

Three-Dimensional Reconstruction for Cultural Heritage Visualization: Application to the Byzantine Churches of Cyprus

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Abstract

The state of the art of 3D reconstruction techniques is summarized and their contribution to the visualization of Cultural Heritage is presented. An application of the above concerns the Painted Byzantine Churches of the Troodos Mountain in Cyprus. Accurate 3D digital reconstruction of the Painted Churches and their virtual tour in a multimedia environment is created. Contemporary photogrammetric and terrestrial laser scanning techniques are employed, combined with virtual reality methods and multimedia techniques. Furthermore, a Monument Information System (MIS) has been developed to provide a wealth of qualitative and quantitative information. The system may operate either autonomously or on the web, through Google Earth environment. The result is a unique product of virtual realism for the visualization of Cultural Heritage objects, while at the same time it is able to provide virtual touring services adapted to the users' needs.

Keywords

Digital techniques, orthophotography, GIS, Virtual Reality

1. Introduction

Geographical Information Systems, Computer Graphics, Virtual Reality and Multimedia Technology are well established technologies used for the geometric documentation and virtual reconstruction of cultural heritage objects. 3D accurate reconstructions – for the documentation of monuments – are widely applied nowadays, using contemporary geodetic measurements, photogrammetric procedures and terrestrial laser scanners.

Such techniques were used for the Painted Byzantine Churches of the Troodos Mountain in Cyprus (*Fig. 1*), dated from the AD 11th to 14th century. These churches, unique monuments of Byzantine architecture and religious art, have been included in the UNESCO list of World Heritage Monuments since 1985 (except the Church of Ayia Sotira, of the Transfiguration of the Savior, “*tou Soterou*”, which was added in 2001). UNESCO's criteria for inclusion were both the architecture and the landscape design, but also the fact that these monuments are an “exceptional testimony to a cultural tradition”.

The region of the Troodos Mountain is characterized by one of the largest groups of churches and monasteries of the former Byzantine Empire. The



Church of Ayios Nikolaos (St. Nicholas) tis Steyis	Kakopetria
Ayios Ionannis (St. John) Lambadhistis Monastery	Kalopanayiotis
Church of Panayia (The Virgin) Phorviotissa (Asinou)	Nikitari
Church of Panayia (The Virgin) tou Arakou	Lagouthera
Church of Panayia (The Virgin)	Moutoullas
Church of Archangelos Michael (Archangel Michael)	Pedhoulas
Church of Timios Stavros (Holy Cross)	Pelendria
Church of Panayia (The Virgin) Podhithou	Galata
Church of Stavros (Holy Cross) Ayiasmati	Platanistasa
Church of Ayia Sotira (of the Transfiguration of the Savior) tou Soterou	Palaichori

Fig. 1. The region of Mountain Troodos (marked with a square) with the complex of the ten churches (as shown in the table), which are included in the UNESCO list of World Heritage Monuments.

complex of ten monuments, all richly decorated with murals, provides an overview of Byzantine and post-Byzantine painting (frescoes, religious paintings) in Cyprus. They range from small churches, such as the Church of Virgin Mary in Asinou, whose rural architectural style is in stark contrast to the highly refined decoration of monasteries like St John Lampadistis (<http://whc.unesco.org/en/list/351/>).

2. Bibliographic database

The volume of bibliography, relevant to these unique Byzantine Churches, is very large. The themes of literature are quite rich and among others include the history of the monuments, detailed description and analysis of their architecture, photographs, descriptions from travelers (local and foreigner), references to wall paintings, theology of icons and frescoes and much more.

