Documenting Architectural Heritage
Looking for a balance between automation and control

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Abstract

New development in surveying techniques are profoundly changing the way architects, archaeologists, surveyors, engineers are documenting Cultural Heritage. In this paper, we examine some of them as seen through personal experiences.

Most of the examples presented concern surveys of Gothic churches in Europe. There is also a brief account of a work done in Afghanistan. The techniques presented are traditional surveying techniques, total station measurements, digital photogrammetry, laser scanning, 3D model construction and visualisation and Internet access to models and databases.

This is also an account of a work in progress, of a methodology in construction. To keep the paper short, technical details are omitted and emphasis is given to potentials and limitations of the techniques under discussion. References are made to more detailed papers for the interested reader.

1 Introduction

International charters (Venice Charter 1964, Appleton Charter 1983 [1]) and Conservation experts [2, 3] stress the fundamental importance of documentation for Cultural Heritage identification, conservation and management. Thorough documentation is the necessary foundation of appropriate conservation interventions, i.e. sensible decisions based on a clear understanding of the situation (a detailed list of reasons to document can be found in [2]).

Due to the rapid development of new techniques (sensors and software), this is also a very active field of research. ICOMOS [1] (the international organisation grouping experts in conservation of monuments) set up together with ISPRS [4] (the International Society for Photogrammetry and Remote Sensing) a joint scientific committee, CIPA [5], treating specifically of all aspects related to the documentation of Architectural Heritage. ISPRS has also various commissions...
and work-groups working on aspects related or useful for Cultural Heritage Conservation. The three organisations put a lot of information on the Internet. CIPA, ISPRS and other groups with common interests are regularly organising international symposia, conferences and workshops which are always very successful.

With the advance of technique and the resulting growing interest shown by authorities, more and more 3D models are produced [6]. Following Patias [3], modern documentation should be recording a vast amount of four dimensional (i.e. 3D plus time) multi-source, multi-format and multi-content information, with stated levels of accuracy and detail.

But the construction of high quality 3D models requires more means and work than 2D models.

2 Measurements of vaults

In the 1990s, we were working on the structural assessment of Gothic churches in a team of the University of Leuven (K.U.Leuven) in Belgium. Masonry rib vaults, as they introduce potentially destabilising horizontal forces, were particularly important to study.

In most existing surveys of Gothic churches, the vaults are only visible in 2D sections, very often idealised. This is not sufficient to analyse their stability. Vaults have a complex 3D geometry strongly influencing their stability and the thrust they produced on the walls. It is in particular by defining a suitable shape that space can be covered with a material only able to resist to compression.

In one of the first analysis that we did (Predikkerenkerk, Leuven, 1991), we were lucky enough to have at our disposal an accurate traditional photogrammetric survey. This is an exceptional case. Traditional photogrammetry is a very effective technique but it requires expensive equipment and highly qualified operators familiar with the type of object under investigation. It is also time consuming and, in practice, very few churches have such surveys of their vaults.

For the analysis of the church of St James again in Leuven (1994-), no accurate survey of the vaults was available and we therefore decided to prepare one by ourselves. A combination of techniques was used to produce the model: (1) a total station was used to survey the extrados of the vaults (the upper surface), (2) theodolites to survey the ribs on the intrados and (3) photogrammetry to survey the webs.

For the extrados, a total station was placed in the attic of the church and an assistant carefully moved on the vaults with a prism target on a pole. The technique is commonly used by surveyors to produce digital ground models (DGM). The result was not particularly accurate as the surface was quite steep and the verticality of the pole was critical.

The precise 3D path of the ribs was determined from a set of points measured on their intrados by spatial intersection. Two theodolites were used and a laser point was projected on the rib to facilitate an unambiguous identification of the points. The profile of the ribs was measured manually using a comb from a scaffolding.

