A Report on Multiple Approaches to the S. Frutuoso of Montélios Chapel Survey

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Abstract

This paper's purpose is to present the current state of a research project entitled "Architectural Heritage Documentation: a Methodology to 3D laser scanning and Digital Photogrammetry Documentation". This is a multi disciplinary funded research project involving three Portuguese universities, Technical University of Lisbon (FAUTL), Minho University (UM) and the Coimbra University (UC), as well as the Portuguese Institute for the Architectural Heritage Management (IGESPAR). Its duration is from October 2007 to September 2010. Approaching one of the goals for this project, the systematization of survey methods and processes supported by low cost digital photogrammetry and 3D laser scanning, case studies are being used to create the bases for a minimum system of survey and documentation of Architectural Heritage. Our focus is to define a reference framework both in the context of Architectural Conservation, directed towards analysis and diagnosis, as well as in the Archaeology of Architecture context, allowing a consistent process of documentation. It is also intended to compare these methods with more classical ones such as topographic surveying and manual surveying. The work presented here refers to the survey of S. Frutuoso Chapel in Braga.

Categories and Subject Descriptors (according to ACM CCS): J.2 [Physical Sciences and Engineering]: Archaeology J.5 [Arts and Humanities]: Architecture J.6 [Computer Aided Engineering]: CAD

1. Introduction

In the way as it is today presented, built heritage corresponds to the final stratigraphic accumulation product of constructive elements and established (cultural) connections with the surroundings, assuming itself as a long term archaeological context. Therefore it is subject to the principles and means of archaeological analysis, particularly those related to stratigraphic sequence [Ram02] [Dog97]. Archaeology of Architecture is the discipline that researches and registers the history of buildings and their construction phases, materials, forms and spaces. Buildings are considered in its constructive uniqueness, in their social, economical, artistic and technological particular contexts. It should give us knowledge about form and function of the building, about techniques and materials used and about their change through out the time. Its exercise implies the manipulation of data of diverse nature, this consisting as an essential analysis instrument for the attainment of the necessary knowledge to any informed intervention on the built heritage [FMC06].

The manipulation of advanced technological resources, especially CAD tools, 3D modeling and information systems, is each time more and more essential in the architectural analysis of the buildings and also constitutes, today, a powerful instrument in the spreading of the results, as it is proven in the area of multimedia contents.

In an archaeological study of any building, the first stage is documentation and recording. This constitutes a fundamental phase, being particularly important the attainment of accurate surveying data of the existing condition. This data is a very important tool to support the analysis of constructive evolution and simultaneously constitutes a set of documents that testify the state and characteristics of the building at a particular time. This can also serve as basis for a careful conservation and safeguard actions.

In Archaeology of Architecture it is considered to be recommendable to survey at full scale. To do so, many techniques and methods can be used, from manual drawing, digital photogrammetry, and 3d laser scanning, among others. The drawings obtained from these several approaches are the basis on which different constructive contexts are identified (minimal stratigraphic units with uniform characteristics and well defined boundaries). Stratigraphic reading corresponds to the identification of constructive contexts and is recorded in analytic and descriptive forms.

2. The case study - S. Frutuoso Chapel

S. Frutuoso of Montélios Chapel, a mausoleum with a visigothic origin, was built c. 665 by the bishop Frutuoso of Braga. Through the times it suffered several deep changes until it was restored by the former DGEMN (National Buildings and Monuments General Direction) in the third decade of the XXth century [Fon89]. It has an approximate area of $100m^2$ with a Greek cross plan and 10.5m height. In this case study several recording and graphical surveying methods were accomplished.

3. Surveying

The objective with surveying was to generate redundant data, in the form of 2D and 3D deliverables that could be compared in terms of geometric accuracy, time use, advantages and limitations, costs and adequacy to the archaeological studies to perform. This data will be used to test an information system under development, as well as to define a reference frame of work in this area. Several surveying techniques and strategies were used.

First a topographic survey of control points, with a total station (Nikon DTM 100 + MicroPrism 25 mm), was carried out. Data generated defined a local coordinate system that provided the basis for the accomplishment of some other surveying techniques as well as for the evaluation of metric quality and accuracy of the survey methods applied. Then several surveys were carried out: classical manual drawing, convergence photogrammetry with Photomodeler, drawing rectification with Autocad superimposed to the topographic survey, and 3D laser scanning.

3.1. Manual survey

Manual drawing survey was accomplished taking into account the local coordinate system defined. Measurements were done making use of traditional auxiliary tools such as metric tape and plumb line. Then those measurements were registered on paper at a scale of 1:20 for later digitalization and vectorization. In this way, this survey could be compared with the others.

3.2. Convergence photogrammetry

For photogrammetric surveying a Canon 400D camera, 10Mp (+ 18-50 mm zoom lens) was used. Software Photomodeler Pro v.5.2. was used to process the data. First camera calibration was done. It is important to refer that for this kind of survey in an archaeology context, it is more important to have a wireframe model than a texturized one.

