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Virtualizing a Byzantine Crypt: challenge and impact

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ABSTRACT

This paper presents the work that was accomplished in preparing a multimedia CDROM about the history of a Byzantine Crypt. An effective approach based upon high-resolution photo-realistic texture mapping onto 3D models generated from range images is used to present the spatial information about the Crypt. Usually, this information is presented on 2D images that are flat and don't show the three-dimensionality of an environment. In recent years, high-resolution recording of heritage sites has stimulated a lot of research in fields like photogrammetry, computer vision, and computer graphics. The methodology we present should appeal to people interested in 3D for heritage. It is applied to the virtualization of a Byzantine Crypt where geometrically correct texture mapping is essential to render the environment realistically, to produce virtual visits and to apply virtual restoration techniques. A CDROM and a video animation have been created to show the results.

Keywords: range data, 3d modeling, photo-realistic, texture mapping, virtualization, photogrammetry

1. INTRODUCTION

The capacity to create, display, manipulate, archive and share a digital representation of the shape and appearance of an existing object (as-built) finds a most challenging class of applications in high-resolution recording of heritage-related objects and sites. When combined with immersive technologies, a virtual 3D visit can become a quite appealing way to study or to promote a cultural site. However, beyond photo-realistic rendering, a 3D model contains a wealth of information that can be analyzed and enhanced. Features that are small or only visible from a distance can be interactively examined, thus, allowing the study of fine details such as tool marks or surface texture. Furthermore, sites that must be closed for conservation reasons can still be studied and visited once a 3D model has been created. Computer-based visual enhancement and analysis techniques can be applied to the digital model in all of these situations. One such application is found in virtual restoration of an historical site. As opposed to "traditional" restoration that is performed on the physical object or site, virtual restoration is applied directly onto the digital copy that is editable in both shape and surface appearance properties. What's more, virtual restoration is always reversible unlike the traditional one. For instance, architectural elements that have been added over the years can be removed and the digital 3D model of the site can then be viewed in the correct historical context. Finally, virtual restoration can help with an in-depth study on possible interventions of traditional restoration.

When preparing a multimedia CDROM about the history associated to a particular archeological site, spatial information is usually presented using 2D images that are flat and don't show the three-dimensionality of that site or environment. An effective approach based upon photo-realistic texture mapping onto 3D models generated from high-resolution range images was used to present that spatial information that is usually lost about a site. The methodology, which should appeal to people interested in 3D for heritage, is applied to the virtualization of a Byzantine Crypt where geometrically correct texture mapping is essential to render the environment realistically. The technical aspects of the project are described in Beraldin et al. [1]. As a way to demonstrate the proposed method, we selected a Byzantine Crypt (see Fig.1) that is not part of a typical tourist itinerary in Italy, i.e., the Crypt of Santa Cristina located in Carpignano, Apulia. It measures about 16.5 m × 10 m × 2.5 m. Notwithstanding its size, this 1000-year old crypt presented many challenges

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from the technical and historical point of view. In order to model a complete site like this Crypt, a 3D photographer would have to be skilled in a number of 3D modeling procedures. The 3D photographer could be a specialist that does this type of work on contract basis. Or, in cases where the property of data is of concern, it can even be a technician directly linked to the agency requesting the work. Furthermore, he or she might be faced with the fact that the acquisition of the 3D shape could have been done before the acquisition of the texture images or that no high-resolution texture information is available from the 3D laser scanner. The combination of range data and texture information was examined from a user point of view. Section 2 presents an overview of general aspects in 3D modeling and section 3 describes the modeling techniques used for the Byzantine Crypt. Section 4 surveys some large projects pertaining to object and site modeling and then shows how the challenges were addressed for the Crypt. Section 5 discusses some practical aspects in such a project. Finally, concluding remarks appear in section 6.

a)

b)

Figure 1. Byzantine Crypt, a) the two outside entrances, b) view of the interior located underground.

