

Documentation and Monitoring of World Heritage Sites Using Integrated Surveying Techniques: Practical Case “Hofkirche”

Mostafa Abdel-Bary EBRAHIM¹, Klaus Hanke²

¹Professor, Civil Engineering Department. Faculty of Engineering - Rabigh, King Abdul Aziz University. Kingdom of Saudi Arabia

²Professor, Institute of Basic Science in Civil Engineering, Faculty of Engineering, Innsbruck University. Austria

Abstract: *Documentation and conservation of cultural heritage sites are being increasingly seen as tasks of national, ultimately international priority. Different types of surveying techniques including photogrammetry are used in the field of archaeology for excavation, monitoring, and documentation of the world heritage sites. The main purpose of this paper is to show the ability of documenting and monitoring of the world heritage sites using the integration of some surveying techniques. The "Hofkirche" in Innsbruck, Austria is the last existing gothic hall church, well known for German Emperor Maximilian I's tomb and its black bronze statues. At the end of the 18th century, an earthquake seriously damaged Hofkirche. To investigate the earthquake influence on this church structure, e.g. the inclination of pillars of the church has been observed and shows significant values. Using digital photogrammetry and reflectorless tachymetry in measurements yield to the geometry of deformed sections of vaults. The possibility of integrating both measuring techniques as well as the advantages and disadvantages of these surveying techniques to document and monitor the world heritage sites will be shown.*

Keywords: Photogrammetry; Surveying; 3D scanning; Archaeology; Documentation; Heritage sites; Monitoring; 3D Modelling

1. Introduction

No doubt that ways to document our heritage sites in a reasonable way which keep it in save with all its fine details is needed. There are many researches, which have been done to document the world heritage sites.

In past, the only way to document the world heritage sites was writing the target description in files and keep it in a save place. This method was dangerous as it is very easy to lose the document by fire or bad saving condition.

Many precious old cultural heritages sites remain all over the world. These heritage sites are of great value for human being in both history and art. Some of these old cultural heritage sites face a crisis that these are going to be collapsed naturally and/or artificially. These become gradually worse by weathering, plants, animals and human activities. Appropriate treatments for these are urgently requested at present. Although various technologies have been attempted to preserve or restore old cultural heritage sites, it is the most important to record the current status of the object precisely and preservation or restoration histories of them accurately. These records are necessary to monitor status of both damaged parts and restored parts of the target. A restoration researcher can make an appropriate preservation or restoration plan based on these records. However, precise and accurate records of an old cultural heritage sites are not necessarily available. Precise records of the current status of the object have been available by photogrammetric technique (Kenji Hongo, et al, 2000).

The documentation and preservation of archaeological sites often require the development of fast and easy techniques for 3D data acquisition, also in difficult conditions.

Nowadays with the development of the computer science and its uses, the documentation of the world heritage sites became easier and accurate. It can be done by using different types of surveying methods. Lots of methods, techniques, and software are used to document the world heritage sites. Some of these methods end with a special techniques and software, but some others using the already exist commercial software. The “Digital Photogrammetry” which depends mainly on the imagery and computer models can be integrated with other different types of surveying techniques for documenting and monitoring the world heritage sites as well.

The graphic representation of historical monuments is traditionally performed with the assistance of tape measure. With this purpose, all the necessary elements for its representation are measured is based on direct measurements on the monument. These measurements are time consuming dependent on the conservation state of the monument. They can even damage the monument.

Sometimes, for the object and/or the environment situations, the used measuring techniques could have some limitation which influencing the accuracy of measurements. Therefore, the use of combination of surveying types and techniques is solving the problem.

When we talk about the word World Heritage sites Documentation, it comes to our mind three of the most famous international organizations, which are concerning about it. These organizations are: UNESCO, CIPA, and ICOMOS. These international organizations are fully or partially concerned of the world heritage sites preservation, conservation and documentation.

After the Second World War, the conservation of monuments was motivated, leading, in 1964, to elaboration of the International Charter about conservation and restoration of monuments, known as Charter of Venice. Since then, several countries began to establish programs for maintenance of their historical monuments. The International Council of Monuments and Sites – ICOMOS recommended that each country should constitute a photogrammetric record of its monuments and sites, since photogrammetry is considered the main and more advanced method for surveying (Simone da SILVA *, Quintino DALMOLIN, 2000).

