Parametric shape model for conservation oriented surveying

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ABSTRACT

This paper present a project concerning the scissors arches of Wells Cathedral (UK) (see Figure 1). These arches brace the central crossing of the cathedral and were built following the uneven settlement of the central piers, after an initial attempt to heighten the central tower.

The scissors arches and adjoining parts are surveyed with a method combining reflectorless total station measurements and photogrammetric techniques. A 3-D model is constructed and forms the base of a database, collecting the information necessary for an in-depth study of its construction and subsequent alterations. Access is provided through Internet connections, allowing collaborative management.

Keywords: Cultural Heritage, Survey, Database, Management, Augmented Models, Reconstruction, Visualisation, Gothic Architecture

Figure 1. Nave of Wells Cathedral

1. INTRODUCTION

The project has three main objectives:

- To identify the present geometry of the scissors arches, the central crossing and adjacent bays, with particular reference to their construction details, so as to provide reliable data for structural analysis.
- To record the exact state of conservation of this part of the church in terms of stone decay and mortar conditions, with particular reference to substitutions, alterations and manumissions occurred during its life.
- To develop a documentation methodology based on digital surveying techniques for the recording of the present state and of any future work carried out on the crossing and tower.

The main output of the project is a 3D digital model providing metric and qualitative information on the scissor arches via a searchable, query-oriented, database. The 3D model will consist of surface elements (mesh of triangles) and it is designed to fulfill two major requirements, consistent with structural conservation: (1) accurate survey of the fabric and existing material, (2) interpretation of the existing deformations and structural pathology.

For this purpose the target accuracy has been set to about 10 mm. While this level of accuracy is not sufficient to provide a reference for the monitoring of the evolution of active deformation phenomena, it will allow the identification and localisation of existing active problems and on the basis of analysis carried out with the structural models will allow, if it appears to be necessary, a better planning of monitoring installations.

Different surveying techniques are conceivable: traditional techniques, digital photogrammetry (DP), reflectorless total stations (RTS), laser scanners (LS)… Due to accessibility problems, direct measurements are difficult. Time to be spent on site and the possible disturbance of the daily routine of the cathedral are another constraint. Non-contact techniques are more suitable.

LS [Barber et al. 2001] was discarded on the ground of its cost Moreover if LS were to be used, the density of point must be high to record accurately edges and mouldings and specific procedures need to be implemented to simplify the model, so as to make it manageable. If the number of points is not sufficient to reproduce the shape with the standards expected, post-processing will be needed. In any case, parts of the profiles remain hidden from any possible station. We will discuss later the implications of that fact. In our specific case, the post processing necessary in order to circumvent the above-mentioned difficulties was foreseen to be complex and overly laborious.

DP is an appropriate technique to collect the material and constructional information imbedded in the object. On the other hand, the extraction of data useful for the building of 3d structural model requires substantial amount of post processing work. Direct measurements with RTS would be the answer to this, but the number of point to be directly measured quickly escalates to tens of thousands if the accuracy with respect to the fabric is not to be compromised. Also, once the points are measured, automatic routines need to be developed to connect them to obtain meaningful objects.

A possible solution to the problem was therefore identified in developing a hybrid approach, combining elements of RTS and DP (see also Scherer [2001]).

The aim is to minimise the time spent on direct measurement and interpretation of the photogrammetric takes. The experimental nature of the approach and the software development necessary (a set of programs written in C++) let nevertheless uncertainty in that respect. Sufficient elements of generality are introduced in the procedure so that, once the methodology is fully developed, it can be used for the recording of similar artefacts.

The main phases are: (1) construction of a model of the shape from a reduced set of measurements (using RTS), (2) projection of high resolution pictures on the model (using DP), (3) construction of a database using the textured model (stones, pathology, phases of construction…) and (4) enrichment of the database with supplementary data and refinement of the model with data acquired by direct inspection. This paper will deal with phases 1 to 3. The last phase is still under development. More results will be presented at the end of the project.

2. PRELIMINARY WORK

A control network (CN) of 28 points is established. It defines the main coordinate system, serves as the skeleton from which all further measurements are to be taken and as a datum for possible further surveys. In order to minimise interference with the building fabrics, a minority of control network points are materialised by topographical nails, while the others by holes of 3mm of diameter. These points are mostly set on the building's floor.