2. USING 3D INFORMATION IN A MULTIMEDIA CDROM

When trying to present the history of a heritage site, the use of spatial information becomes very important in order to facilitate an understanding of that particular site. One can resort to hand drawn or computer generated isometric views, CAD models based more of less on reality and 3D models built from reality. The source of information includes among other things drawing/paintings, papers/digital photographs, or laser scanner data. Some of these provide dimensions directly but others need indirect ways to get scale and/or dimensions. We opted to represent our site (a Byzantine Crypt) using both photogrammetic techniques and dense 3D laser scanner information combined with high-resolution color images. The selected Crypt was excavated (rupestrian site) around the 9th century c.e. and it is characterized by two entrances. One of them leads to the area that served as a cemetery and the other, as the church. The church portion is divided into two naves according to a structure that is typical of the period. Furthermore, irregularly shaded walls covered with a number of fairly well preserved frescoes characterize this Crypt. One of them, Christ (Pantocrator) and the Annunciation, is dated at 959 c.e. and is signed by Theophylact. The Pantocrator sits on a richly decorated throne, holds the Gospels in his left hand and blesses with his right hand. The structure of the image is similar to images of the same period, present in Constantinople and in Cappadocia (Turkey). Experts of the Byzantine period come from around the world to visit and study this site. During the course of history, a Baroque altar was added (1775 c.e.) along with three pillars that replaced one that collapsed. Environment or site modeling is more difficult than object modeling because of the size and complexity involved. Several methods and a variety of sensors exist, however, given the application requirements, selecting and implementing the most efficient method for data collection and modeling is not a trivial task. Applications include virtual museums, historical site documentation, mapping of hazardous sites, as-built modeling of industrial and power plants, and virtual production for the entertainment industry. Many aspects of sensing and modeling must be understood before starting such a large project. All these factors combine to give a non-expert a formidable obstacle in producing a complete 3D documentation of a site. The typical processing pipeline used for 3D modeling includes calibration/verification, geometric modeling, and appearance modeling. The sequence of steps required is well documented [2,3,4,19] and we summarize briefly some of them.

2.1 GEOMETRIC MODELING

A model is a digital representation of the object or site on which one can perform operations. Of course, this broad definition emphasizes the task-oriented nature of the model. If the only goal is the generation of photo-realistic images for visualization, then purely image-based rendering techniques offer a general solution. However, if the goal is to analyze the works, to preserve and share a record of their geometry and appearance, then explicit shape information must be acquired and stored in an adequate representation that also includes some form of appearance modeling. Acquiring dense 3D data of surfaces has been a hot topic of research in the last 20 years. Though not as mature as photography, 3D imaging is seeing new applications emerging every year. Numerous commercial systems are available to measure dense 3D data. Some supply a color texture in registration with the 3D image but in most cases with very limited visual image quality. Apart from these systems, Rioux [5] presents a system that uses a color laser to measure both 3D and reflectance information of objects and that, at high resolution.

2.2 APPEARANCE (COLOR TEXTURE)

Appearance modeling includes methods like image perspective techniques (IPT) [6-13] which are concerned with direct mapping of photographs onto a 3D model and reflectance modeling. IPT that maps real-scene images onto the geometric model have gained a lot of interest. High-resolution color images can be precisely mapped onto the geometric model, provided that the camera position and orientation are known in the coordinate system of the geometric model. The main challenges faced by people in that field are accurately computing lens distortions, estimating 2D camera to 3D-model pose, dealing with hidden surfaces and incomplete views [3,6]. Those that don't possess the complete processing pipeline will have to rely on ad hoc methods. For instance, it is possible to transform photographs into orthophotographs and then map them manually onto a 3D model using commercial software. Unfortunately, geometrical error in the projection process will diminish the realism that one can attain. These photographs are constructed in such a way that the effects of perspective and tilt are removed. Orthophotographs are used a lot in terrain mapping because of the high distance camera-object, perspective and tilt effects can be minimized.

