: Main façade, south side; C: South-western side (belfry, nave, arches and access to the chapel are visible); D: Bell tower and north wall; E: Panoramic of east walls.

The camera was calibrated at laboratory conditions, but additional self calibrations were carried out with field control points. Diverse tests with wide angle and normal lenses have shown that camera calibration at laboratory and the use of control points can minimize the systematic errors present in non metric cameras when stereopairs are used. But if the photogrammetric network is appropriate a field self calibration can improve the final accuracy. Our experiences have shown that errors between 5-20 mm can be reached at object-camera distances up to 15 m. (longer distances have not been tested) even in the case of single stereopairs. In this case, the accuracy it was for usual architectural/archaeological applications enough. As main drawback of this camera we can point out the low sensor resolution (3.2 MP). So when camera/object distance increases or high oblique photographs are employed the image quality of the final product reduces considerably. (Cardenal et al 2004)

## 2. PHOTOGRAMMETRIC SURVEYING

### 2.1 Introduction

Diverse photogrammetric instruments and methods have been applied since a wide variety of conditions were found. Instruments were: terrestrial metric, semi-metric and non metric cameras (analogical and digital); both photogrammetric and desktop scanners; analytical and digital plotters. Stereoscopic pairs and convergent photographs were used.

Data reduction was made with conventional stereoplotters (analytical and digital), analytical rectification and usual image processing software. The overall accuracy of the photogrammetric survey was better than 3 cm. In the case of rectified photographs, this accuracy concerns to points in the rectification surfaces.

### 2.2 Data acquisition and reduction.

The belfry, 17 m height, vault and inner walls were photographed with different cameras, both semi-metric (reseau plate) and non metric, analogue and digital, cameras: Hasselblad 500 C/M (with a reseau plate installed); Pentax 67 II and a digital Canon D30.

These cameras were used in both normal and convergent cases. Convergent photographs were taken in order to reach a favourable geometry for bundle adjustment (selfcalibration) and control point densification, and also when the object/camera distances were limited.

Combination of a metric camera (UMK 10/1318) analytical plotter and normal case has been used in the main façade and main external walls (in the east side). In these cases both elevation drawing lines and rectified images mosaics were done (Figures 2 and 3).

Figure 3 illustrates the architectural lines, cracks and indications of main disorder in the walls in the east side. These walls show large deformation, with a dangerous trend to collapse. In fact, the walls have ties and they are shored up.

The study of the rib vault that covers the chapel (Figures 1 and 4) was made by zenithal shots organised in three parallel strips (5 photos per strip), with a CANON D30 camera. This chapel has an asymmetrical plan (between rectangular and trapezoidal) of 6 x 7 m and a height between 3.5 m (at the rib springing) and 7 m.

A selfcalibration was performed with this block in order to refine the inner parameters (computed at laboratory) in real conditions. Control and check points were used. Errors in check

points were +5 mm and +12 mm, expressed as standard and maximum residual errors in coordinates, respectively.

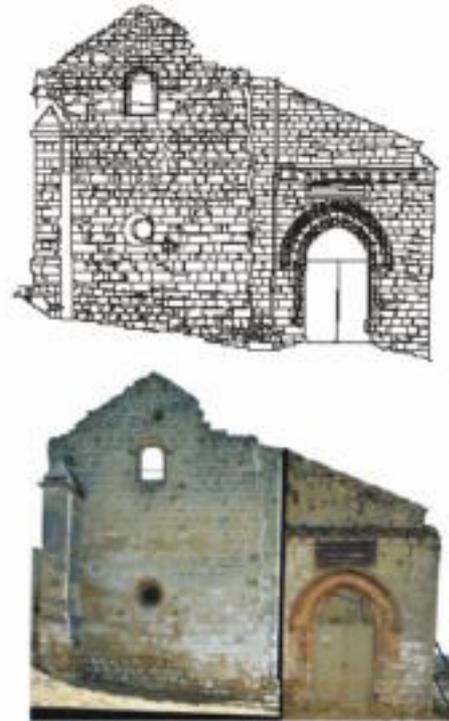


Figure 2. Elevation view of the main façade and mosaic of rectified images (Canon D30 Digital Camera).

