DIGITAL AND ANALYTICAL PHOTOGRAMMETRIC RECORDING APPLIED TO CULTURAL HERITAGE. A CASE STUDY: “St. DOMINGO DE SILOS’ CHURCH (XIVth CENTURY, ALCALA LA REAL, SPAIN)”

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ABSTRACT:

This paper is about a complete photogrammetric record of St. Domingo de Silos’ Church (XIVth century), in Alcala la Real (Jaen, Spain). It was declared National Monument in 1931. At present it is a ruin heavily damaged and near to collapse. So, local authorities have decided urgent actions for the reconstruction. Previous to the restoration works, different surveying and photogrammetric techniques were 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. A wide variety of photogrammetric methods and instruments has been applied: analytical and digital plotters; terrestrial metric, semi-metric (reseau plate) and non metric cameras (analogical and digital). Stereoscopic pairs, when possible, were taken with the help of a device which allowed for stereoscopic shots. Convergent photographs were also taken in order to reach a favourable geometry for bundle adjustment (selfcalibration) and control point densification. Both photogrammetric and desktop scanners were used. To maintain low costs, the main final products, in case of planar surfaces, were mosaics of rectified photographs. Cross sections, modelling and structural analysis of deformation of walls and a vault were also made in order to support the final architectural restoration project.

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, Figure 1). 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 (Ayto. Alcala la Real, 2003; Figure 2).

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.

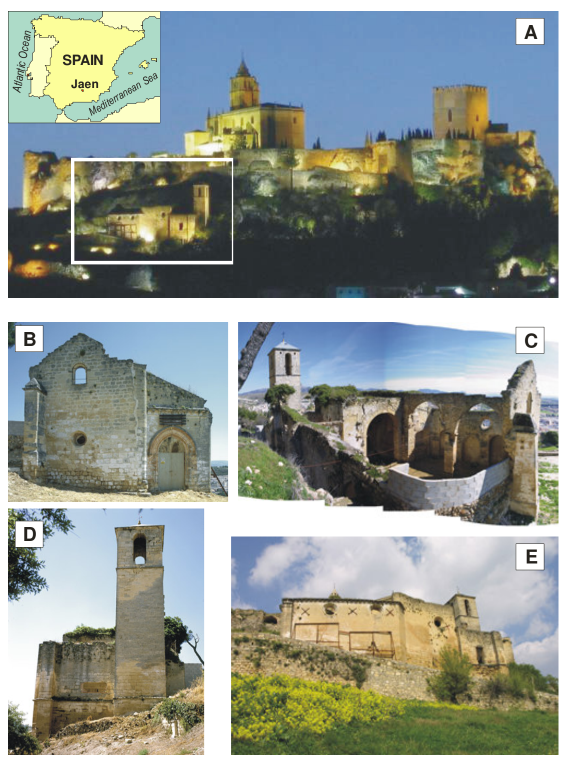

Figure 1. A: Panoramic view of La Mota Fortress, Santo Domingo de Silos’ Church (white rectangle) and geographical location of Alcala la Real (Jaen). B: Main façade, south side; C: General view from south-western side (belfry, nave, arches and access to the chapel are visible),; D: Bell tower and north wall; E: Panoramic of east walls.

2. SURVEYING

2.1 Introduction

Survey works were carried out for obtaining the ground plan of the church and the control points for the photogrammetric surveying (Figure 2). These works were the design, measurement and data reduction of the traverse and the measurement of plan church points and control points.

2.2 Measurement and data reduction

The traverse network was defined by 14 stations, both in exterior and inside of the church (Figure 2). All traverse stations were set permanent for further use in restoration works. Moinot method and forced centring were used. Least square adjustment was employed for obtain final station coordinates. The planimetric definition of the ground plan was obtained by means of points measured at the base of the church walls.

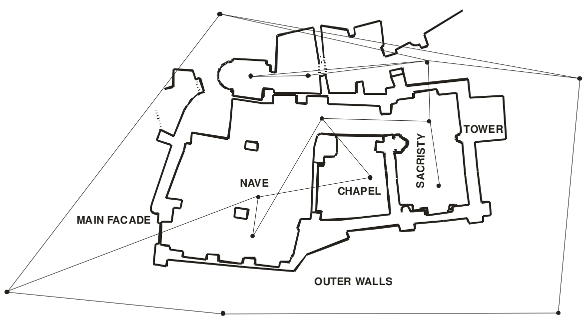

Figure 2. Church ground plan and traverse scheme.