Due to the level of detail required and hardware limitation, the building was segmented in several parts. For each one a photogrammetric project was done that was later exported to CAD. For each project a limited number of images were used with the criterion that each reference point, a topographic point, should appear in at least 3 images. First, from calibration data (internal orientation) and reference points identified in multiple images, one proceeded simultaneously to relative orientation and absolute orientation. After these two steps were complete, the remaining points were determined by intersection only. This was done in two different ways: by identifying homologous points in more than two images, or by defining a surface on which one projected the points. In this later case, points only have to be identified once in a single image and as a rule of thumb points should be identified in the most frontal image with respect to the auxiliary projection surface defined. Otherwise one risks lack of rigor. Then all projects were assembled together in a CAD file on the common coordinate system previously defined (figure 1). Topographic points, which were used for the Photomodeler projects as reference points, allowed us to perform this step. From the CAD file, multiple 2D drawings can be generated by defining projection plans.

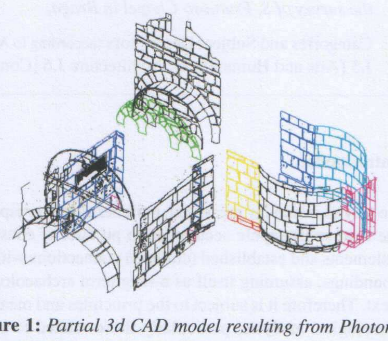

Figure 1: *Partial 3d CAD model resulting from Photomodeler restitution.*

3.3. Drawing rectification

This procedure, as described in [Mat08], consists on importing digital images to a CAD file, then to draw over those images and proceed to drawing rectification according to control points coordinates provided by the topographic surveying or other means.

To rectify drawings, a routine similar to Homograf [IJOV05] was designed and implemented [Mat08]. This routine works on a different algorithm and allows one to select lines besides points as control data. Vanishing point determination routines were also designed and implemented because sometimes it was necessary to consider the perspective nature if images. By selecting a set of straight lines that one knows to be parallel, vanishing point is determined by a least squares adjustment taking into account a weight factor that is a function of line size and angle between lines. These routines were programmed with autolisp programming language and run with autoCAD.

To take advantage of images potential, high resolution panoramas were created. From these one could have both access to general geometry and to details in the same image. To generate the panoramas the software PTGUI and HUGIN were used. First step, after images were inserted into the CAD file, was to draw over and to identify topographic control points. After that step one proceeded to drawing rectification. Then rectified drawings are aligned with 3d topographic control points to produce a 3D wireframe model (figure 2).

It is important to notice that the type of representation problems that can be solved with this approach can not be directly solved with the simple use of rectified raster images. In some situations it is required to draw over the images to put auxiliary control points into position (figure 3). This procedure can be applied whenever a plane containing a figure to be drawn can be identified, even if that plan is not a facade plan.

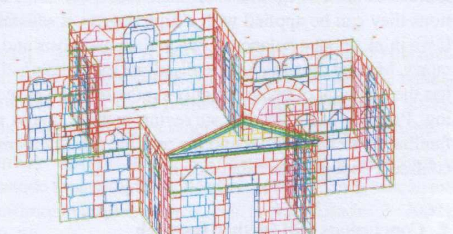

Figure 2: *Partial 3d CAD model resulting from drawing rectification.*

3.4. Laser scanning

A phase based scanner, the Z+F Imager 5006, was used for laser scanning surveying. To generate radiometric information a 14Mp Camera, Pentax K20D, was used. This survey was commissioned to an exterior company, 3D Total.

To process laser scanning point clouds two different approaches can be considered. One makes use of control data such as topographic points and allows us to work with less

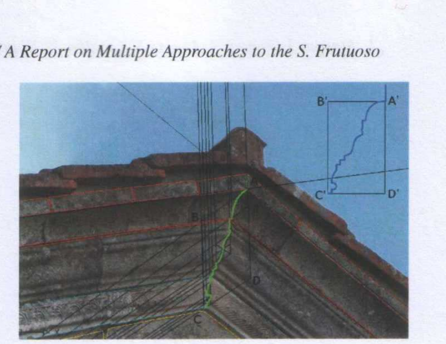

Figure 3: *To define the cornice frame geometry, two topographic control points, A and C, were used and two other points, B and D, were determined with auxiliary vanishing points.*

overlapping clouds. The other is self referent and requires more overlapping clouds of points once it is on the overlapping area that we can gather information to proceed to registration with an algorithm such as ICP [Kra07].

