Contemporary Digital Methods for the Geometric Documentation of Churches in Cyprus

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Recent advances in digital methods incorporating information technology have enabled the traditional surveyor and monument recorder to work faster, more accurately and in an automated way in order to produce advanced digital products, more versatile and more useful to the end users. Such methods include tacheometry, digital photogrammetry, as image-based method, terrestrial laser scanning and the development of specialized software in order to fully exploit the digital data acquisition. Usually, a combination of these methods gives the most efficient cost benefit results, by providing 2D vector and raster products and 3D textured models. In this paper two examples of the implementation of these methods in the geometric documentation of two churches, both significant for the history of Cyprus, are presented. It is concerned with the churches of Virgin Mary (Panayia) Podithou, in Galata and St. George Nikoxylitis in Droushia. The applied methodology, using classical and contemporary techniques of commercial and in-house developed software is presented. Comparative tests for the achieved accuracies and the completeness of each method’s products have been made, and their merits and usefulness are explained.
1. INTRODUCTION

Monuments are undeniable documents of world history. Their thorough study is an obligation of our era to mankind’s past and future. Respect towards cultural heritage has its roots already in the era of the Renaissance. During the last 150 years archaeological excavations became common practice and they matured during the 20th century. Over the recent decades, international bodies and related agencies have passed resolutions concerning the obligation for protection, conservation and restoration of monuments. The Athens Convention (1931), the Hague Agreement (1954), the Chart of Venice (1964) and the Granada Agreement (1985) are only but a few of these resolutions, in which the need for geometric documentation of the monuments is also strongly stressed, as part of their protection, study and conservation.

The geometric documentation of a monument may be defined as the action of acquiring, processing, presenting and recording the necessary data for the determination of the position and the actual existing form, shape and size of a monument in the three dimensional space at a particular moment in time [8]. The geometric documentation records the present of the monuments, as this has been shaped in the course of time and provides the necessary background for the studies of their past, as well as the plans for their future.

Geometric documentation should be considered as an integral part of a greater action, the General Documentation of the Cultural Heritage. This comprises, among others, the historical documentation, the architectural documentation, the bibliographic documentation etc. The Geometric Recording of a monument involves a series of measurements and -in general- metric data acquisition for the determination of the shape, the size and the position of the object in the three dimensional space. Processing of these data, results to a series of documents, i.e. products, usually at large scales, which fully document the geometry and other properties of the monument. Usually such products include two dimensional projections of parts of the object on horizontal or vertical planes, suitably selected for this purpose.

Technological advances in recent years have spectacularly multiplied the variety of sources for collecting metric information at such large scales. In order to fully exploit these data, special techniques should be developed. Moreover, the advancements in computer industry have enabled the three dimensional visualizations of the monuments in a virtual world. The compilation of 3D models of historical monuments is considerably facilitated by the use of dense point clouds, which are created by the use of terrestrial laser scanners. Their combined use with photogrammetric procedures, such as the production of orthophotos, allows the realistic 3D representation of complex monuments such as sculptures. In this context virtual reality tours have been created for simple or more complex monuments. This ability has greatly contributed to the thorough study of the monuments, as well as to the creation of virtual visits.
2. CONTEMPORARY METHODS

Nowadays, traditional surveying work has been greatly affected by technological advances. Telemetry, using electromagnetic radiation of many forms, and digital imaging have completely revolutionized the fieldwork, but also the variety of end products, as, at the same time, digital processing has also evolved dynamically. At the same time terrestrial laser scanning has rapidly developed and has thus become another important and useful tool to enhance the quality and the variety of the end products. So, geometric documentation of cultural heritage can be performed by different approaches; in most cases a combination of methods and techniques, regarding their benefits, may be the optimum solution.

Surveying and photogrammetric methods for the geometric documentation of a monument are always applied in combination [7; 1]. The required percentage of each one in each case depends on the size and the complexity of the object, the accuracy specifications and the level of detail, i.e. the qualitative information of the monument required for the final product. Classical survey measurements provide accurate determination of specific points, which form a rigid framework within which the monument details from the photogrammetric survey are being placed. This framework provides strong interrelations of the measured points in 3D space, necessary to serve as a base for the photogrammetric and other procedures.

Nowadays it is possible to produce highly accurate measurements of single points, collect point clouds describing any surface and determine the form, size and position of any detail, however complicated, from conventional or digital photographic images. The possible products comprise two-dimensional or three-dimensional vector or raster drawings in printed or digital form. The photogrammetric methodology is capable of providing adequate overall accuracy common for all points measured and details surveyed. The photogrammetric methods may be categorized to single image, or monoscopic, two-image, or stereoscopic, and to multi image methods [5].

