3D RECONSTRUCTION AND MODELLING OF ARCHITECTURAL DOMES

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ABSTRACT

This paper is focus on the graphical documentation and divulgation of the Renaissance frescoes discovered at the high altar of the Valencia's cathedral last June 2004. In this study, digital photogrammetry and surveying techniques have supported the 3D modelling and reconstruction of two different domes, one visible and Baroque, and another covered up and Gothic. The distance between both structures is about 0.5-2.0 m. The constituent frescoes on the Gothic vault were painted by two Italian painters Franco Pagano and Paolo de San Leocadio, and are extremely well preserved and genuine. Besides, they have not been neither graphically documented nor shown to the people in general and to the scientific community in particular.

1. INTRODUCTION

Today, the demand of three-dimensional models is increasing in many different fields, architectural and archaeological in documentation, tourism, environment, industrial applications and so on and so forth. The idea of 3D documentation is a major concern in inventories, conservation and restoration purposes when the documentation tasks are unique and complex to simplify in 2D plotting. Furthermore, some cultural heritage monuments and sites require accurate documentations and studies in order to make both right analysis and right decisions for present or future interventions.

This paper is focus on the graphical documentation of the Renaissance frescoes discovered at the high altar of the Valencia's cathedral in 2004. They were painted on the Gothic vault in 1481, and they are occluded more than three centuries behind the Baroque dome. Last year they were discovered behind the present Baroque dome because of the high altar restoration tasks performed therein.

In this study, digital photogrammetry and surveying techniques have supported the 3D modelling and reconstruction of both domes. Additionally, the use of photogrammetry and advanced Internet programming has allowed us to make virtual reconstructions of the Renaissance frescoes mosaics. They have never been graphically documented nor shown to the people in general. Thus, these are the aims and challenges of our study.

The organization of headings is as follows: In heading 2 some historical references are reviewed. Data collection is described in heading 3, including surveying and photogrammetry. In heading 4, raster processing is explained. After that, three-dimensional modelling and reconstruction are described. A summary of the results is addressed in heading 6.

2. HISTORICAL REFERENCES

The Valencia's cathedral is one of the most important buildings Valencia. This 1262 cathedral represents a number of styles, including Romanesque, Gothic and Baroque. The Cathedral is mainly of early Gothic style, although the high altar is in Baroque style despite the centred Renaissance reredos (Fig. 1).

In 1472 the cardinal Roderic de Borja entrusts to the Italian master painters Paolo di San Leocadio and Francesco Pagano the fresco paintings of the high altar. Works were finished in 1481. It is considered one of the most important examples of such a Renaissance art in Spain.

In 1674 some restyle was requested by Luis Alfonso's archbishop because of some light smokes, oil, wax and incense. The Baroque reorganization occluded the Renaissance paintings, but fortunately artists did not scrape the frescoes off. Some air pocket was projected between both structures, the Barroque one and the Gothic one; the distance between them is approximately 0.5-2.0m.

Figure 1. Valencia's cathedral. Frontal view of the high altar.

Nowadays, frescoes are extremely well preserved and genuine. They depict angels playing instruments against a golden raised starry blue-sky background (Fig. 2)

Figure 2. Picture of the 15th century Italian fresco.

3. DATA COLLECTION

A set of more than one hundred photogrammetric images was collected in order to document and reconstruct the top area of the high altar. The recording process for the Baroque dome followed the well known 3x3 rules as suggested by Herbig *et al* in 1997. However, the image data collection of the Renaissance frescoes was

constrained by the use of scaffolding, on the one hand, and the availability of holes, on the other. Figure 3 shows two images taken on site. Figure 3a shows in detail the Baroque style on the top of the actual high altar, meanwhile figure 3b shows the shape of the Gothic arches and the Renaissance frescoes painted on them. The number of holes was limited to one or maximum two per arch. Holes were approximately 30 cm x 30 cm.