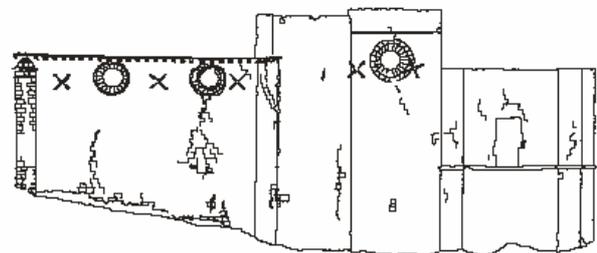


Figure 3. Elevation view of the walls in the east side.

A digital surface model (DSM) of the vault was created using matching techniques and manual edition in a DPW (Socet Set®). The DSM post spacing was 0.025 m with a total of 76500 points. This DSM allowed a contour map of the vault with an interval of 5 cm and subsequent profiles of main sections of the vault. These sections and contour map have illustrated clearly the large deformation of the vault, which at present is near to collapse. Finally, an orthophotograph (3 mm GSD) was created (Figure 4).

The image rectification has been used as main technique. This was the case of the belfry, all inner walls and the most of the outer walls. Both stereoscopic pairs and convergent photographs were taken and the two networks were used in order to reach a favourable geometry for bundle adjustment and control point densification. In these areas image rectification was found to be suitable, since most walls and arches could be projected onto a surface without accuracy loss (the required accuracy should be better than +4 cm) and the final project cost had to be moderate.

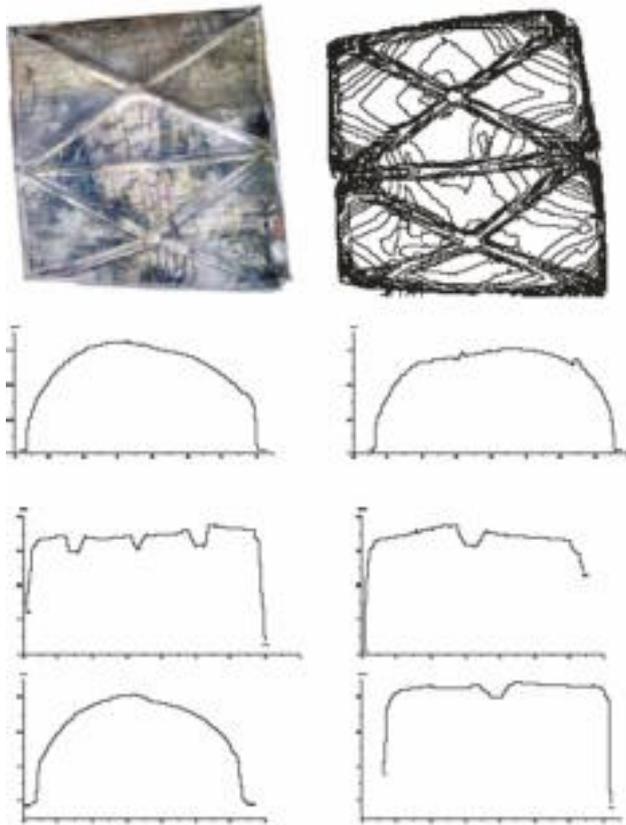


Figure 4. The Orthophotograph, contour map and main profiles showing the deformation in the chapel vault