Photogrammetry in principle uses photographic images of the objects of interest as raw data. Complicated techniques have been developed over the years in order to produce specialized visualisations -mostly orthogonal projections, vector or raster- of these objects of interest from these particular images. Lately, sophisticated digital techniques have been developed in order to produce three dimensional views of these objects on computer screens, thus satisfying the necessity of the human observer to grasp the environment in 3D. The laser scanner technology has been employed to this very end for the benefit of geometric recording of monuments with highly impressive results. In this way the adventure path, which started at the real object with the direct measurements, returns to it (Figure 1) via a series of digital processing, image transformations and representations [2].
3D modelling and visualization of monuments constitutes a very sophisticated and integrated method for the geometric recording, for the documentation and for the preservation of cultural heritage. It is particularly effective when applied for the documentation of significantly large and complicated monuments, not easily grasped in their entirety by human eye. When the 3D modelling is composed by high accuracy detailed data, it is in fact the final product of a long series of extensive processes with a number of intermediate products, such as 2D and 3D vector and raster plans.

Supported by laser scanning instrumentation and related software these 3D renderings together with traditional techniques may play an important role, as they are able to exploit the detailed work carried out by traditional surveying and photogrammetric techniques, which are characterized by indispensable accuracy and high detail content. Therefore for certain applications of 3D visualization of objects, classical techniques are and should still be used with impressive results.

As implied above, especially in cases of cultural heritage documentation, more than in other applications, choosing the appropriate technology and procedure is always a challenging matter. Several technically correct applications have been presented in similar fields, using either image based methods or laser scanning techniques, and more frequently a combination of these methods for providing products from fusion of data acquired by different techniques with varying measurement accuracies (i.e., [4; 9]). In any case the selection of the best procedure, assuring that the final products are in accordance with the technical specifications, must combine fast data collection, use of low cost techniques and user friendly procedures, limited laborious manual interventions and time consuming interactions. So, techniques requiring the use of various expensive instruments are not appropriate, while automated methods and use of specialized software -most likely in-house developed- adjusted to the specific requirements are preferable.
An example of alternative solution for the production of 2D or 3D raster products and textured models is the use of software packages incorporating photogrammetric algorithms of multi-image management with bundle adjustment, i.e. Photomodeler™ software [6]. In these packages, by pointing manually and monoscopically on homologue points on more than two overlapping images the optimum ray intersections are determined. The creation of the 3D model is achieved by selecting points that create planes or other mathematical surfaces (parts of cylinders, cones or spheres) and by adding geometric constraints in space. They provide for camera self-calibration, production of models without control points, while the scale is determined by measured distances, creation of TIN and wireframe models, applying texture to the model and production of orthoimages at defined projection planes. A definite advantage of this technique is its simplicity in application, since no expensive tools are used and the field measurements and data processing are made by user-friendly interface.

Another example is the use of in-house developed software to produce 2D raster products, such as the ZPR software, which was developed in the Laboratory of Photogrammetry of NTUA in Greece [3]. A novel and simple method for the production of orthophotos at large scale, using a point cloud and freely taken pictures of the object is used, thus achieving two goals. Firstly the user may work independently from the practical constraints imposed by the commercially available software and secondly there is no need for specialized knowledge for implementing complicated photogrammetric techniques, or specialized photogrammetric or pre-calibrated cameras, since self-calibration may take place, thus making the method attractive to non-photogrammetrists. The developed algorithm includes the determination of the interior and exterior orientation of the image, the correspondence of the colour information from the image to the points of the cloud and, finally the projection of the coloured points onto the desired plane. It is obvious that no rigorous photogrammetric setup is necessary for the image acquisition phase. Contrary to the conventional procedure, where image tilts are of utmost importance for the quality of the final product, they play no significant role in this present case. The final projection plane may be defined at will, thus enabling the production of a multitude of orthophotos from the same point cloud. The basic steps of the algorithm are:

- Determination of image and point cloud orientation
- Point cloud colouring by relating points to pixels
- Selection of projection plane
- Coloured point cloud rotation
- Point visibility classification depending on their distance from projection plane
- Hole-filling on the resulting orthophoto.
The variety and complexity of the available techniques requires the involvement of a specialized expert, who has an updated knowledge about the available data collection and processing methods, the capabilities and restrictions of each technique for the selection of the most appropriate procedure and the workflow design in each application.

3. IMPLEMENTATION

Some of the above presented contemporary methods have been used and tested in the geometric documentation of two historical churches on Cyprus. This action is part of a larger research project, which aims at the geometric documentation of all Byzantine Churches on Troodos Mountain. Ten of these churches are included in the World Heritage list of UNESCO, mainly because of their famous wall paintings. The two churches of the present study have completely different characteristics and, hence, they are fine examples of the usability and adaptability of the methods, in order for the optimal result to be achieved.