Photogrammetry is an indirect measurement method, to extract geometrical information of spatial objects from a number of photos. For data acquisition, increasingly digital cameras are used.

As a discipline, architectural photogrammetry is currently undergoing profound changes. New technologies and techniques for data acquisition (CCD cameras, Photo-CD, photoscanners), data processing (computer vision), structuring and representation (CAD; simulation, animation, visualization) and archiving, retrieval and analysis (spatial information systems) are leading to novel systems, processing methods and results (Hanke K., 1998).

Working with digital images needs special computer equipment (hard and software). Recently, systems are under development, which combine the functionality of former analytical plotters (stereoscopic restitution) with the accuracy of bundle adjustment and the advantages of digital imaging systems. This "digital photogrammetric plotters" are relatively new for architectural applications, but will replace all "classic" systems in the near future. They can automate the measurement process to a high extend.

Results of photogrammetric restitution are 3D coordinates of all points that show up at least on 2 photographs. In addition, lines and faces between them are part of the topological model output. Including coordinative known control points to the restitution process will lead to a framework of points, lines and faces, which can easily be exported to any CAD environment. Further results of digital photogrammetry, beside facade plans and orthoimages, are 3D-models of the monuments. These virtual models can be completed with original image texture on their surface to give photorealistic presentation.

Thus created "photomodels" can be used to visualize e.g. damages on sensible cultural heritage sites to serve as a tool for the best decision of the responsible authorities (Hanke K. and Ebrahim M., 1999).

Close range photogrammetry and terrestrial laser scanning are the most common techniques used combination. These techniques made it possible to obtain a high level of detail and accuracy and result to be very effective, especially for small or medium-extension archaeological sites (up to tens of hectares). However, for large archaeological sites close range photogrammetry and terrestrial laser scanner are not always the most suitable survey techniques; whereas, the information obtained from aerial or satellite images provide

an overview of the study area, which is fundamental for the interpretation of archaeological structures. M. Lo Brutto, et al, 2012 mentioned that "such images have some limitations linked to the geometric resolution" (typically of some decimeters and inadequate for detailed studies), to the periods of acquisition (which does not always correspond to a given particularly useful date for the purposes of the archaeological work), and ultimately to the cost.

To ultimate the accuracy of measurements and consequence the modelling, different types and techniques of surveying is recommended. Several scientific researches tries have been done to integrate different types and techniques of surveying for documentation and preservation of the historical buildings purposes.

V. Bonora, et al, 2003 tried to fix only one reference system to enable comparing places and lounges locations and establish the assumption to make correct models according to a metric point of view for Royal Palace of Turin. They used opening data for this experience about different metric models creation, which extracted from the topographic survey of the whole Palace. Detailed topographic measures, integrated with traditional distance measures, allowed them to form vectorial plans of different levels to be obviously altimetrically referenced. Because of traditional underwater surveying is not very accurate, costly, and time consuming, Marco Canciani, et al, 2003 decided to use a very simple and cheap Photogrammetric way for work in progress on an underwater excavation of a Roman imperial wreck located in SecchedellaMeloria, in front of Livorno, Italy.

Nowadays the technological progress is centered both on the improvement of systems capable of implementing data and on the necessity of handling models of representation using automatic numerical procedures.

G. A. Massari, 2003 has used different technologies to observe the visible aspects of an architectural work produce various kinds of knowledge. Digital photogrammetry and laser scanning aim at a complete description of the work. A team on average four people carried out the topographical and photogrammetrical work. The measurements of the polygonal and the topographical points were taken using a Topcon GPT 1001 total laser station. The photogrammetric shots were taken using EPR Ektachrome 64 film and a 9-reseau semi-metric Rolleiflex 6008 camera.

Jason Church, 2012 has presented a lecture answering some important questions about the use of surveying types and techniques for the archaeological observations. One of these questions was "Which technology is most appropriate for a given application and when a combined approach may be more productive?"