Planimetric measurements were taken with a RTS (Leica TCR307) and high-precision fibre tape measure (for control). Levelling is made with a parallel plate level (Wild NAK2). Measurements are redundant to give control and increase accuracy. Points' coordinates are calculated in Excel, using the least-square method. The accuracy is estimated to be 3mm, for a network of about 60m by 40m.

3. PARAMETRIC MODEL

The first step is to construct a model of the shape from a reduced set of measurements.

Before going further, it may be interesting to have a critical view on the surveying activity. The reality of an existing object is infinitely complex. In practice, only a limited set of dimensions can be examined. This is due to limit of time or capacity but this is also desirable because one of the aims of surveying is to extract aspects considered significant and to put them in evidence. More formally, survey is a two-time process [Feiffer 1993; Smars 2001]. During a first qualitative moment, a model is developed. It consists of two constituents [Smars 2000]: a space of states (whose dimensions can be coordinates, colour, temperature...) and a law of behaviour, expressing relations between a set of variables and parameters. During a second quantitative moment, the parameters of the model are measured. In this way, a continuous problem is transformed in a discrete one. A simple model of a column could consist of a circle (law of behaviour) drawn on a sheet of paper (space of states), the parameter being the radius. Particular survey techniques are related to specific laws of behaviour. A wall can be considered vertical, inclined or bulged. The quality of the results follows the quality of the two phases. Hereafter, we will present a specific paradigm appropriate to the object and technique chosen.

All gothic buildings and Wells Cathedral particularly, have many columns, arches, clustered pillars or ribs. These elements are characterized by a predominant dimension. They are formed by a profile, extruded along a path. Starting from this observation, all architectural elements constitutive of the cathedral might be classified in: punctual (0D), linear (1D), surface (2D) (see Figure 2) ad-hoc measuring techniques can be devised. Elements are named following a uniform convention.

Figure 2. Element types: (a) punctual, (b) linear, (c) surface

In our object, surfaces are present in the vaults' webs, spandrels, clerestory windows' trumeaux. Points are measured with RTS, on a regular pattern. The point cloud is then meshed using Delaunay triangulation. The distance between the measured points is chosen in order to give a smooth surface representation. The total station is connected to a laptop computer running a custom-made program drawing the points in real-time.

Figure 3. Total Station with real-time Visualisation

Linear elements are the most common. Ideally, they can be represented by a path and a profile (see Figure 4.a). In fact, the profile varies along the path. Hence a number of profiles are measured along the path, and interpolation is used in between. This is not straightforward. The first operation is to measure the path. A well-defined edge is chosen. Points are measured regularly with a RTS along that edge (the number of points depends on the shape and regularity of the edge; typically 30 points have been measured). More points are then computer generated using B-spline interpolation (50-100).