These two churches are Virgin Mary (Panayia) Podithou, near Galata village on Troodos Mountain and St. George Nikoxylitis near Droushia village in the western part of the island (Figure 2). They were selected as they are representative specimens of religious architecture of Cyprus.

3.1. Church of Virgin Mary in Podithou

The Church of Virgin Mary (Podithou) is the Katholikon of an old Monastery founded in the late 15th c. AD. Buildings of the Monastery surrounding the church stood until the 1950’s, when they were demolished. The monument is under the patronage of the Holy Metropolis of Morfou and the Department of Antiquities of Cyprus. The church is a single space basilica surrounded by a pi-shaped corridor, which was added at a later
stage (Figure 3). On the north and south walls of the main temple there are two nearly semi-circular closed arches. The eastern ends of these arches, which are in the altar area are filled with wall constructions and are painted. At the ends of the eastern wall, but also at the eastern ends of the north and south walls, there are four niches with arched cover. The external dimensions of the church are 11 × 17.70 m and the maximum height of the roof is approx 11 meters.

The church (Figure 4) is covered by a double sided roof made of stone slabs. The main temple is covered by a double wooden roof; the inner one which consists of wooden tiling and the outer one, which is covered by roof tiles. The north and south arcades are covered only by the extension of the outer roof. As a result a rather dark inner space is formed. This is why during the repair works of 1956 four triangular shaped roof windows were constructed. Despite the positive result as far as lighting conditions is concerned, this was considered a major structural and architectural intervention and hence the windows were removed during the 2001 repair works and the roof was reinstated in its original form.
3.2. Church of St. George Nikoxylitis in Droushia

The Church of St. George Nikoxylitis is part of an old Monastery, which is situated about 3 km north of the village of Droushia, on the western part of Cyprus. The Monastery has been established back in the 10th century, or even earlier. This monument is under the patronage of the Department of Land Consolidation and of course the Department of Antiquities of Cyprus.

There are no reliable sources about the exact date of the establishment of the Monastery, as there are no explanations about the strange adjective escorting the name of Saint George either. Only wild speculation may be used to attribute the name to the large amount of wood (= xylo in Greek) which may be found in the area (Figure 5).

The church surviving today was rebuilt in the early 1920’s, using material of the older church, on the exact position of the ruined old church of the Monastery, remnants of which may still be distinguished today.

The church is a single space basilica, initially with a vaulted roof (Figure 6). The roof seen today has been added later for reasons of protection. The
outside dimensions are $13 \times 7 \times 8$ m. There are eight rectangular pillars along the two long sides of the church, which support four inner vaults and the roof (Figure 7). The bell tower was destroyed in 1923 and was replaced by a simple pi-shaped construction 1.5 m in height on the eastern part of the roof.

**Figure 7.** The plan of St. Georges church.

### 4. METHODOLOGY

Technological advances of the recent years have resulted to the production of several contemporary pieces of instrumentation such as the terrestrial laser scanners, digital cameras of high resolution and reflectorless laser total stations of high accuracy. At the same time, sophisticated software has been developed, in order to enable the processing of the collected data. This software may be either commercial, dedicated photogrammetric software (e.g. Z/I SSK, Photomod® etc.) or simplified software developed for use by non-experts (e.g Photomodeler® etc.), or even in-house developed software to address special needs (e.g. ZPR). The combination of the above instrumentation with the right software enables the production of highly specialized end products, suitable to cover all needs for the geometric documentation of the monuments.

For the geometric documentation of these two churches different combinations of the above contemporary methods were employed. They were selected in such a way as to suit the peculiarities of each monument and serve the final products in the best possible way as far as accuracy, completeness and quality are concerned.

The employed instrumentation included a digital camera (Canon EOS 1D MarkII™, 8Mpixel) with a set of appropriate lenses (24mm, 16–35mm and 28–85mm), a terrestrial laser scanner (HDS 2500™) and a reflectorless laser total station (Pentax R-323NX™). For the photography around the church of St. George, a special forklift vehicle was also employed for enabling branch cutting and of course photography. Pre-marked targets were used as ground control points for both churches where possible. For their co-ordinate determination standard surveying procedure was employed with special care for the accuracy of the final calculations. All targets were
determined with an accuracy of less than 20mm, as the final scale of the drawings was set at 1:50.

4.1. Church of St. George

Specifically, for the Church of St. George Nikoxylitis it was decided to produce 2D products, i.e. orthophotos for the four main façades, a horizontal section of the monument, two main vertical sections along and across the church and a general survey of the surrounding area. This was decided, as the form of the church is adequately documented by such products.