At this stage a database was created (*Fig. 2*) using Microsoft Access (E-R data structure) for the

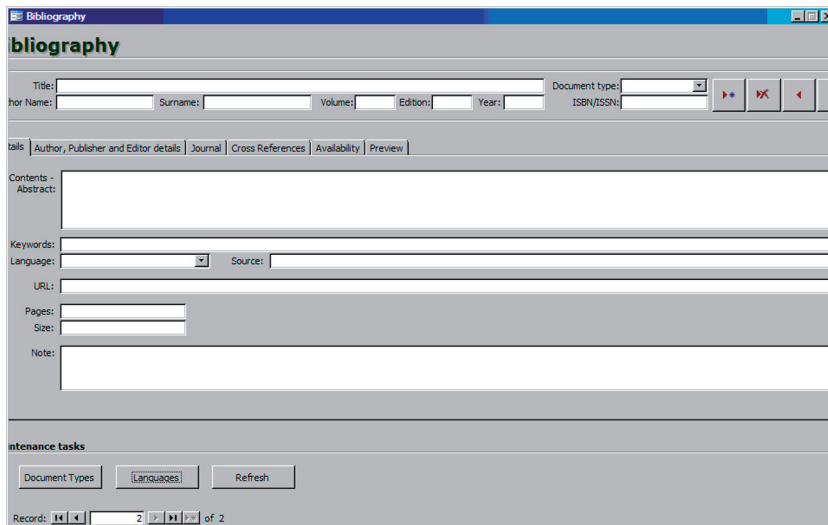


Fig. 2. Database interface.

recording of the literature (Prague *et al.* 2004). The database includes more than 30 entities which allow a full and correct documentation of the specific literature. An interface created for this purpose combines both quick registration of the literature references (related to the historical Byzantine churches of the area of Morphou)

and also allows the registration of other important information, such as the availability of each book or article, the specific website if these are on the web etc. The database is easily searchable through keywords, which allows the user to find books or articles on a specific topic, or to search by author, etc.

So far more than 400 books and articles have been recorded in the database. These books and articles are located in the main libraries of Cyprus, such as the Cyprus Library, University of Cyprus Library and the Archbishopial Library of Cyprus but also on the web as e-journals. The user is also able to locate where one can find the book, if it is available for loan, etc.

3. Digital Reconstruction of the terrain – Monument Information System, MIS

Moreover, a detailed 3D reconstruction of the area surrounding the monuments was produced. Grayscale

orthophotos with an accuracy of 0.5m were used for creating a photomosaic of the digital terrain (*Fig. 3*). These orthophotos cover an area of 23 x 36km² (828km²), mainly over Mountain Troodos. It should be noted that these orthophotos overlap each other and they were produced with rigorous photogrammetric procedure using aerial photos taken over the area in 1993. The orthophotos were kindly provided by the Department of Lands and Surveys of Cyprus, and their contribution is acknowledged.

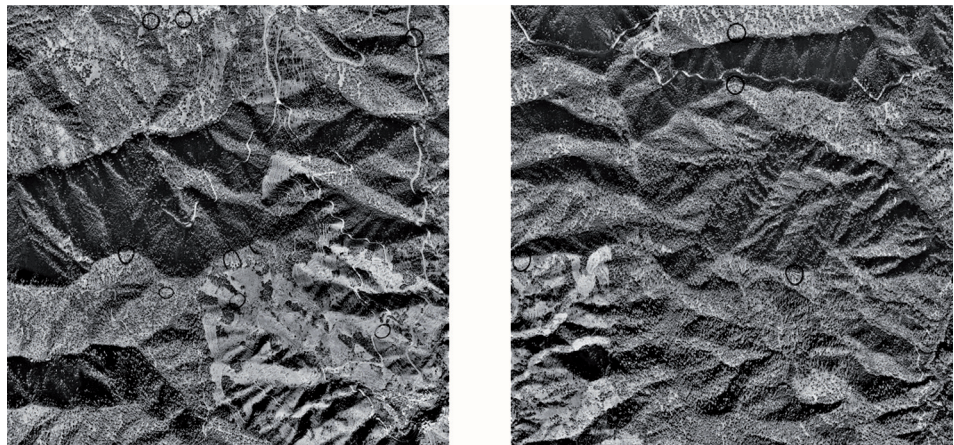


Fig. 3. Examples of the provided orthophotos of the area.

Some of the key issues, which have been tackled with regarding the reconstruction of the terrain, were the digital database storage requirements (over 6 GB required) on the one hand and computer resources used on the other. An evaluation of these parameters would allow us to achieve the maximum performance in order to have the best result, especially at the stage of visualization.