Schaich, 2013 presented his workflow to support Archaeology and Cultural Heritage sites using a combination of 3D scanning and photogrammetry surveys 3D Database. He used different surveying measuring tools leading to 3D models such as Total station, GPS, 3D laser scanner, high-resolution structured light scanner, and Structure from Motion (SFM) photogrammetry. The workflow was a good example of the integration between

the different surveying types and techniques serving the documentation and preservation of the world heritage sites.

At an archaeological site in Saku-city, Nagano, Misuzu recently conducted a topographical survey utilizing Topcon's ImageMaster PRO, a 3D photogrammetry software, and a detailed survey and stakeout with the GPT-9000A robotic total station (Isamu Kumaki, 2014).

S. GonizziBarsanti, et al, 2013 have applied a combination of different surveying techniques to test and evaluate 3D surveying and modelling methods to document the remaining ancient byzantine city walls of the archaeological site of Aquileia in Friuli Venezia Giulia, Italy. Their objectives were threefold:

- 1) To use 3D data to create maps, façades and sections that provide information useful for archaeological purposes such as the investigation of architectural construction techniques or construction phases,
- 2) To evaluate and compare photogrammetric and laser scanner data in order to identify the advantages and disadvantages of the two 3D surveying techniques for archaeological applications and needs and
- 3) To draw broader conclusions about the applicability of photogrammetry and laser scanning for documenting and analysing ancient walls within a particular set of environmental circumstances.

The starting point of their work in Aquileia was the collection of both photogrammetric and laser scanner data of the site. First, they made surveying measurements with a Topcon 3005N total station to acquire ground control points to geo-reference and bring the two models into a common reference system.

Second, they made a laser scanner survey on the entire site. Third, they collected data using two types of photogrammetric techniques:

- 1) An Unmanned Aerial Vehicle (UAV) survey collected data for the entire site;
- 2) A terrestrial photogrammetric survey was used only on a sub-set of walls that were in an ideally-suited (standing with no or few presence of grass, etc.) For 3D modelling purposes.

2. Case Study

At the end of the 18th century, an earthquake seriously damaged the court church which well known as "Hofkirche" in Innsbruck, Austria.

To prove the success of the integration between different types and techniques of surveying in documentation and monitoring the world heritage sites, a practical case representing the documentation and monitoring of the damages that happened to the "Hofkirche" in Innsbruck, Austria has been done.

The Hofkirche in Innsbruck, Austria, built in the middle of the 16th century. The Hofkirche (Court Church) is the last existing Gothic hall church, located in the old Town section of Innsbruck, Austria, and is well known for German Emperor Maximilian's tomb and the 28 larger-than-life

black bronze statues. Innsbruck was the residence of the Habsburg Dynasty between 1420 and 1665. The Hofkirche with its tomb of German Emperor Maximilian I is one of the most famous and outstanding historical monuments, being in the property of the State of Tyrol. It was built between 1555 and 1565 under Ferdinand I (the brother of Emperor Karl V). The cenotaph (i.e.: empty tomb) of Maximilian is located in the center of the church's nave. The cenotaph itself has a base of about 3 m x 5 m. 24 very delicate white marble reliefs are attached to a black marble structure which is decorated by bronze elements. With the kneeling Emperor and four more bronze statues on top of the monument, it is about 5 m high. For centuries, the tomb was separated from the visitors by a black iron lattice. In addition, the fine caved marble plates were covered by glass. Because of a basic conservation and restoration of the tomb, lattice and glass plates were removed for the first time ever since its construction in the 16th century. For a short period in May 2002 all sides were accessible after the temporary housing of the restoration technicians had been removed from one side and not yet been moved to the other side for the second restoration period. (Boehler W. et al, 2003)

Heavily damaged during an earthquake (1689), the church was restored and decorated with enormous Baroque ceiling stuccos under Emperor Leopold I. Prince's Choir of Archduke Ferdinand II, designed as a Renaissance gallery with wooden inlays; other features are Renaissance organ (1560); Classicist altar by N. Pacassi, donated by Maria Theresia (1758). Tombs: Katharina of Loxan (with Sarcophagus by A. Colin), Bishop J. Nasus, A. Hofer (body transferred there from Mantua in 1823), etc.