At that time, digital photogrammetry software had appeared and, for the measurement of webs surfaces, the software Phidias[7] was used. In photogrammetry,
to find the 3D position of an object point, its projections have first to be identified on a set of photographs. The accuracy of the measurement is obviously strongly influenced by the ability to identify precisely and unambiguously the projection of the point on each photograph. Now, in our case, the webs were plastered and it was very hard to identify corresponding points on the photographs. We had therefore first to materialise recognisable points on the surface. A regular triangular grid printed on a lithographic plate was projected on the vaults using a slide projector, photographs were taken and the corners of the grid were measured.

This combination of three techniques allowed us to produce a complete model of the vaults, suitable for the structural analysis.

Affordable digital photogrammetry software now offer the possibility to architects and other cultural operators to do photogrammetry by themselves using inexpensive amateur's cameras.

For the analysis of the stability of another church in France, the time and means at our disposal were more limited and we used a different approach. A limited number of key elements were measured on the vaults using a theodolite by spatial intersection.

This was the starting point of our interest for parametric models.

Reality is complex and, to be able to record it, we should be able to make an infinitely large number of measurements (position, colour, resistance,...). As it is obviously impossible, the person in charge of the documentation has to decide what is meaningful and what is meaningless: i.e. to decide how many and which measurements are necessary. It is his expertise which allow him to choose a sufficient number of measurements in order not to miss any important aspect of the object. This kind of reflection is certainly familiar to architects surveying temples.

A parametric model is a model which depends of a limited number of parameters. From what was said above, it is clear that all models are parametric, even if they are not explicitly called like that.

This was an interesting experience as the necessity to define a parametric model encouraged us to think carefully about construction techniques, shapes and types of deformation, much like architects using traditional surveys techniques are routinely doing. It was also an occasion to think about the importance of controls of conformity between models and reality. Simplifying the situation, this kind of survey is maybe qualitatively closer to the object but quantitatively not as accurate. A synthesis of the two approaches is certainly possible.

In 1998, we had once again a vault to survey but, at that time and with the newly available reflectorless total stations, the situation had completely changed. The whole process was much faster.

Plastering of the surfaces was not any more a concern. The webs could be measured directly from the ground: 670 points were measured on its highly deformed surface.

The path of the ribs could be more accurately measured as the operation was faster and the profiles could be reconstructed from transversal scanning of the ribs (profiles were voluntarily simplified). The model shown in Fig.1 was prepared in just one day: half a day for the measurements on site and half a day for the model construction. Because of a denser network of points, the quality of the model was also higher.
3 Automation and surveyors' expertise

Notwithstanding the development of reflectorless total stations, digital photogrammetry is still an attractive technique. Cameras are more flexible than total stations. Photographs can be taken from difficult positions, they contain a wealth of information worthy to use and digital photography is a software solution, potentially cheaper.

Our previous experience in documenting architecture let us think that it would be profitable to

1. automate part of the tedious process of digital photogrammetry.
2. use photographs to help the surveyor enrich the geometrical model with information on materials, state of conservations...
3. integrate the information relative to a building in a single database organised around a model of the geometry

From 1999 to 2001, a project called Vieterf ran at the University of Leuven (Belgium) [8, 9, 10, 11, 12]. Its aim was to develop a computer software, a “three-dimensional digital information system for the documentation, representation and conservation of architectural heritage”. It resulted from a collaboration between three departments of the University.

The department of electrical engineering had experience in the automatic construction of 3D models from images using stereo-correspondence algorithms. They developed a module to acquire geometrical data (points) from a set of images and reference points.

The department of mechanical engineering had experience in 'reverse engineering' and developed a module to mesh and optimise point clouds coming from the first module.
The department of architecture, of which we were a member, had experience in the use of computers in conservation practice [13, 14] and developed a module to visualise, enrich and query the model built with the first two modules.

At the issue of the project, interesting results were achieved. The software offers the possibility to:

1. quickly generate complex 3D models (dense triangle mesh)
2. project images on the model (giving a ‘texture’ to the triangle mesh)
3. interact with the model in a ‘3D window’
4. draw points, lines and polygons directly on the model
5. qualify the model, associating attributes (like material type or state of conservation) to parts of the model.
6. export data to external software (dxf, vrml, tiff...)