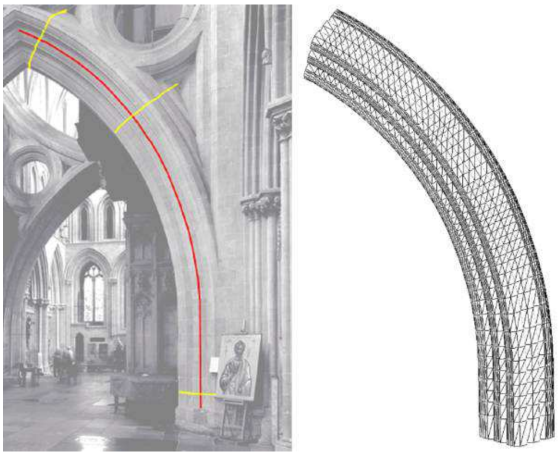

Figure 4. Linear element: (a) path profiles, (b) generated shape

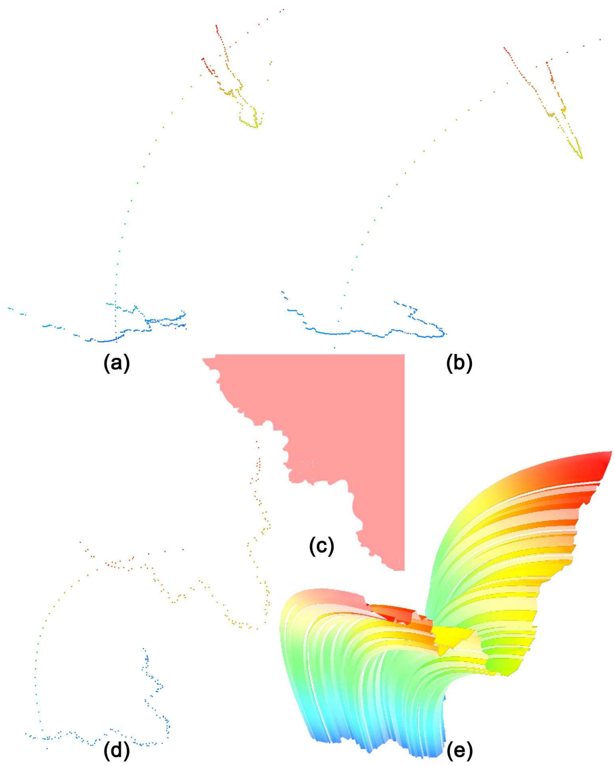

Figure 5. Stages of profile construction: (a) rough measurements, (b) flatten profiles, (c) architectural sketches taken in-situ, (d) minimal set of points, (e) extruded element

The second operation is to measure the profiles (usually 3). Points are measured at close interval with a RTS (roughly perpendicularly to the path) (about 100, Figure 5.a). Follow a series of operations in office to 'normalise' the profile: (1) points are rotated and put in a mean plane perpendicular to the path (Figure 5.b), (2) profiles are edited in AutoCad to keep the number of point to a minimum maintaining a good shape fit and to insure that every profile has got the same amount of point (Figure 5.d). From the path and normalised profile, a shape is then generated (see Figure 4.b and Figure 5.e). If the surface is not smooth enough, the number of points along the path or the profiles can be increased.

Once the measurements are taken, most of the operations are automated. However, in order to develop the 3D surface, some editing is still required and this is labour intensive and time consuming. Even with a dense scanning and real-time control on the computer screen, the rough measurements are not sufficient to define precisely a profile. Many parts remain invisible. They can be measured from different points but that increases significantly the time necessary for the scanning. This was done in certain occasions but not systematically. Furthermore, it doesn't always solve the problems. From the measurements taken, it is therefore necessary to go on the site and from careful observation and knowledge about gothic profile design, to complete the profile and produce drawings like the one presented in Figure 5.c. This operation is time consuming but is also very interesting because it allows the surveyor to trace the original design of the templates. From the original measurements, with the help of the reconstructed template and using similar copies of similar profiles to possibly provide likely data in invisible zones, it is therefore possible to define the points to be used for the profile extrusion (Figure 5.d).

Some elements like capitals, baskets or *cul-de-lampe* do not enter in the previous two categories. They can be seen either as punctual (0D) or as 3-dimensional elements (3D). In our case, they are usually decorative elements much more difficult to measure. As they cannot easily be represented using shape primitives, a great amount of points should be measured to reproduce accurately their surface. If their architectural importance is indisputable, their structural influence is very limited. Quantitatively speaking, they also represent a rather limited surface of the object. We don't intend to measure them with the same standards.

The elements constructed (0-2D) are then assembled to form the complete model. Intersections are not calculated, some triangles of one element are just hidden by triangles of another element (see Figure 6.a).

4. IMAGE PROJECTION

The second step is to project high resolution pictures on the shape model.

Tests have been made with different cameras and negatives. Our final choice is to use a terrestrial photogrammetric camera (Wild P32) with Ilford PanF films. The negatives are scanned and organised in a database.

No reference points are materialised on the building (difficulty of access and visual nuisance).

The first operation is to take pictures (with an average scale of 1/150). Feature points are then marked on the picture and measured with RTS. Their image coordinates are measured (sub-pixel accuracy). Using images' and world's coordinates, the internal (focal length, radial distortion) and external (camera position and orientation: pose) parameters are then computed. The image is then un-warped and projected on the shape model (see Figure 6.b).

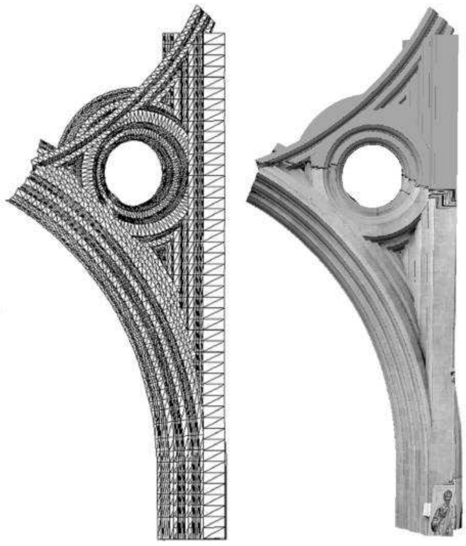

Figure 6. (a) composite model, (b) textured model

All these operations are done using custom-made programs.