Figures 1 through 5 show the location from google earth, inside photo and outside photos. The church forms a three-nave hall with a single-nave choir (Figure 6). Five pairs of columns structure the hall into six bays the first and the last ones carrying galleries, thus centering the hall to the (empty) tomb. The building shows a mixed style of Italian renaissance and German gothic including even Romanesque and baroque elements, thus being of high interest for building-historians.



Figure 1: HofKirche location by Google earth



Figure 2: Hofkirche 3D view by Google earth



Figure 3: Inside photo of Hofkirche



Figure 4: Outside photo



Figure 5: Outside photo

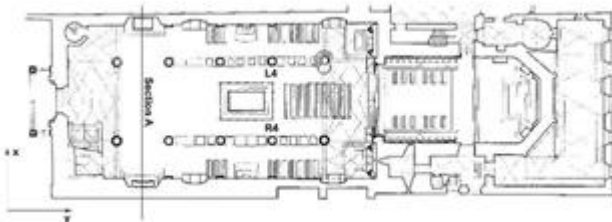


Figure 6: Ground plan of Hofkirche

A complete building recording is an indispensable basis for analysing and understanding of the structure of historical buildings. Every kind of protection and revival of historical buildings requires a three spatial polar measurement elements detailed geometric model of the object, in scale and known coordinate reference. It gives all the necessary information for a monitoring as well as further visualization of damages and their spatial attitude.

3. Methods and Instrumentation

To document and monitor the world heritage sites, a combination between different types and techniques of surveying has been used as a data acquisition tools. Integration between the tachymetry survey and digital photogrammetric techniques has been established to bind between the gathered data in one referencing system.

To investigate the damages that occurred to the church due to the earthquake and its influence on the structure, e.g. the inclination of pillars of this church has been observed and shows significant values. Digital photogrammetry and reflectorless tachymetry both yield to the geometry of deformed sections of vaults (figure 7).

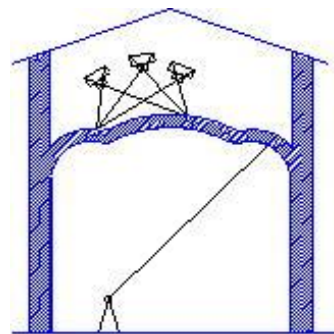


Figure 7: Tachymetric and photogrammetric measuring area

To obtain such complete building recording in 2D and/or 3D, some measuring limitations may be faced. To solve such critical issues, a combination of different surveying measuring techniques was needed.

3.1 Photogrammetric Practices

The photogrammetric measurements of the upper surface of the vaults was done using an analogue semi-metric camera "Hasselblad SWC". For each quadrangle 8 photos have been taken with convergent angles and from different camera positions. The photogrammetric restitution was done by simultaneous bundle-adjustment of all images.

3.2 Tachymetric practices

The instrumentation that has been used is a combination of a theodolite and a distancer (so-called "Digital Tachymeter"). Thus, the bearing, vertical angle and spatial distance from the instruments position to the object-point are recorded. These data in combination with the point number and a point classifying code are automatically stored on a chip card. Having finished the measuring work, data are transferred to a PC running a surveying software. All evaluations are done referring to a pre-defined coordinate framework. That is why the digital tachymeter was installed on a point with known coordinates and orientated according to the coordinate system.

3.3 Comparison of measurement techniques

Tachymetry results mainly in 3D coordinates of discrete points whereas photogrammetry yields - besides the geometry - to additional quality information of the surface

(e.g. color etc.). The photogrammetric restitution is not restricted to discrete points, but can also produce continuous lines and faces. Photogrammetric images are also a proper storage-media for future work, i.e. if the density of the evaluated points has to be increased.

As a sectional method, photogrammetry needs at least two images from different camera positions (or one photo with additional information about the object's geometry). The polar reflectorless tachymetry on the other hand needs only one set up of the instrument and is therefore suited for hardly visible areas.

3.4 Basic geodetic network

The results of photogrammetry and tachymetry can be combined and compared when all evaluation is done in a common coordinate system. The points of a trigonometric three-dimensional network covering the whole project area represent this framework. The relative position of the points is determined by measuring angles and distances using the digital tachymeter. The final coordinates result from a least squares adjustment procedure that gives the opportunity to detect blunders and errors in the data and to improve global accuracy.