For the 3D reconstruction of the area, the existing Digital Elevation Model (DEM) in Cyprus Cadastre was used as elevation data. At first, a Triangulated Irregular Network (TIN) model, using hundreds of 3D points as data, was created. Afterwards, we produced a uniform rectangular grid model (Grid), which was used as the 3D digital terrain for our study (Fig. 4). All the available orthophotos were draped over this DEM, creating a truly three-dimensional (3D) photorealistic visualization of the area, on which the complex of the ten monuments is situated.

A Monument Information System (MIS) in ArcGIS environment, which allows both collection and storage of any data related to the monuments, was created. This MIS combines spatial and non-spatial information. Spatial information includes DEM, orthophotos and the 3D coordinates of the ten Byzantine churches. The user can “fly” over the photorealistic visualization of the area and locate the monuments or any other characteristics of the area with a high accuracy and reliability (Fig. 5). Non-spatial information is related to each monument through tables of attributes (Fig. 6). Through these tables any kind of information is available, such as history, architecture, information about opening hours, web sites related to churches etc. (Fig. 7).

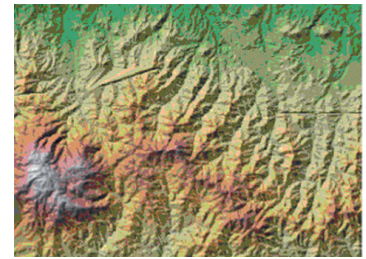


Fig. 4. Digital Elevation Model of the area.

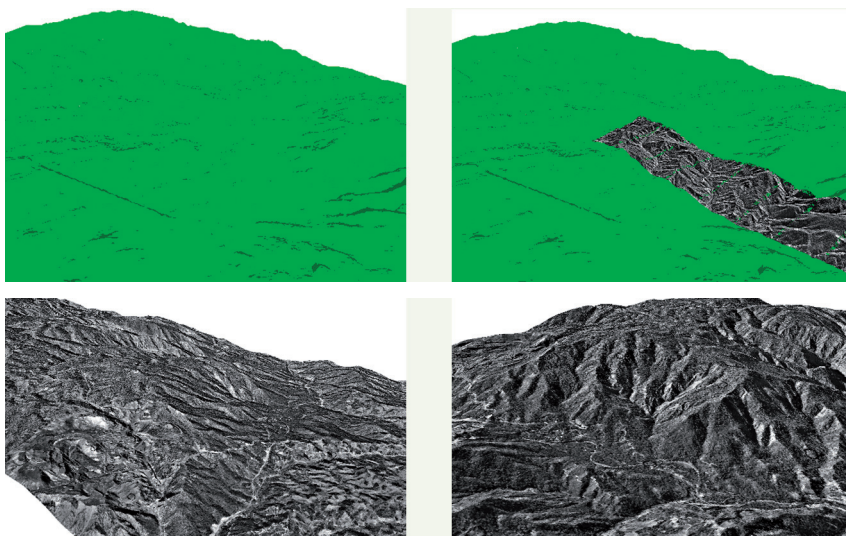


Fig. 5. DEM of the area (top left), procedure of creating the photorealistic visualization (top right) and the final result of visualization (bottom).

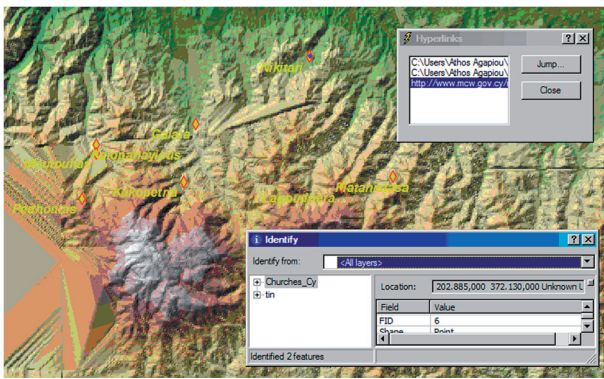
4. 3D digital reconstruction – visualization of the painted churches

The 3D reconstruction procedures may be divided into three main categories according to the method used:

- rigorous methods producing detailed and accurate models,
- methods using software packages developed and intended for non-specialists and
- non-rigorous methods producing “light” models, mostly for web applications.