5. DATABASE CONSTRUCTION

The third step is to construct a database from the information (stones, pathology, phases of construction…) extracted using the textured model.

Between 1999 and 2001, a digital photogrammetric program was developed at the University of Louvain in Belgium (K.U.Leuven) [Virterf; Smars et al. 2001]. This program (*virterf*) has a module to visualise and enrich textured models. It is used in this project and extended to deal with its specificity.

Virterf allow to define and organise information in themes (materials, pathology), comprising layers (materials' types for instance) and to visualise them by colour maps (see Figure 7.b). The extensions concern accessibility and ease of use. The data is now stored in a MySQL database, accessible through the internet. To facilitate the management, basic elements are defined. In our case they are the stones, defined by picking their borders on the textured model. PHP interfaces allow the user to add information (stones' attributes) from a web browser. Controls are provided to restrict the access to authorised individuals. Before editing a particular zone of the model, a suitable image has to be chosen. It is then loaded from a server and projected on the model.

From the textured 3D model, it is easy to produce dxf files of sections through the object or of lines drawn on its surface (see Figure 7.a). Ortho-photographs can also be exported as tif or jpg files.

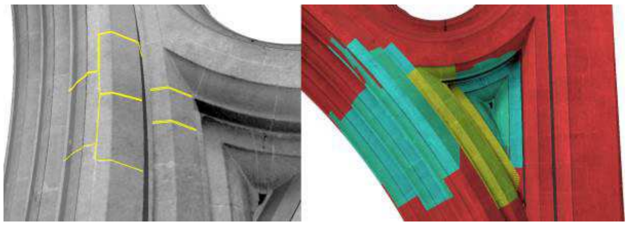

Figure 7. Database construction: (a) lines, (b) colour map

When the project will be completed, a hierarchy of access to the database will be provided.

- level1: Model Building. Access is reserved to the team responsible for the model construction. At this level, the database structure is implemented, the geometrical part of the model is edited, the information necessary for the projection of the images on the model is computed and the basic elements (stones in our case) are defined. Some operations can be done trough the intranet, others need to be done from the server where the database is stored.
- level2: Model Querying. Access is reserved to the people managing the cathedral (manager, architect, clerck of the work, conservators...). It provides a reading access to the database and gives some possibility of editing (create and edit new themes). Access is provided through the internet, via PHP interfaces. This level is still in an experimental stage. It will facilitate collaborative works.
- level3: General Information At this level, information about the aims and developments of the project is offered to the general public and interested researchers. This level is already partially implemented. It will contain documents presenting the project, a reduced database of images and examples of output.

6. VALIDATION

No point of the model is coming from direct measurements; they have been subjected to rotations, interpolations, extrapolations, projections… It is therefore necessary to have procedures to validate the model. This is not complicated: (1) qualitative conformity can be controlled at the interface between basic elements (if there is a step in between them, its height is a measure of the quality), (2) conformity can also be controlled by checking whether the images are projected correctly (the image of an edge should be projected on the model edge), (3) finally, quantitative conformity can be controlled by RTS measurements (distances between points measured at random on the physical object and on the model are measures of the precision) and by comparing model and photogrammetric coordinates.

7. CONCLUSIONS

The project is still going on. Only preliminary conclusions can be drawn.

The portion of the model already constructed demonstrates the effectiveness of the technique developed to obtain an accurate 3D representation of an object of complex shape.

The developments of the *Virterf* software improve its potential as a collaborative tool between professionals involved in monument conservation. The organisation of the information in a *MySQL* database facilitates exchange with other software and access through the Internet. In this way, different individuals, with different needs, rights and competence can access and/or edit information relevant to them.

A great amount of data is necessary to represent accurately the geometry and texture. Fast Internet connections and powerful computers are necessary to handle it. If it can be still a problem today it will become more and more easy in future.

At this stage of development, the construction of the model is still labour intensive. Pieces of software were progressively added and improved to accelerate the process. Nevertheless, some bottlenecks still exist. For instance, the preparation of the profiles before their extrusion still requires lengthy user interventions.

8. ACKNOWLEDGMENTS

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