The coordinate system can in principal be chosen arbitrary. For practical reasons one will try to adapt it to the object's demands. So for the Hofkirche, to increase the clearness of presentation, the Y-axis was identified with the centerline of the central nave, the X-axis perpendicular to it (Figure 6).

The network consists of 5 points in the nave of the church and 12 points in the loft. A difficult task was the connection of the two parts. Because inside the church there is no possibility, we marked one point 50m outside the church in the longitudinal-axis (Figure 8). From this point, we had a good view through the main entrance to the nave as well as, via three window-sills, into the area of the loft, linking the loft-part to the network. There the points were marked by round targets fixed at the joists. These targets were used as photogrammetric control points, thus transferring the coordinates of the network to the photogrammetric restitution.

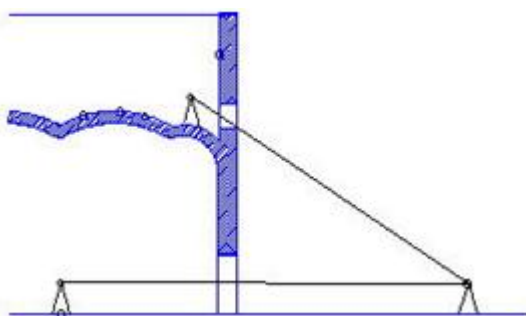


Figure 8: Geodetic network, linking church and loft

The tachymeters used in building surveying nowadays are equipped with a reflectorless distance meter using a powerful red LASER beam. It is visible, producing a red spot on the object, and is therefore a useful help in targeting. So targeting is much easier than using the cross-hair.

Calculation of the three-dimensional coordinates means a transformation of polar to Cartesian coordinates: (direction, vertical angle, spatial distance) (X, Y, and Z). The result is anyway a set of evaluated 3D points.

Point by point recording requires a preceding reduction of the continues object's surface to a set of representative discrete points. This selection should be done in a way that the points could be identified and related mutually during restitution. This will need a sketch with the position of points to be measured and their topology. After measurement, the points must be transferred to a CAD software and correlated into lines and faces.

Alternatively, to the chronological separation of measuring and restitution, these two-steps can be done simultaneously. Data are transferred directly to a laptop where the coordinates of the points are calculated and lines and surfaces between directly drawn in a CAD software. Because drawing is done while viewing the object, sketches are obsolete and the risk of errors by wrong identification is significantly eliminated.

3.5 Optical Plumbing

The tachymeter was used for investigating the deviation of the columns. The method, known as optical plumbing, works as follows (Figure 9): the tachymeter is set up as far away from the column as possible. The direction to the highest, to the middle and to the lowest point of the column is obtained by measuring the right and the corresponding left tangent point and averaging the values.

The small angles between the both upper points and the base point combined with the easily measurable horizontal distance result in the inclination perpendicular to the line from tachymeter to column. In order to get the deviations in direction of the nave and perpendicular to it, the measurement was arranged parallel to the coordinate axes.

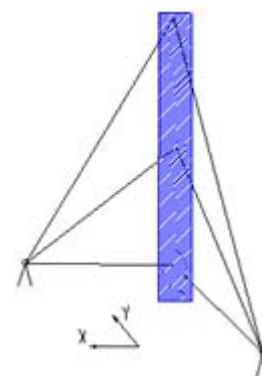


Figure 9: Column with tachymeters, targeting high, middle and low

4. Results Analysis

Documentation of Vaults and Sections

The documentation of Hofkirche had several aims. On the one side a complete photo-documentation of the surface of the vaults has been requested, on the other hand the geometrical shape of chosen sections of the vaults should be measured to monitor an existing deformation possibly

resulting from an earthquake in 1697. Beside this, the measurements should be used to build a geometrical basis for a fundamental static survey of the building's structure.

The result was a 3D-model of the photographed quadrangle of the vault (figure 10). To incorporate the model into the coordinate system of the church all visible control points have been used for transformation. From this model, sections of the vault have been derived.

A detailed ground plan and longitudinal as well as transversal sections of the interior part of the church were measured by digital tachymetry with a reflector less distancer (Figure 6). This measurement system has also been incorporated into the common coordinate system by including network-points.