Intentionally, laser scanning was accomplished in a total independent way from topographic procedures. One of the objectives was to verify, after comparison, if reliable results arise from a self referent approach at this building scale. A total of sixty four scans were done at several resolutions according to the level of detail that was intended for each element to record. The criteria to define the point density were as shown in [MB06]. All clouds of points were registered with manual alignment followed by the use of ICP algorithm with the software JRC 3D Reconstructor. After a positional model was complete, color information was mapped on meshes that were generated with different decimation levels according to the principle that recognizable morphology should be identifiable. This mapping was done with manual calibration for each image. Mapping the meshes takes full potential of raster images. A set of sixteen topographic points were used to align the final model with the local coordinate system adopted. From this alignment resulted an RMS error of 2,7cm (figure 4). This alignment was done with the software JRC 3D Reconstructor. After the model was aligned several 2D and 3D data were generated: colored ortho-images (sections, elevations, and plans), VRML 2.0 models, CAD models and videos.

3.5. Data comparison and evaluation

In order to make a comparison possible it was defined that all 3D data should share the same coordinate system and that all projection planes that were considered to define 2D data should have a 3D representation within the same coordinate system. For each 2D representation, for example south view on figure 5, the same projection plane was considered whether an ortho-image from laser scanning data, a manual drawing or a photogrammetric project were being produced.

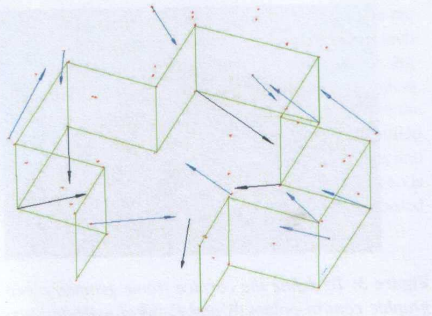

Figure 4: *Residual vectors of the alignment points magnified with a scale factor of 100.*

Figure 5: *Drawing rectification elevation drawing overlapped to laser scanning ortho-image.*

Two types of data comparison were carried out: a 2D comparison and a 3D comparison. Considering this paper refers to ongoing work, mainly 2D comparison is available.

After aligning the laser scanning model to the local coordinate system defined, as previously pointed out, a set of 28 topographic control points (not used for the alignment) were used to verify the discrepancies between the model alignment and the topographic survey. Considering the residuals of all points an overall RMS error of 3.1cm was verified. In our opinion it is higher than expected, although the model presents an internal coherence. As probable reasons for these discrepancies we point out the following: homologous points were identified manually meaning that operator errors might have occurred, the registration between the interior and exterior of the building was done using only one cloud of points and errors might have been committed in topographic surveying. It was important to process laser scanning data independently from topography in order to be able to identify these kinds of problems and to be able to consistently study and propose a more effective methodology to laser scanning surveying. This doesn't necessarily mean that we will recommend topography to be used. It might mean that a different approach to laser scanning survey planning has to be considered in order to grant that always a "closed polygonal" of scans is always done in order to avoid registration errors.

Overlapping data, in the same projection plan, derived from laser scanning with data obtained with topography as an auxiliary means necessarily reflect the discrepancies pointed out (figure 5). On the other hand, when we overlap in the same projection plan data that in some way derived from topography fewer discrepancies occur. For example, overlapping drawing rectification and hand measured drawing show discrepancies generally smaller than 2cm in homologous points.

Comparing the several surveying methods applied puts in evidence that laser scanning allows a faster acquisition of data in 3D position, and a possibility to survey an amount of detailed data that would be impossible to perform with more traditional means. We may say that it is the less time consuming method although it is still the most expensive. Both photogrammety with photomodeler and drawing rectification take a long time to be produced but are less expensive than laser scanning. These methods have limitations with the survey of highly decorated surfaces in particular drawing rectification that is applicable only to planar regions. Being less expensive methods they are more accessible to the professionals that work with built heritage, the archaeologists and architects even for direct use once it is recommendable that those professionals can themselves perform surveying tasks or at least be able to coordinate them. For some situations they can be applied with a high degree of satisfaction if we think about a balance between time use, costs and adequacy. Manual drawing has the disadvantage of being 2D but has the potential of being a highly synthetic mean of recording. Probably it is also the surveying method that is more familiar to archaeologists and the one that most of them feel confident enough to use themselves.

4. Conclusions and further research

Considering this paper refers to undergoing work, and surveying has to be completed, only preliminary conclusions are available. For the purposes of archaeology of architecture all surveying methods applied can be considered valid and can provide reliable data. The choice of the most adequate methods to a given situation is the ethical and scientific responsibility of the professional that deals with built heritage. He has the responsibility to define the terms with which he can communicate to the service providers whenever exterior services are required, always considering cost-benefit analysis. These terms refer in first place to the clear definition of the survey method, the precision level required and type and nature of the deliverables. With this particular case study and results we think that we give a real contribution to this matter although the experience has to be expanded to other type of buildings and contexts.

5. Acknowledgments

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