This project was the occasion of a reflection on advantages and disadvantages of automation. One of the key ideas is that the aim of documentation is not the production of ‘drawings’ or ‘computer models’ but of understanding. Instruments are good at gathering data but it is by the cogitations of surveyors and various specialists that knowledge will be produced from this data. Unfortunately (or fortunately), this operation cannot be automated!

If we are interested in the cultural heritage, it is to try to preserve its peculiarities and so its difference, its uniqueness. Documentation is a learning process and the period of contact between the operator and the object is necessary to assimilate features recorded[8]. Data is organised, qualified and information is divided in understandable chunks.

Instruments and software are useful in this respect; they facilitate acquisition and treatment of the data. Understanding comes at different moments: on the site, during data processing and from the produced documents which allow exchanges of opinions. At each step, instruments and software can have a contribution.

The process followed in the Virtref program is to build a geometrical model with a high level of automation and then to have tools to qualify the model, to transform the raw data into information and knowledge.

The main problem of this approach is that it was and is still experimental and that, at the current level of development, the accuracy of the model is not yet sufficient to satisfy conservation standards. Data points are produced reconstructing the 3D position of points identified automatically on the images. But points do not generally correspond to features of the object and their density, though being high, is not sufficient to produce an accurate 3D model. Like it is often seen in models built from laser scanner data, edges are poorly reproduced (see section 8). The result is good for visualisation purpose but not accurate enough for conservation purpose. As the quality of digital camera, the power of computers and fundamental research will progress, the method will of course produce better results but it is not yet a mature technique. A technical description of the process and its limitations can be found in Schouteden et al. [12].
4 Parametric modelling

Between 2001 and 2002, the software tools developed in the framework of the viterf project (section 3) were further developed at the University of Bath in UK in the framework of a project financed by EPSRC (research council in UK) [15, 16].

This project was concerned by the survey of the 14th century masonry arches, reinforcing the crossing of Wells Cathedral: the famous scissor arches.

As the software developed in Leuven could not achieve the required accuracy, another approach was devised for the construction of the model. A hybrid technique was chosen, making use of (1) laser measurements to construct a parametric model and of (2) photographs to refine and control the model. It was a much slower process than the one used by the viterf software program but what was lost in automatism was gained in control and accuracy.

The first step was to measure the shape of the object (Fig.4, left). Three types of architectural elements were identified on the arches (but are actually common to many other structures) (Fig.3).

1. Linear elements (1D), characterised by a profile and a path
2. Surface elements (2D), characterised by smoothly variable surface
3. Volume elements (3D), complex elements whose shape cannot be described as linear or surface elements.

In-house software programs were developed to assist the model construction.

For surface elements, the solution was quite simple. 2D surfaces were meshed automatically from a regular pattern of points measured on the surface (following the technique illustrated on Fig.1). In that way, pavements, walls & vaults could easily be modelled.

The measurements of 1D elements was carried out in two steps: (a) measurement of their path and (b) measurement of a few profiles (sections perpendicular to the path) (Fig.4, left). The elements were then generated extruding their
profiles along the path. Software flexibility allows modelling of irregularities like twisting and deformations of the sections.

It appeared quickly that control of the measurements on-site was important to verify their validity and sufficiency. A software program was then developed to connect the total station with a computer, giving a real-time and interactive 3D view of the model in construction, helping us to keep a perfect control.

Once points were measured, many operations of model construction were automated but not all of them. In order to develop the 3D surfaces, some editing was still required and this labour intensive task was time consuming. It was therefore not possible to produce the model directly on the site. One of the main problems was that, even with a dense scanning and real-time control on the computer screen, the rough measurements are not sufficient to define precisely architectural elements. Many parts remain invisible. They can be measured from different stations 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 problem. From the measurements taken, it was necessary to go on the site and, from careful observation and knowledge of those elements, to complete them using AutoCAD. We are now working on ways to eliminate this bottleneck.

It has to be noted that this careful observation and analysis, if time consuming, was also very interesting because it allowed the surveyor to trace the original design of the architectural elements.