Analytical rectification has been made by means of the well known two-dimensional projective transformation (Novak, 1992): Once transformations were computed, each single image was warped using ENVI®. The resampling was made by bilinear transformation. The computed radial distortion coefficients (by selfcalibration) were taken into account to avoid curved edges due to the large distortion values of the non metric lenses used. In most cases, a single image was not enough to cover the whole wall or arch surface. So rectified image mosaics were necessary. Seam lines between rectified images were smoothed by selecting an edge feathering distance of 20-30 pixels. Finally, a radiometric adjustment was made to homogenize the mosaics (Adobe® Photoshop®). Figure 5 shows the mosaic formation process. This mosaic corresponds to the south wall of the sacristy. A total of 10 photographs and 15 control points were used. In some photographs the number of control points was 4 or less, so in order to apply the projective transformation with redundancy, additional control points were necessary. A bundle adjustment was carried out for the control point network densification.

Also the UMK images have been used for image rectification mosaics. So in outer walls (east and north sides) all available cameras were used. Figure 6A shows a mosaic in the outer east walls with UMK and Hasselblad (tower) photographs. Rectified single images from the different walls (with several orientations) were mosaicking. Planes were projected onto a surface parallel to the belfry west side. Figure 6B shows the north side walls (Canon D30) and belfry (Pentax camera).

In other areas of interest, some complications appeared. So, in the arches crossing the nave (Figure 7), space limitations and height of the arches made necessary large number of photos (Figures 7, 8 and 9). Besides, in some parts of the arches the photos had to be highly oblique. These conditions added

problems to the mosaic formation. On another hand, these problems made more complicate the set up of the control/check point network.



Figure 5. Original images from Canon D30 and mosaic of rectified images in the south wall of the sacristy.

Figure 7 shows a selection of highly oblique photographs employed in the bundle adjustment to solve the upper section of the rear arches. Workplace limitations made extremely complicate the measurement of control points due to excessively inclination of sight. So, most part of control points was by means of photogrammetric network densification.

The rectified images mosaic of the rear arches is illustrated in Figure 8.

Figure 9 shows the front side of the arches. In this case stereopairs with the Canon D30 were taken. Because limitations at the right side impeded the use of stereopairs, the right pillar was covered by convergent photographs. In the left part of the mosaic the deformation of walls and arch is noticeable. Thus this arch is leaning toward the chapel.

In both Figures 8 and 9 images of the nave walls have been

added in the background only for visualization.

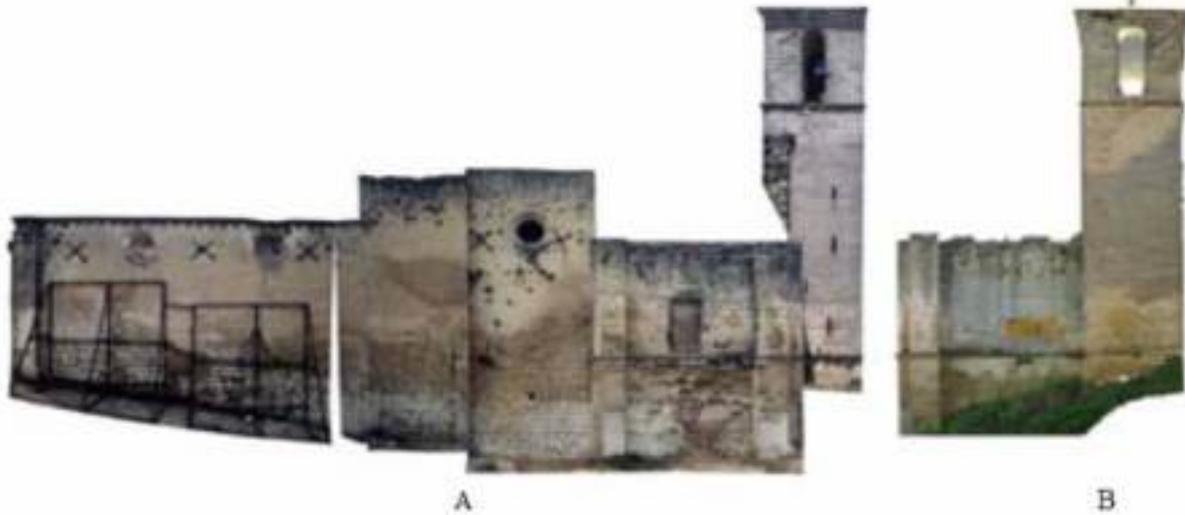


Figure 6 A: Image rectified mosaic of outer east walls and belfry. B: Image rectified mosaic of outer north walls and belfry. East side walls show large deformations in the projected surface.