Attributes of Churches_Cy					
FID	Shape *	Id	File ID	Name Monu	Location
0	Point ZM	0			
1	Point ZM	0	1	Church of Panayia (The Virgin) Phorviotissa (Asinou)	Nikitari
2	Point ZM	0	2	Ayios Ionannis (St. John) Lambadhistis Monastery	Kalopanayiotis
3	Point ZM	0	3	Church of Panayia (The Virgin)	Moutoullas
4	Point ZM	0	4	Church of Archangelos Michael (Archangel Michael)	Pedhoullas
5	Point ZM	0	5	Church of Panayia (The Virgin) Podhithou	Galata
6	Point ZM	0	6	Church of Ayios Nikolaos (St. Nicholas) tis Steyis	Kakopetria
7	Point ZM	0	7	Church of Stavros (Holy Cross) Ayiasmati	Platanistasa
8	Point ZM	0	8	Church of Panayia (The Virgin) tou Arakou	Lagoudhera

Fig. 6. Attribute table of the monuments.



The churches were sketched up using simple photogrammetric procedures (like rectification) topometric measurements of each plane of a monument and field. The 3D wireframe result was a combination of lines, arcs, rectangles and circles (Fig. 8). The design was made only for the outside facades of the churches and they were also shaded using the software tools (Figs 9–10).

The texture of each church was extracted from recently taken digital images. Some main

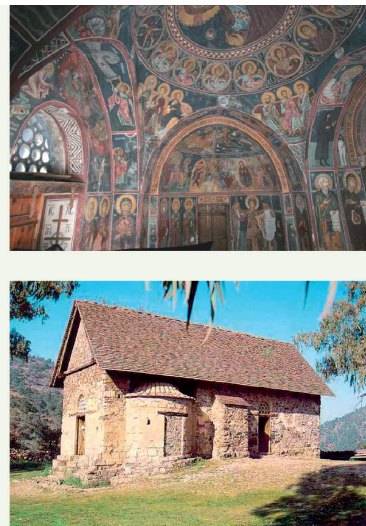


Fig. 7. Spatial and non-spatial information as displayed in the MIS, like images or web sites.

During the last years the last method, although its final product has no high accuracy, has become very popular, especially for computer technologies such as Virtual Reality and Multimedia Technology. Some of the main advantages of these methods are small product size (from a few Kb to some Mb), low cost of production, ideal for web applications etc.

There are many free (or at least low cost) programs on the web that can be used for this purpose. In this study for 3D Digital Reconstruction and Visualization we have chosen the Google SketchUp Pro program, a software that may be used not only to create or modify 3D models but also to share them freely. These models may be exported to Google Earth, a non-cost and popular software available on the web or even to more specialized programs such as any popular CAD or even 3D Studio Max (http://www.google.com/intl/en/sketchup/3dwh/pdfs/modeling_a_city.pdf and <http://sketchup.google.com/intl/en/product/gsu.html>).

characteristics of each church, like wooden doors, arches, UNESCO World Cultural Heritage label, were specially photographed (Fig. 11), in order to achieve a more realistic result. For the rest of the patterns of the church, either “sample material” was used or the whole facades, or in some cases both (Fig. 12). At this stage it should be remembered that the model’s size had to remain low (i.e. lower than 10 Mb) for the real-time rendering on the web to be feasible.