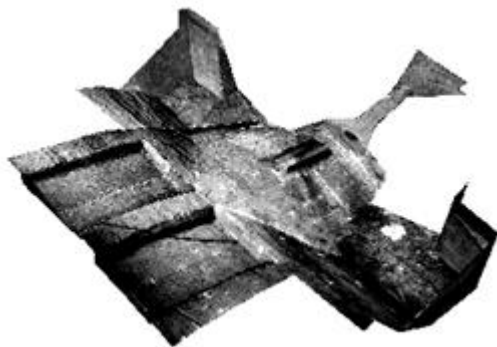


Figure 10: Perspective view of vault quadrangle with photogrammic texture

Figure 11 shows the combination of both methods in section A, figure 7. On the right side, the photogrammetrically derived part is outlined. On the left side the differences between the evaluated section and a mirrored (dotted) line of the right side shows the distorted symmetry of the vault. Thus, the combination of photogrammetric measurements on the upper side and digital tachymetric measurements on the bottom side leads to a representation of the entire vault. As a result, important parameters for the static survey, like the thickness of the vault or the exact shape can be derived.

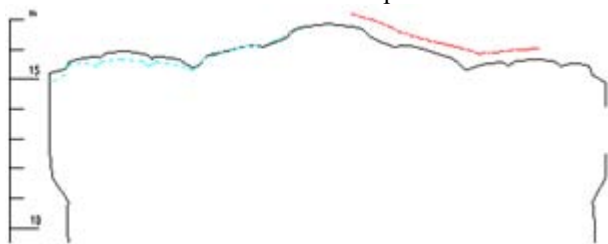


Figure 11: Upper part of section A

Inclination of Columns

The obvious inclination of the 10 marble-columns (Figure 6) is an indicator for the effect of the 1697 earthquake. For determining the amount and the direction of deformation the deviation of the capital and the middle of the shaft relative to the base were investigated. The largest deviations were detected at columns L4 and L5. They are exemplary shown in Figure 12.

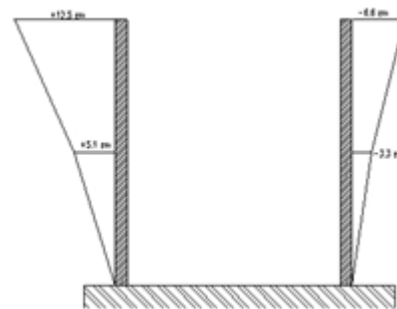


Figure 12: Deviation of columns L4 and R4, transverse to the nave (x-direction)

5. Conclusion

To document and monitor the world heritage sites in an accurate way, it may require to combine different types and techniques of surveying as data acquisition tools.

To prove the success of the integration between different types and techniques of surveying in documentation and monitoring the world heritage sites, a practical case representing the documentation and monitoring of the damages that happened to the "Hofkirche" in Innsbruck, Austria has been done. Hofkirche building was used as a practical case as it was definitely damaged by an earthquake in the 18th century.

Integration between the tachymetry survey and digital photogrammetric techniques has been established and used successfully to bind between the gathered data in one referencing system for documentation and monitoring of historical buildings.

The results were useful documentation of vaults and sections as follows:

- A 3D-model of the photographed quadrangle of the vault.
- Sections of the vault have been derived.
- A detailed ground plan and longitudinal as well as transversal sections of the interior part of the church were measured.
- A representation of the entire vault using the integration of both measuring techniques.
- Important parameters for the static survey, like the thickness of the vault or the exact shape can be derived.
- Obvious inclination of the 10 marble-columns was an indicator for the effect of the 1697 earthquake.

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Author Profile



Mostafa Abdel-Bary Ebrahim received the B.Sc. and M.Sc. degrees in Civil Engineering from Faculty of Engineering, Assuit University in 1986 and 1992, respectively. During 1995-1998, he stayed in Institute of Geodesy, Innsbruck University, Austria to study the evaluation and application of digital close range photogrammetry for Ph.D. He has been awarded his Ph.D. degree on 1998. He now working as full professor at King AbdulAziz University, Kingdom of Saudi Arabia.