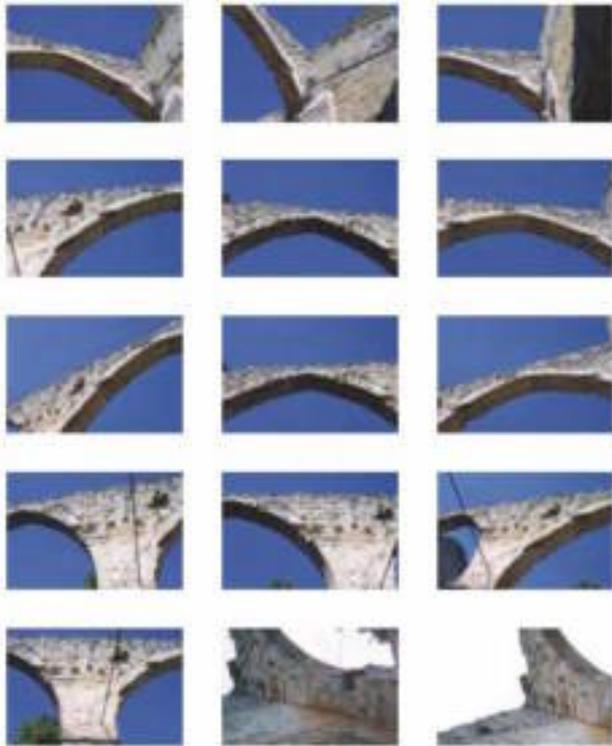


Figure 7. Photographs upper part of rear arches in the nave.  
Camera Canon D30 and 35 mm lens.

### 3. MODELIZATION

#### 3.1 Modelization

The photogrammetric network and the rectified images (both single images and mosaic) were employed in modelling the church. The common reference coordinate system was obtained from the surveyed control point network. Previous to the full 3D model, several commercial programs were used for

modelling parts of the church (Shapecapture© and Photomodeler©). This modelization was only at visualization level (WRML files) but not for metric applications. An example is shown in the Figure 10.



Figure 8. Images rectified mosaic of rear arches in the nave



Figure 9. Images rectified mosaic of front arches in the nave.



Figure 10. Partial 3D model of the church. Left chapel wall and vault textures have been suppressed to allow the visualization of the camera positions inside the chapel (screen capture from Photomodeler©).

Besides, a full 3D model of the church (with higher metric quality) has been carried out with the commercial programs 3D StudioMAX© and Autocad© (Ramos, 2005). The ground plan of the model has been taken directly from surveying (Figure 1). The profiles of the main walls, arches, etc have been digitized from the rectified images and mosaics. These profiles have been oriented and inserted in their correct position in the ground plan, so, an initial wireframe model has been obtained. Then, the generated profiles were converted in surfaces. (Figure 11). Both sides of the walls, defined by the surfaces, have been assembled to create 3D solids (Autocad©).

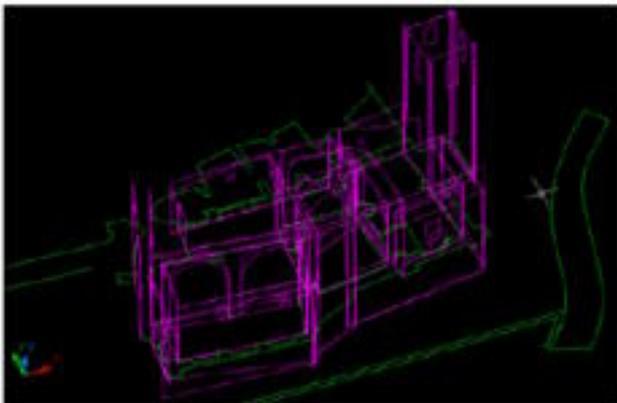


Figure 11 Initial 3D wireframe model with the ground plan and the walls profiles.