Reflectance modeling is used to extract from the measured color and shape those physical properties of an object that are intrinsic to it and that determine its appearance when viewed with artificial lighting on a computer screen. The true appearance of an object is the result of the interaction of light with material. Many mathematical models to describe this phenomenon have been proposed in the literature. The knowledge of such a model is important in order to reproduce hypothetical lighting conditions under varying observation points. A method developed by Baribeau et al. [14], allows the recovery of a small number of parameters for each surface element. These parameters relate to the color reflectance of the material and to local specular characteristics. The method is based on a careful calibration of the brightness images produced by a camera equipped with an RGB laser. Bernardini et al. [3] focus on methods to construct accurate digital models of scanned objects by integrating high-quality texture and normal maps with geometric data. Their contributions include new techniques for processing range, reflectance, and surface normal data, for image-based registration of scans, and for reconstructing high-quality textures for the output digital object.

3. MODELING TECHNIQUES USED FOR THE BYZANTINE CRYPT

To model the Byzantine Crypt (Fig.1), we chose for the outside (i.e. main and secondary entrances located above the Crypt) a photogrammetric technique and for the inside (the actual Crypt) a laser range scanner based upon triangulation that provided un-organized clouds of points. The laser scanner came equipped with a verification object and modeling software that performed 3D-image registration based on spheres. However, since no useful texture is derived from the scanner, it had to be acquired separately with a high-resolution digital camera.

a) b) c) d)

Figure 2. Models of the two entrances of the Crypt built with photogrammetry, a) main entrance model with texture, b) wire frame model, c) secondary entrance model with texture, d) wire frame model.

3.1 2D IMAGING FOR IPT AND GEOMETRIC MEASUREMENTS

Current CCD technology is supplying sensors that pack more than 6 Mega-pixels in commercially available products. CMOS technology promises even more pixels on a sensor. Access to high quality texture images is now within reach of everyone. Two-dimensional imaging is not only used to record appearance but also to perform geometric measurements, i.e. photogrammetry. Proper camera calibration and bundle adjustment algorithms combine to give accurate feature coordinates and reliable pose estimations. More and more people use digital photogrammetry as a means for obtaining accurate measurements and building 3D textured models from digital photographs [15]. Many commercial packages perform this task quite nicely [16]. The resulting 3D models for the Crypt's entrances are shown on Figure 2. A lens-interchangeable SLR-type digital camera with an image resolution of 3008 x 1960 pixels was used for the texture acquisition (Nikon D1x). Proper texturing of the 3D model requires special lighting fixtures in order to control illumination (Fig. 7a). Good uniformity of the illumination is essential in order to ease the virtual restoration tasks. The main problems with lighting are the amount of heat generated by high power lamps and UV content. These must be kept to a minimum to avoid damage to the frescoes. Xe flashtubes with a color temperature of about 5600 K were used to acquire textures. The tubes are UV coated and the stored energy is about 500Ws (stability at ±1%) with duration of 1/700 sec. All of the images were acquired with a fixed focal length to ease calibration of intrinsic parameters and an f/22 aperture to produce a large depth of field.

3.2 3D IMAGING

In order to create a dense 3D model of the Byzantine Crypt, a MENSI SOISIC^{TM}-2000 SD model was used. This triangulation-based laser scanner can acquire 3D images at a minimal distance of 0.8 m and at up to 10 m. The range uncertainty on a cooperative surface at 2.5 m is about 0.4 mm (1 sigma) and the data rate is 100 3D points per second. The Byzantine Crypt is relatively large (16.5 m by 10 m by 2.5 m) and we wanted to model it with a fairly high spatial resolution. For these kinds of environments (distances between 2 m and 6 m), there are not a lot of range cameras on the market that could provide us with the desired level of spatial resolution and low measurement uncertainty. This range of distances represents the transition between optical triangulation and time of flight technologies. The generation of the model was done with both the camera manufacturer's own software 3Dipsos^{TM} and Polyworks^{TM} [25] software from Innovmetric. The Polyworks^{TM} software gives the standard deviation of the alignment error after each alignment. For properly calibrated 3D data, this value is useful to determine the range measurement uncertainty. The software 3DipsosTM instead provides only the errors between matching spheres present in the scene in order to align two adjacent 3D scans. Both methods were extensively tested and experimented with. From Polyworks^{TM}, the actual measurement uncertainty was about twice the value given for cooperative surfaces, i.e. 0.8 mm at a distance of 2.5m.