Photogrammetric control and check points were measured both in face left and face right. More than 300 control/check points were measured with a Leica total station reflectorless measurement. These points were natural points selected in field in the original digital images. Examples of theses points are shown in Figure 3.

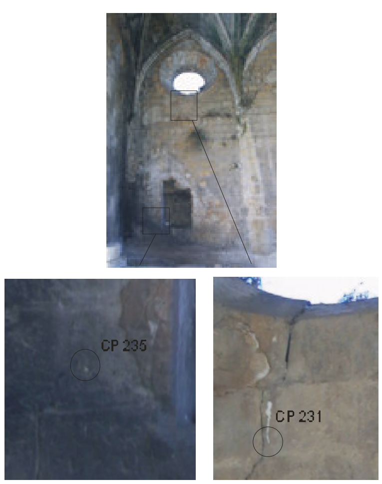

Figure 3. Details of natural control points. Photograph shows an inner wall in the main chapel.

3. PHOTOGRAMMETRIC SURVEYING

3.1 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 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 concern to points in the rectification surfaces.

3.2 Data acquisition

Main eastern external walls and the façade were plotted using analytical stereophotogrammetry with UMK 1318/10 photographs. When necessary, shots were made from a mobile hoist (Figure 4). Stereoscopic base lines were situated with a total station and heights were measured with a tape from the platform.

Figure 4. Stereopairs in the west walls were taken with the help of a mobile hoist.

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 Carl Zeiss 80/2.8 lens (with a 25x25 reseau plate installed); Pentax 67 II with Pentax 4/45 and 4/200 lenses; and a digital Canon D30 (3.2 MP) with Sigma 20 mm and Canon 35 mm lenses.

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. In some cases, stereopairs with these cameras (without orientation devices) were taken with the help of a steel tool (installed on conventional photograph tripods) which allowed for stereoscopic shots (Figure 5).

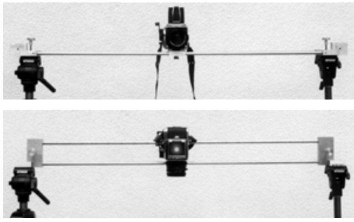

Figure 5. Hasselblad installed on stereoscopic bar

Analogue UMK and Hasselblad photographs were digitized with an Intergraph TD Photoscan at 1814 dpi, and Pentax images with a desktop scanner Nikon Super Cool SCAN 2000 at 3000 dpi.

3.3 Data reduction

The data reduction methods employed in this project were conventional analytical plotting, stereoscopic softcopy photogrammetry and rectification.

3.3.1 Conventional analytical plotting. Combination of a metric camera (UMK 1318/10) 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 6 and 7).

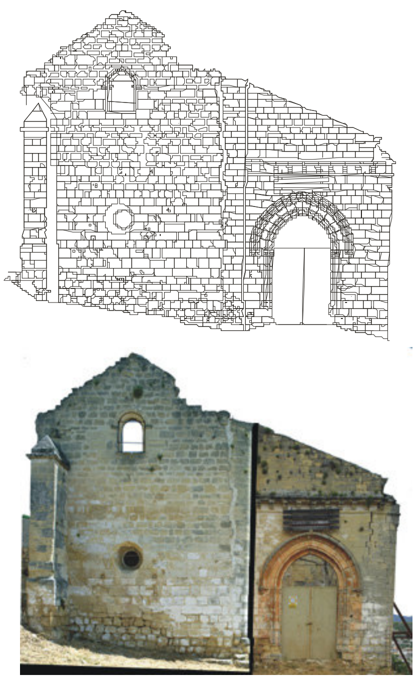

Figure 6. Elevation view of the main façade and mosaic of rectified images (Canon D30 Digital Camera)

Figure 7 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.

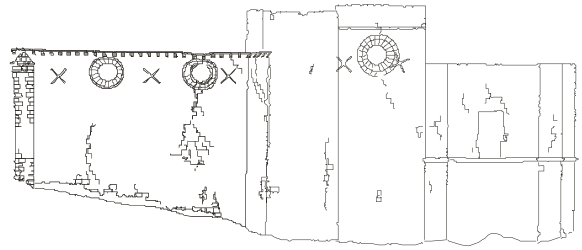

Figure 7. Elevation view of the walls in the east side.

3.3.2 Digital Photogrammetric Workstation (DPW). The study of the vault that covers the chapel (Figures 2 and 8) was made by zenithal shots organised in three parallel strips (5 photos per strip). Camera positions were situated in the ground by means of a grid and helped by tripods.