In order to achieve the best possible results in this case, different combinations of the available contemporary methods described above were necessary. For the orthophoto production of the Church of St. George standard digital rectification was employed for the planar parts and digital stereophotogrammetry for the non planar ones. In Figures 7 and 8 specimens of the first results of the geometric documentation are presented. For the geodetic measurements standard surveying technology was employed. Multiple rectifications of the large scale images were performed for the production of the raster products, i.e. orthophotos. Special methodology is required for their completion with the roofs.

4.2. Church of Panayia Podithou

On the other hand, for the Church of Virgin Mary Podithou it was decided to produce a 3D visualization of the monument in addition of the standard products as above. This would best describe and document the complex shape of the construction, which called for three-dimensional treatment. Hence a large number of scans were performed, in order to fully cover and document the outer surfaces. The resolution of these scans was set to 20mm. In this way a detailed point cloud for the whole monument was produced (Figure 9).
In addition, a large number of high resolution digital images were taken with the two different processing techniques in mind. Hence, near frontal images, as well as images with arbitrary and highly convergent camera axes were taken (Figure 10). This would highly enable the advantageous use of the Photomodeler® software.

For producing orthophotos of the Church of Podithou, an in-house developed alternative and simpler approach was employed; this simpler method for producing orthophotos involves, by employing the ZPR algorithm [3], the establishment of the geometric relation of a point cloud to a digital image, in order to assign colour information to the points in space. The then coloured point cloud may be projected onto any desired projection plane in order to produce the orthophoto (Figure 11).

The registered point clouds acquired around the church were later used to produce a 3D visualization of the monument. Multimedia enhancement of the latter produced a short video depicting a virtual visit around and inside the monument. In any case scans of the monument from positions around it were acquired and they were later combined to a unique point cloud with suitable registration, as already mentioned (Figure 9).

The same result for the 3D visualization was achieved employing the Photomodeler™ software. It was employed in order to combine information from the digital images taken with large convergent angles (Figure 12) in order to achieve the final result. The creation of the model is achieved by selecting points that create planes or cylinders (Figure 13) and by adding geometric constraints in space.

The software actually employs the standard bundle adjustment method in order to relate the available images with each other and with the object itself. It then gives the possibility to the user to produce a 3D textured model or the orthogonal projection of that model to predefined planes. In
Figure 14 two views of the rendered 3D model produced with Photomodeler™ are presented.

The orthophotos in Figure 15 have been produced by the orthogonal projection of the 3D textured model. It is planned to proceed with the production of the full range of products for the geometric documentation of the churches and perform a thorough comparison for assessing their accuracy, wealth and reliability of content and, of course, time and cost.
A comparison of these products in terms of time, cost and reliability proves that the employed methods are relatively fast, compared to the traditional photogrammetric procedure. This is valid both for the field work and the processing stage.

4.3. Evaluation

Accuracy tests performed show promising results. The above products were compared with each other and also with orthophotos produced with a commercial digital photogrammetric workstation, i.e. the Z/I SSK Image Station:

Figure 13. A screen shot of Photomodeler™, with homologue points marking.

Figure 14. Views of the 3D textured model produced with Photomodeler software: a north-western (up) and a north-eastern (bottom) view.
– Firstly, the facades produced with the help of the ZPR algorithm have been evaluated using control points measured geodetically, but not used for the image orientations. The RMS values computed from this comparison are 2.5mm for x and 2.1mm for y axis.
– The comparison of nine (9) measured distances, between detailed points of the four facades, on the ZPR products with the ones produced on SSK gives an RMS of 5.1mm.
– Finally, the differences between measured distances (10 on each facade) on the ZPR and the Photomodeler™ produced orthophotos are in the order of 10mm, which is quite logical, considering the methodology employed by Photomodeler™.

5. CONCLUDING REMARKS

The recent technological improvements have allowed the development of several alternative solutions for the geometric recording of cultural heritage. Data collection instruments, like total stations, digital cameras, terrestrial laser scanners, have been improved and automated, but mainly the data processing systems have been improved by using specialized software for the production of 2D and 3D products. Production of 3D textured model has provided for new options in products visualization and documentation and for their most efficient usage by the end-users.
In this paper it has been shown that the suitable combination of contemporary methods of surveying, photogrammetry and terrestrial laser scanning, with the help of suitable software may provide in a relatively short time invaluable results to the experts who take care of the well being of Cultural Heritage. The methods applied vary from the classic surveying and photogrammetric techniques, up to the use of specified contemporary methods and procedures. The results in terms of completion and accuracy tests do not lead to the conclusion that one unique technique is recommendable. The selection must be done according to the complexity of the object, the accessibility of the surrounding area and the data acquisition possibilities, the technical requirements for the final result and other specific parameters related to the application.

However the achieved accuracies in vector and raster products have shown that at least for the documentation of Byzantine churches, satisfactory results can be achieved by using simple and low cost means for data collection and processing as long as the necessary know-how exists for the right selection and application of the best fitted method.

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References


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