(a) (b)

Figure 3. Detail on the top of the high altar: (a) Baroque style. (b) Gothic and Renaissance styles.

Regarding the Renaissance image collection, the number of images taken was increased in order to overcome geometric problems, fields of view, and, last but not least, lighting conditions. The whole image acquisition process was collected with a Canon EOS D60 digital camera. Maximum resolution (6.3 Mpixels) and wide-angle coverage (15 mm principal distance) were set on this project.
Besides, some B/W targeted control points were place on the top of the high altar for Baroque surface fitting. Additionally, some control points were also measured in awkward positions. All the control points were measured with a Leica TPS1200 reflectorless total station.

4. IMAGE PROCESSING

Image processing is a fundamental step in the documentation of cultural heritage if the provider wants to offer (and the user wants to receive) satisfactory and maximum quality results, both in geometry and in colour information. The management of planar features or objects is an easy issue because the techniques used to rectify the images are well known in literature (Lerma, 2002) and there is much software available in the market.
Besides, questions of developing or projecting mathematically curved surfaces are not so easily understood and applied, although they have been successfully addressed in the past (Karras et al., 1997). Additionally, there exists some problem when the image development is not considered as a whole, but as a part of the image mosaic.
It is necessary and an important issue the close range image colour balance and adjustment to mosaic large amount of images when dealing with paintings. More and more if they are occluded or partially visible and the spotlights can not be properly targeted because of physical constrains, as it was the case in the documentation of the Valencia's cathedral Renaissance frescoes.
Figure 4 shows a set of images corresponding to one side of one of the Gothic arches. As it can be appreciated, the images were unfortunately shot from only one hole; it was not allowed to make more holes. Therefore, geometries of outer images are rather tilted because of photo attitude. Additionally, the illuminating condition was only excellent for some of them, and partially right for the others. However, in the following paragraphs we will show you that it was possible to get the original shape and colour reconstruction using both digital photogrammetry and digital image processing, on the one hand, and advanced programming techniques for visualizing and reconstructing 3D domes and vaults, on the other.
The geometric processing considering both linearity and image mosaic does not guarantee the recreation of the original paintings shape. The more the curvature is changing from one area to the next, the more deformation is produced on the final image mosaic (Fig. 5).
Similarly, warping of input images without progressive colour correction and enhancement makes continuity but unfortunate shape performance (Fig. 5). Therefore, it is not recommended to follow only geometric corrections.

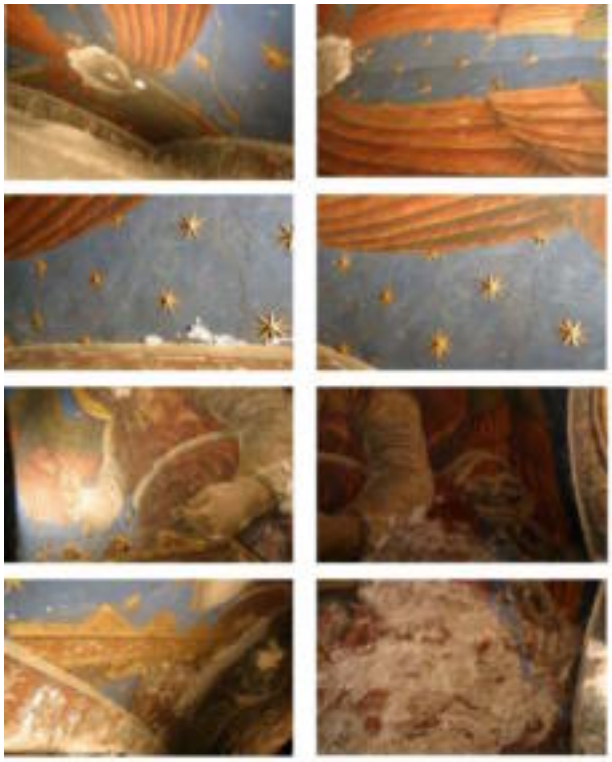

Figure 4. Full set of images for half of an arch structure

Figure 5. Example of rough mosaic. Original input image colours (without correction) and inappropriate local geometric corrections