Then the model was exported to 3D Studio MAX© where the textures, taken from the rectified images, were added to give the photorealistic look. Some details have been modelled separately and then assembled in the full model. For instance the figure 12 shows the 3D model of a column in the sacristy modelled previously with Photomodeler©. This column is located in the wall sacristy shown in the figure 5. The full 3D model and partial view of the church are shown in figures 13 and 14.

A special case is the 3D model of the vault. In the full 3D model this part has been simplified and the vault surface was generated from the upper parts of the walls profiles of the chapel. Anyway, a detailed 3D of the vault was obtained from both the DSM and ortophotograph (Figure 4) with the TerragenTM. Some additional final products were generated for visualization purposes, such as some walkthrough movies in the inner of the church and anaglyphic images (Figure 15). The anaglyphic

images were made from stereopairs obtained from the 3D model of the church. The combinations of colour channels have been made with Photoshop©.



Figure 12 Wireframe and solid (with photorealistic textures) of the column of the sacristy.



Figure 13. Full 3D photorealistic model of the church.



Figure 14 View of the 3D of the church. The textures are mapped from the rectified mosaics. View from nave to chapel.



Figure 15 Examples of anaglyphic images: vault in main chapel (above); and access to sacristy (below).

#### 4. CONCLUSIONS

As conclusion, different photogrammetric techniques were successfully used for a reconstruction project and cataloguing of an important historical building, but at moderate costs with the extensive use of non metric and semi-metric instrumentation.

The combinations of different methods, cameras and instruments have shown to be effective. These different data acquisition and reduction methods were necessary due to the wide variety of situations found.

This work has shown that the Canon D30 digital camera can be used for conventional architectural and archaeological surveys including stereoplotting, DSM, ortophotographs, rectified images, 3D modelling, but also control point network densification.

The employment of digital cameras has been useful because in some cases the data acquisition had to be very fast due to the

stability problems and collapse risks were very high, especially in some parts (i.e. the vault).

All details in the church were metrically catalogued for further study, if necessary, for the restoration works. The work has been completed with a full 3D model with metric quality and some anaglyph images and walkthrough movies of the mains details of the church.

#### REFERENCES

Cardenal, J., Mata, E., Castro P., Delgado, J., Hernandez, M.A., Perez, J.L., Ramos, M., Torres, M.. 2004 Evaluation of a digital non metric camera (Canon D30) for the photogrammetric recording of historical buildings In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Instabul, Turkey, Vol. 34, Part XXX.

Mata, E., Cardenal, J., Castro P., Delgado, J., Hernandez, M.A., Perez, J.L., Ramos, M., Torres, M. 2004 Digital and analytical photogrammetric recording applied to cultural heritage. a case study: "St. Domingo de Silos' Church (XIVth century, Alcala la Real, Spain)" In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Instabul, Turkey, Vol. 34, Part XXX.

Novak, K., 1992. Rectification of digital imagery. Photogrammetric Engineering and Remote Sensing. 58 (3), pp. 339-344.

Ramos, M., 2005. Generacion de Cartografía para la rehabilitación de la Iglesia de Santo Domingo de Silos (Alcala la Real, Jaen). Master Thesis University of Jaen.

UJA, 2003. Trabajos fotogrametricos y topometricos de generacion de cartografía para la rehabilitacion de la Iglesia de Santo Domingo de Silos (Alcala la Real, Jaen). Technical Report, University of Jaen (UJA), Spain.

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