From a general point of view, surveying work can be divided in field and office work. Today, maybe surprisingly, the best surveys are still often the result of manual measurements (see for instance [17]). One of the reasons is the importance of the time passed on site carefully analysing architectural elements and devising ad hoc proceedings to measure them. As we said above, surveying is a learning process. For photogrammetry and laser scanning, to gather the data on site is rather fast.
and most of the work is done in office. This certainly presents advantages but also present disadvantages: there is little or no direct control over what is measured.

In our opinion, even when using techniques for which it is possible to separate data acquisition time (in situ) and data processing time (in office), it is in the interest of good documentation of architectural heritage to favor time passed on the site, interacting with the real object. This may still be difficult to achieve today but software developments could change the situation.

5 Photographs

Photography is very attractive for documentation: taking a photograph is fast and cheap, equipment is affordable, necessary skills are not high (arguably) and photographs contain huge amount of information on shapes, colours, materials, state of conservation and even on dimensions of the objects [18]. They are also relatively objective records of a situation.

Actually, their major problem may be an excess of information. Variations of colours are subtle on a photograph but do not indicate clearly whether a stone is sand or limestone. To produce a more readable representation, the interpretation of a specialist using possibly other data is required.

It can be stated that, while photography is a valuable tool for acquiring data relative to the state of a building, abstraction and synthesis associated with the production of measured drawings or computer models is essential for the correct analysis of that state.

Once the model of the crossing of Wells Cathedral was built (section 4), photographs were taken with a medium format camera and the position and orientation of the camera stations was calculated using photogrammetric techniques so that
the photographs could be projected on the model (Fig.4. right). 
Photographs could then be used to
1. identify and draw the joints between the individual stones of the arch directly on the 3D model.
2. help categorising the stones (construction phase, state of conservation) (Fig.2, right) (further discussed in section 6)
3. facilitate the control by thirds of the categorisation of the stones
4. check the good fit between model and projected photographs, confirming the validity of the model.

The Wells Cathedral project showed the interest of "hybrid methods" [6, 19, 20, 21] and of parametric modelling [22] to produce accurate 3D models but some steps in the process are complex and slow and could be optimised.

6 Database

One of the key ideas of the Viterf and Wells Cathedral projects was to apply a Geographic Information System (GIS) "attitude" to architectural documentation. All the information relative to an object is stored in a single database and every piece of information can be associated to parts or elements of the object.

Information gathered during documentation may be large and manifold. It is often the result of the work of various specialists bringing their specific expertise. Every day new aspects are considered. This broadening leads to better definitions of the building's significance.

All aspects being interrelated, it is certainly interesting to organise information in a common structure. The metric survey is a natural support. The classical approach in conservation projects is to prepare sets of thematic drawings (geometry, history, materials, state of conservation, deformations...).

Splitting the information facilitates understanding of hypotheses and interpretation. It also increases the generality of the results. From rough data (already recorded dimensions or new data), a synthesis (interpretation or decision) can be constructed.

Specific research brings insight to others. Looking at stones' pathology, one can discuss choices made to assure their conservation.

For an important category of themes, the basic operation consists in defining categories (type of stones for instance) and identifying zones (the column is a sandstone for instance) (Fig.2, right; Fig.5).

7 Networking

If many individuals contribute to the construction of the model and others may learn from its consultation, the questions of access, data integrity and user-friendliness becomes critical. The viterf program was organised around a system of files but we later thought that the program would benefit of a more flexible access.

In the framework of an extension of the project of Wells Cathedral, a web interface was developed to interact with models using a web browser and to allow
specialists to enrich the database associated with the 3D model. More specifically, this new interface was developed in the framework of the conservation campaign of the “Tree of Jesse” Window, a 14th stained glass window of exceptional quality.

The original system of files was replaced by a database (MySQL) accessible locally using the model construction software or from the network using a web interface. The database contains a set of records referring to the individual glass units of the window. Those records contain fields (or themes) which can be defined according to the needs of the project: colour, material or alteration for instance. Possible values are also user definable. An alteration theme could for instance have the two values intact and damaged.