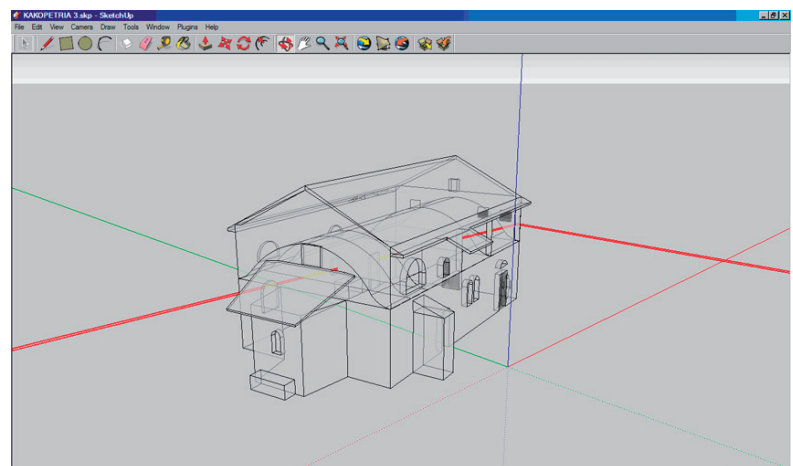


Fig. 8. Wireframe of the Church of Ayios Nikolaos (St. Nicholas) at Kakopetria, in Google SketchUp.

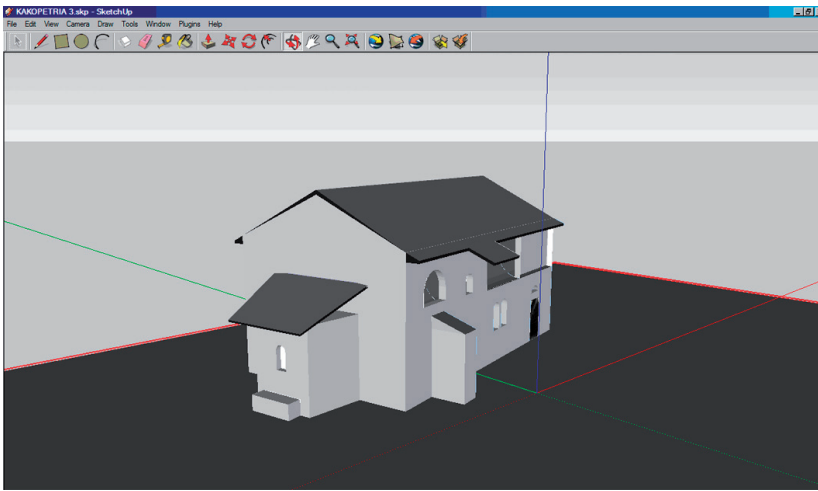


Fig. 9. Shaded facades of the Church of Ayios Nikolaos (St. Nicholas), in Google SketchUp.

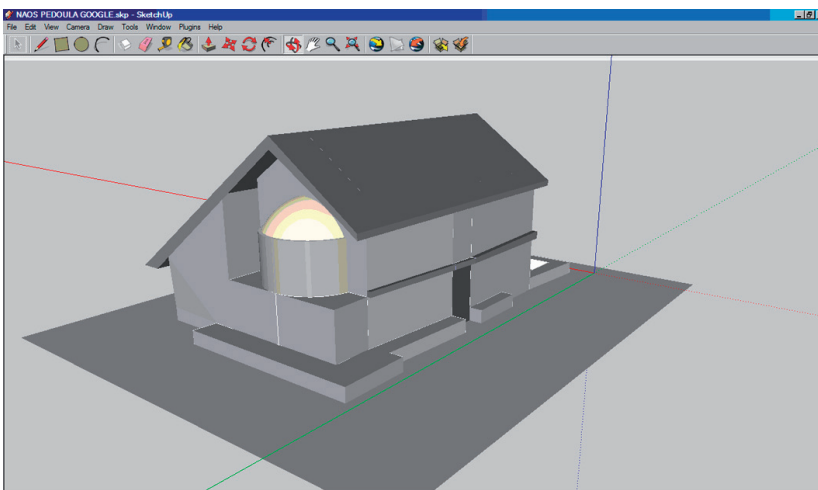


Fig. 10. Shaded facades of the Church of Archangelos Michael (Archangel Michael) at Pedhoulas, in Google SketchUp

These “light” models were initially georeferenced using Google Earth Pro. Finally the model was designed and modified according to its physical terrain, which was imported from Google Earth to Google SketchUp (Fig. 13).

These models were then exported to Google Earth. The user has the possibility to fly over the area of each monument and can see the 3D models of the churches, in real-time. Furthermore the user may be briefly informed about the history, the architecture of the monument and even take 3D measurements of the monument.