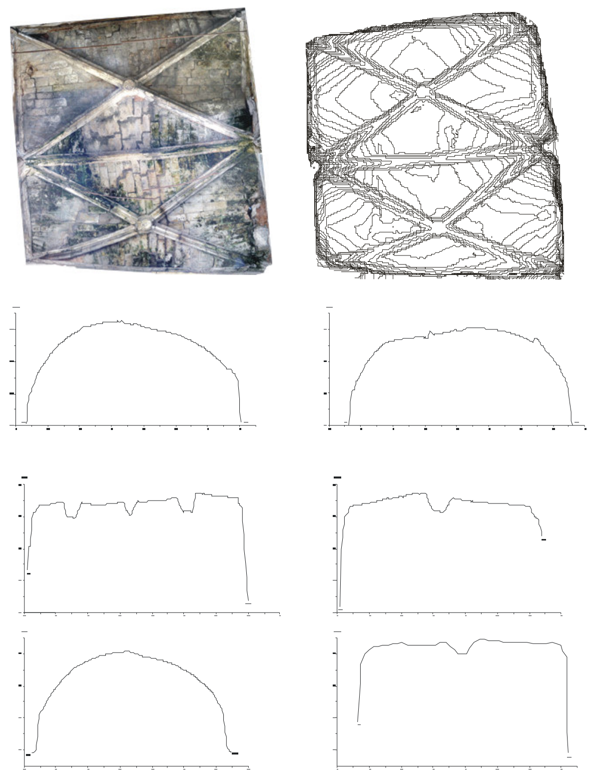

Figure 8. The Ortophotograph, contour map and main profiles showing the deformation in the chapel vault.

The Canon D30 camera with the 20 mm lens was used. Focus was set to infinity. Although the camera had been calibrated in laboratory (by selfcalibration with minimal inner constraints and digital target location; Atkinson, 1996; Cardenal et al., in this volume), an additional selfcalibration was performed with the block of 15 photographs in order to refine the inner parameters in real conditions. Image point measurement was manual. Control and check points were used and calculations were carried out with a routine programmed under IDL® (Interactive Data Language from Research System Inc.). Inner parameters were: focal length, principal point offset and K_1 and K_2 (first and second radial distortion coefficients). Other distortion coefficients (higher order terms or decentering distortion) were not significant. Errors in check points were ±5 mm and ±12 mm, expressed as standard and maximum residual errors in coordinates, respectively.

Data reduction was carried out in a DPW (Socet Set® v. 4.4.2). A new camera file was created with the selfcalibration results and the computed outer orientation parameters were also imported (as initial approximations). Next, an automatic point measurement process was launched in order to increase the triangulation network density. Then new orientation parameters were computed with all data.

A digital surface model (DSM) of the vault was created using matching techniques and manual edition. 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 8).

3.3.3 Image rectification. The belfry, all inner walls and some outer walls in the north side were photographed with the semi-metric (reseau plate) and non metric, analogue and digital, cameras. 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.

Analytical rectification has been made by means of the well known two-dimensional projective transformation (Novak, 1992):

$$u = \frac{a_1 x + a_2 y + a_3}{c_1 x + c_2 y + 1} \qquad v = \frac{b_1 x + b_2 y + b_3}{c_1 x + c_2 y + 1} \tag{1}$$

where u, v = image coordinates
x, y = planimetric object coordinates
$a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2$ = projective transformation coefficients

Once transformations were computed, each single image was warped using ENVI® program (Environment for Visualizing Images, from Research Systems Inc.) 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. The adjustment was made with usual image processing software, Adobe® Photoshop®.

Figure 9 shows the mosaic formation results. In this case the mosaic corresponds to the south side of the belfry and an inner wall of the sacristy. A total of 6 photographs and 16 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 photographs were necessary. A bundle adjustment was carried out for the control point network densification. Most part of photographs was taken with the Canon D30 and 20 mm lens (Figure 9B/F). However, the higher section of the tower (Figure 9A) was photographed from out of the church with the Pentax camera and 200 mm lens. This camera was used since object-camera distance outside the church was excessively considering the Canon D30 resolution. Besides, it was impossible a shot from the sacristy ground because lack of visibility and the photo had been highly oblique.