A graphical interface based on a virtual model of the window allows the user to interact with the database, i.e. to visualise a theme, to edit individual values and to add or remove possible themes and values. The object appears in a window as a 3D interactive VRML model (Fig.5).

Images can be projected on the model to help the user to edit the database. Pictures of details or pictures taken under special light conditions could be used to facilitate the process of categorisation of the pieces of glass. When a specific theme is chosen, the values attributed to the glass units appear in colours overlaying the projected image.
8 Laser scanner

In 2003, we participated to a mission organised in Bamiyan (Afghanistan) by the RWTH-Aachen University and ICOMOS Germany. Its aims were (a) to carry out various surveying activities on the site of the destroyed Buddha sculptures and (b) to document the traditional earthen architecture in the village of Bamiyan.

In the framework of this mission, we processed some laser scanning data gathered by a Japanese surveying company, PASCO.

The point cloud of the niche of the small Buddha statue that we received contains about 1 000 000 points. Our intervention consisted in meshing the point cloud (about 500 000 triangles of an average side size of 8 cm), smoothing the mesh to reduce noise in the measurements, eliminating triangles and simplifying the model in flatter areas (decimation). Contour lines were then generated (Fig.6).

In-house software programs based on the VTK C++ library [23] were used to process the data.

Looking at Fig.6, the qualities and defects of the model are clearly visible.

The smoothly varying surface of the Western wall is a convincing demonstration of the power of the technique to produce models of complex geometries, from which it is for instance possible to extract contour lines (Fig.6, right). Note that, on this wall, the holes correspond to openings in the surface.

To achieve a good representation, the point sampling must obviously be sufficiently dense. The Nyquist-Shannon sampling theorem teaches us that for a given
sampling frequency, only variations of shapes in the object having a frequency lower than half the sampling frequency will be modelled unambiguously. Laser scanners' data is much easier to process in case of objects with smoothly varying surfaces (medieval architecture or caves for instance) than for objects with many sharp edges (Gothic architecture for instance) [24, 25]. From that point of view, the niches of the statues of Bamiyan were reasonably good cases.

Going back to Fig. 6, big holes are visible above the shoulders and head of the destroyed sculpture and smaller holes on its neck and face. They correspond to areas not visible from the station point of the laser scanner. The object is not surveyed in those areas. To complete the model, other points clouds should be gathered from different stations. This is obviously difficult: it may be impossible to place the laser scanner in the required positions. Photogrammetry could probably be used to complete the model: it is easier to take photographs from uncomfortable positions. Since 2003, further steps may well have been taken by other surveyors but we are not aware of them.

If the aim had been to give a pleasant look to the model, it would have been possible to complete the model making some gross assumptions on the surface geometry in the missing areas. After projection of photographs on the model, the illusion would probably be perfect but we preferred to give a clear view on the limits of the model.

9 Conclusion

Digital photogrammetry, reflectorless total stations measurements, laser scanning, parametric modelling and other modern techniques can greatly assist the documentation of Cultural Heritage.

They facilitate the creation, control and dissemination of rich and accurate 3D models which can assist conservators in their work on Cultural Heritage.

Depending of the cases, they can deliver higher accuracies, more depth and address new situations which would have been technically or financially inaccessible.

In most of the situations, a single technique is not sufficient to produce high quality models. “Hybrid approaches”, combining various techniques are the most effective. Traditional surveying skills still have an important place in that scheme.

Being faster, requiring technical skills to be operated and time in office to process the data acquired, new approaches present the risk to be too self-centred and their operators may forget that the main aim of documentation is not the production of beautiful and colourful models but of understanding. This is maybe the reason why communication is often difficult between supporters of traditional methods and supporters of new techniques. This is certainly a pity.

In our opinion, software developments may help tightening up this gap, providing more user-friendly access to those technologies and offering tools facilitating interactivity between surveyors and objects, direct modelling on the site and possibility of quality controls.
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References