The 3D models (in Kmz code for viewing in Google Earth and as a SketchUp model) were uploaded to the official site of Google 3D Warehouse – Models (<http://sketchup.google.com/3dwarehouse>). The user can find the monuments by just searching using keywords (e.g. ‘churches of Cyprus’) where one can read some main characteristics of the monuments. For further information the user may click on the link for the web site that is currently being



Fig. 11. Recently taken digital photos of the Church of Archangelos Michael (Archangel Michael) at Pedhoulas.

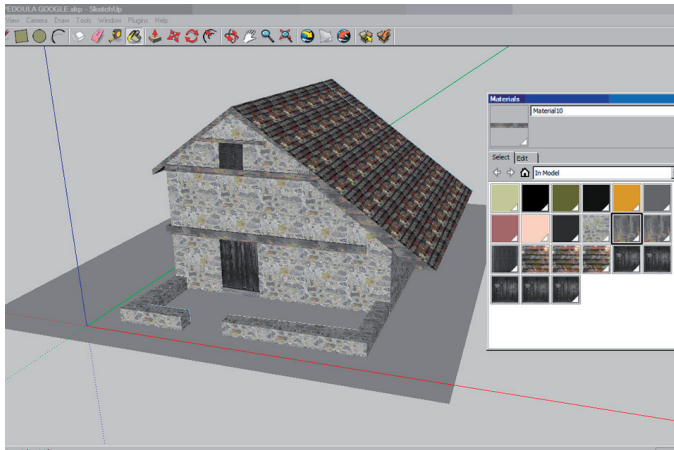


Fig. 12. Texture proceedings of the Church of Archangel Michael (Archangel Michael).

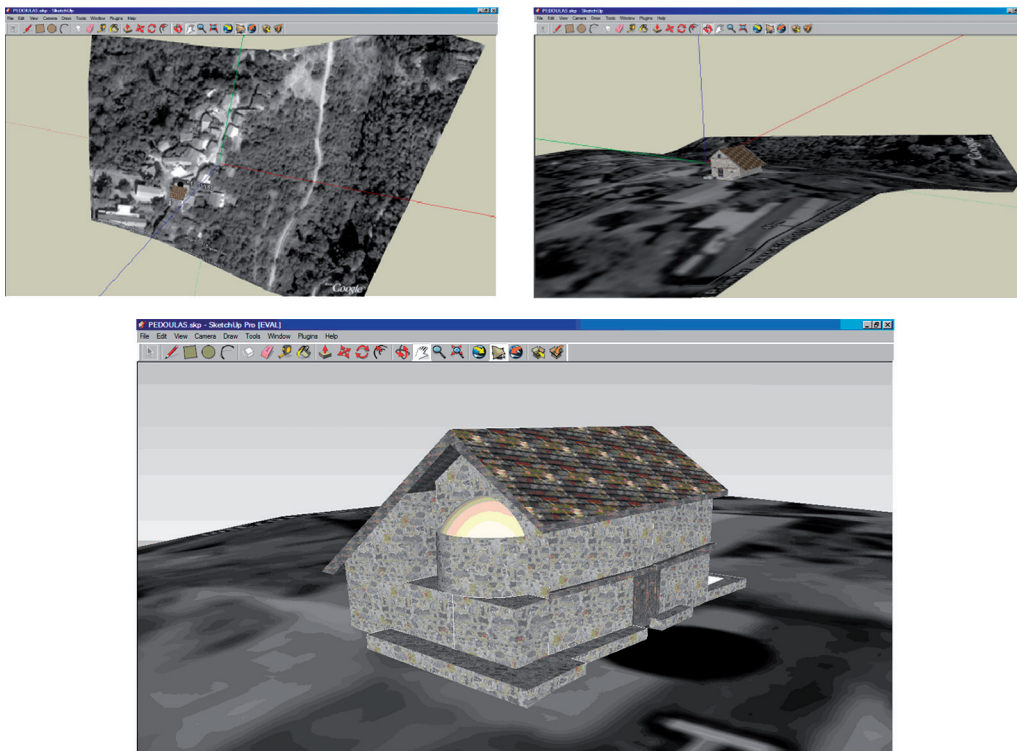


Fig. 13. Google Earth terrain as inserted from Google SketchUp (Church of Archangel Michael).

developed for this purpose (www.byzantinecyprus.com).