Figure 6. Image mosaic after development and color enhancement

Figure 6 shows the development and mosaic of the input images (Fig. 4) once corrected of colour scale. The colour image enhancement was progressively applied from different directions, depending upon lightness. Besides, the geometric mosaic correction considered not only the continuous image matching but also the curvature of the frontal arch. In order to fulfil this latter statement, image development for each half of the arches was carried out on the right end of the arches structure.
The view of the whole Gothic vault is composed of twelve image mosaics such as the one shown in fig. 6. This topic is addressed on the following paragraphs.

5. THREE-DIMENSIONAL MODELLING AND RECONSTRUCTION

The 3D modelling and reconstruction of the Gothic vault was obtained after two main steps: first one, bundle adjustment of the set of images corresponding to the baroque dome; second one, image rectification and mosaic of the vertical walls. This procedure is explained in detail in Lerma et al. (2005).
Figure 7 shows the wireframe model created for the 3D reconstruction of the Renaissance frescoes. After this process, 3D triangulations and back-projections were performed in order to project the original image texture from all the image mosaics (Fig, 8).

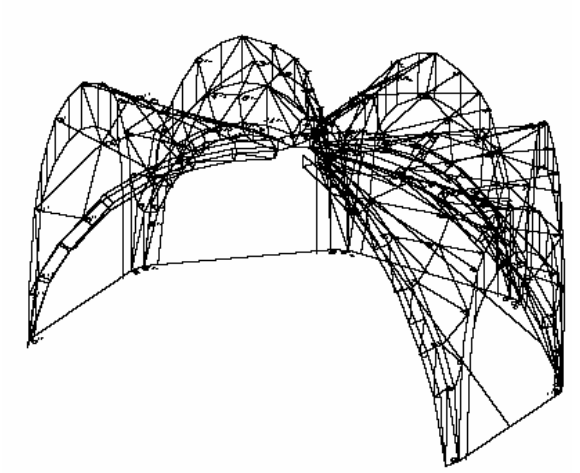

Figure 7. 3D wireframe of the Gothic vault

This reconstruction was designed to allow the user a free navigation through the model in 3D. for this purpose, the 3D model was implemented in the Virtual Reality Modelling Language (VRML97). Besides, it is also possible to switch different reconstructions, e.g. Baroque style only, Renaissance frescoes and baroque style, Renaissance frescoes and Gothic Style removing Baroque reredos, etc.

Figure 8. 3D reconstruction of the Renaissance frescoes keeping Baroque arch ribs.

Finally, all the reconstructed Renaissance frescoes were projected onto other high resolution images of the high altar in order to increase more the realism without avoiding surrounding details. A example of this realistic reconstruction can be found in Fig. 9. In fact, that figure shows the way the high altar of the Valencia's cathedral would appear to the public if only one part of the Baroque dome was removed.

Figure 9. Reconstructed and back-projected top view of the Renaissance frescoes.

6. CONCLUSIONS

The combination of photogrammetric techniques, surveying and digital image processing is promising for the documentation of cultural heritage. A work such as the 3D reconstruction of the Renaissance frescoes of the Valencia's cathedral shows the photogrammetric successfulness for the documentation, visualization and modelling of complex surfaces.
The whole set of images collected provide a valuable graphic archive of the state of the historical monument at present. Additionally, the photogrammetric reconstruction of the covered up frescoes and the simulation of how it would be if some parts of the current Baroque vault were removed become crucial in order to get right solutions for future interventions.
Thus, users such as architects, restorers, historian and politicians, on one hand, and technicians and engineers, on the other, can predict unfortunate decisions. Besides, this kind of graphical information can be used to show the public some part of our visible and invisible cultural heritage.

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