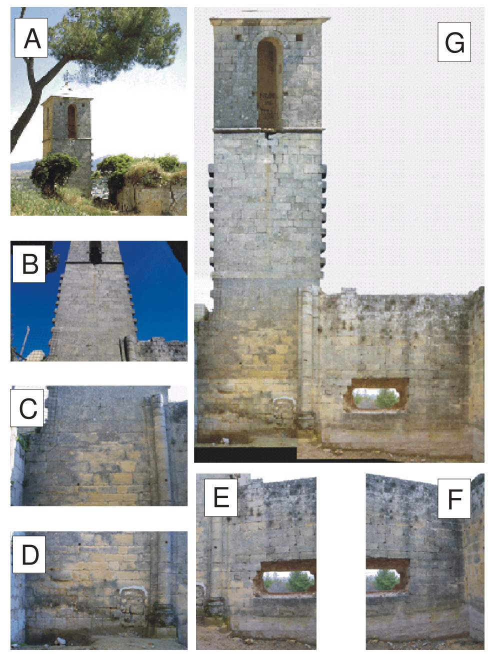

Figure 9. Inner wall in the sacristy and south side of the belfry. Mosaic of geometric (rectified) and radiometric corrected images (G).

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 10A shows a mosaic in the outer east walls with UMK (walls, taken from the mobile hoist, Figure 4) 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 10B 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 1C), space limitations and height of the arches made necessary large number of photos (Figures 11, 12 and 13). Besides, in some parts of the arches the photos had to be highly oblique. These condition added problems to the mosaic formation. On another hand, these inconvenient made more complicate the set up of the control/check point network.

A B

Figure 10. A: Image rectified mosaic of outer east walls and belfry. B: Image rectified mosaic of outer north walls and belfry

Figure 11 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 12.

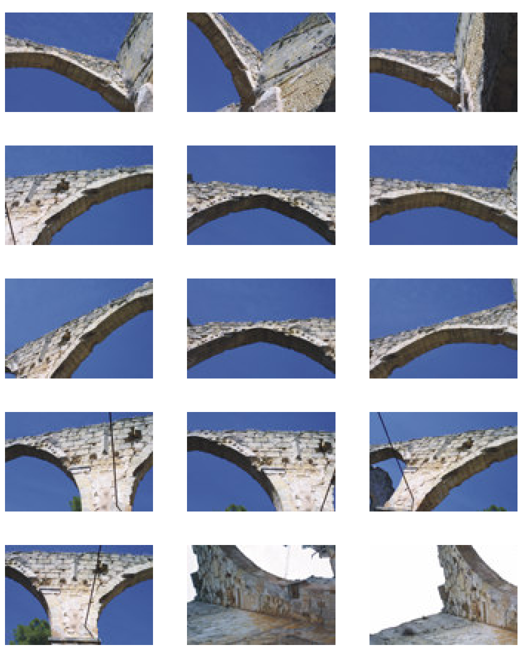

Figure 11. Photographs upper part of rear arches in the nave. Camera Canon D30 and 35 mm lens.

Figure 13 shows the front side of the arches. In this case stereopairs with the Canon D30 and 20 mm lens helped with the stereoscopic bar (Figure 5) 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 12 and 13 images of the nave walls have been added in the background only for visualization.

Figure 12. Images rectified mosaic of rear arches in the nave

Figure 13. Images rectified mosaic of front arches in the nave

3.4 Modelization

The photogrammetric network and the rectified images (both single images and mosaic) were employed in modelling parts of the church (Figure 14). The common reference coordinate system was obtained from the surveyed control point network. Several commercial programs were used with this purpose (Shapecapture© and Photomodeler©). This modelization was only at visualization level (WRML files) but not for metric applications.

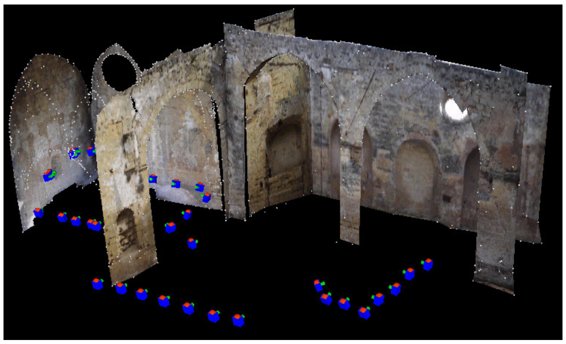

Figure 14. Screen capture (from Photomodeler©) of a 3D model of the nave, arch and entrance to the chapel. Left chapel wall and vault textures have been suppressed to allow the visualization of the camera positions inside the chapel.

4. CONCLUSIONS

As conclusion, different surveying and 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.

In some cases the data acquisition had to be very fast because 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. At present, current work is related with diverse aspects. The work is being completed with a full 3D model with metric quality, horizontal sections at different heights and vertical sections with diverse orientation. All these works will support the final architectural restoration project.

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