Moreover, the models can be found in Google Maps, a service of Google Inc., where one can track the monuments through car tracking systems (with Google Map software provided), smartphones and generally most web-enabled mobile phones. From such devices a user can sideload and synchronize (dynamically) the data through Google Maps.

5. Accurate 3D documentation

An implementation for an accurate 3D documentation to a Byzantine church (Virgin Mary in Asinou) was performed. The purpose was to produce a detailed and accurate 3D model of this church.

Virgin Mary in Asinou (Forbiotissa) used to be the Katholicon (monastery church) of the Monastery of Forbion, as its name implies. According to the dedicatory inscription, which is dated to 1105/6, the monument was built with the donation of Magistros Nikephoros Ischyrios. The monastery was founded in 1099 and it functioned until the end of the 18th century, when it was abandoned

(<http://www.mcw.gov.cy>; Hadjichrostodoulou and Myrianthefs 2002).

For the documentation, geodetic measurements with a reflectorless total station were acquired, and a 3D laser scanner was employed as well. The point clouds were processed with the following procedure: first point cloud registration was performed and then filling the gaps followed. Then noise filtering and size reduction of the file were carried out, and finally a polygon mesh of the monument (ready for rendering) was created (Fig. 14).

Furthermore, stereopairs of terrestrial images were taken in order to produce a 3D model using

rigorous photogrammetric procedures. The total station was primarily used for measuring control points for the images. All images were taken with a professional digital camera (resolution of 10 Mpixels). In order to achieve the best accuracy and to have good intersection angles, the stereopairs were taken so that the B/H ratio was approximately 0.25 (where H is the distance from the monument and B is the base distance between the two photos). Photos were taken of the whole monument, both inside and outside, in most cases using a special crane.

The products of the combined use of all these measurements and procedures were:

- an accurate 3D model of the church (of the exterior and interior surfaces),
- section and facade plans at a scale of 1:50 (Fig. 15), and finally
- a multimedia video product (Fig. 16).

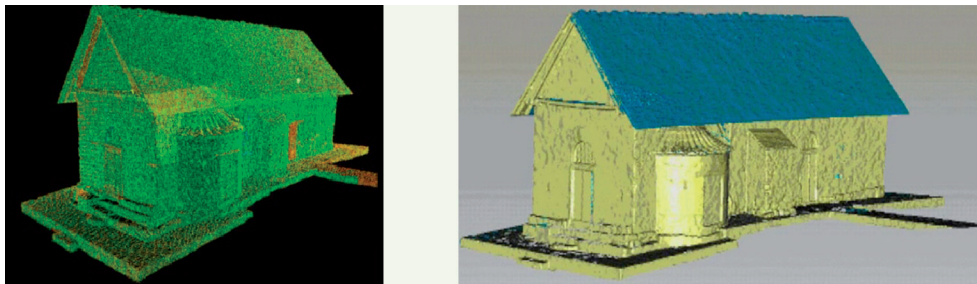


Fig. 14. Point cloud of the church from laser scanning (left), polygon mesh of the church (right).

All this spatial information was integrated into the Monument Information System.

6. Conclusions

In this paper both simple and more complex methods of 3D modeling, accurate documentation using terrestrial laser scanning and photogrammetric procedure, “light” models from free software and an application at a Monument Information System have been presented.

These data can be exploited either autonomously or in real-time on the web. Such technologies are now getting even more popular. The exploitation of 3D visualization of multi-source data has shortened the distance between reality and the virtual, it has enabled virtual 3D measurements and augmented reality through animation, integrating as much

information as possible for the benefit of the final product. Moreover, 2D products may be produced from 3D data practically at will.

The final product can have many uses from virtual reality for the visualization of cultural



Fig. 15. Accurate plans (sections, facade) from the photogrammetric procedure.



Fig. 16. Frames from the video of the 3D model of the church.

heritage objects to virtual touring services adapted to the users' needs, education purposes and many more.

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