To minimize the amount of time spent in the Crypt, a strategy for scanning was defined well before starting the work. In order to keep a quasi-constant spatial sampling on the surface of the walls, 3D vertical scans were used to build the 3D model. The automatic focusing used in that scanner, which gives 0.1 milli-radians of angular resolution, sets the lower limit for the mesh. For instance at a distance of 2.5 m (standoff distance selected), this angular resolution corresponds to a spatial resolution of about 0.25 mm. In practice, this type of spatial resolution would have required very long scanning sessions and therefore in cooperation with the historian it was decided to increase the sampling step on the mesh to 5 mm. This gave an average scan time per 3D image of about 80 minutes. Therefore, surface details like small tool marks were not measured well at that resolution but the overall shape of the Crypt is excellent. Fig. 3 a) and b) present the complete 3D model (without color information) that would appear if one could see through the ground. From this model, a floor plan was created and is shown on Fig. 3 c) and d).

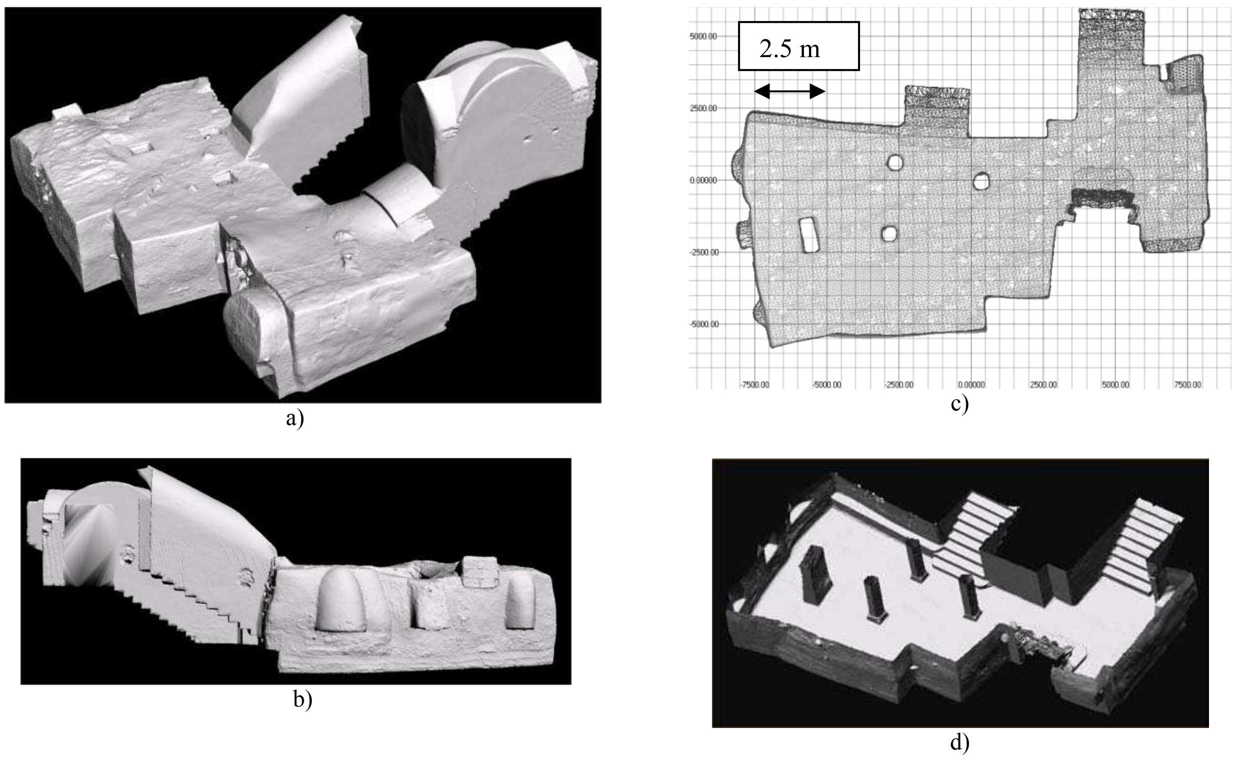
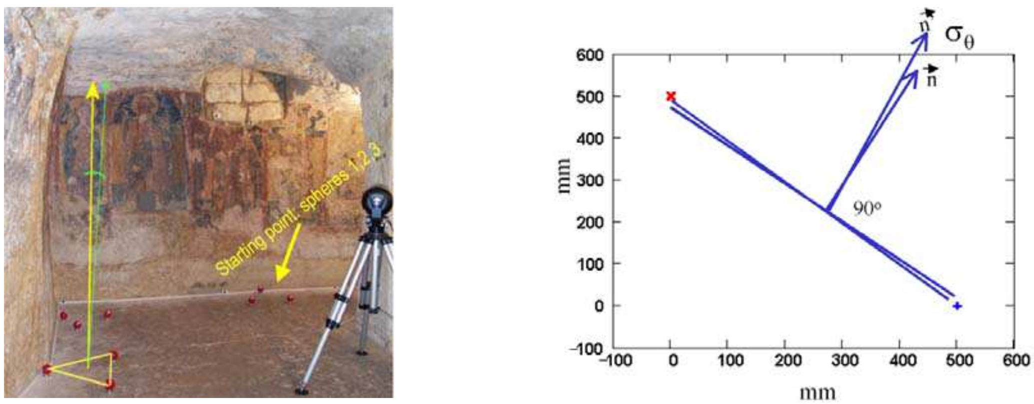


Figure 3. Complete 3D model of the Byzantine Crypt, a) view from outside shown with synthetic shading, b) a particular view of the stairs leading to the Crypt, c) floor plan generated from an orthographic view of the 3D model of the Crypt showing the dimensions, d) section of 3D model showing the space inside the crypt.

3.3 COMPARISON OF TWO ALIGNMENT METHODS FOR 3D IMAGES

We tested two techniques to align the 3D images, the first based upon spheres positioned strategically in the scene and the second, data-driven alignment (ICP-based) followed by a global alignment. For the spheres method, we had to determine an average distance between three spheres that would fit the camera's field of view and where the angular uncertainty of the normal of the triangle formed by those three spheres would be lower than 1 mRad. This error corresponds to an error of 2.5 mm at a height of 2.5 m i.e., the distance floor-ceiling (see Fig. 4a). The computations were performed through a Monte Carlo simulation. This gave an average distance between the spheres of 0.75 m (see Fig. 4). Model building using common spheres present in adjacent 3D images where pair wise alignment is not followed by a global alignment yields an inaccurate model. For instance, in the model of the Crypt, this procedure was tested and it was found that between the first and last 3D image the closure error of the model was 16.87 mm with sphere #1, 16.37 mm with sphere #2 and 18.15 mm with sphere #3. This is about 1:1000 of the total dimensions of the Crypt. The alignment was improved by using the actual 3D data (without the spheres) for the alignment (based on ICP), which was completed with a global alignment procedure. In fact, Polyworks^{TM} gave an alignment error in the order of the actual scanner measurement uncertainty, i.e. 0.8 mm. If the Crypt had not been so irregularly shaped, a careful deployment of those alignment spheres could have had reduced the overall error. A procedure based on spheres would give good results in situations where the model cannot be closed or too many planar surfaces are present in the environment. This is not the case with the Byzantine Crypt. It has a lot of surface relief. In general, both methods ought to be understood and used in the right situation.



a) b)

Figure 4. Sphere-based alignment, a) image showing the grouping of the spheres, b) estimate of angular uncertainty for a given triangular base structure used to align images.

4. PUTTING IT ALL TOGETHER: IPT MAPPING ONTO 3D

Many projects aimed at the construction of large 3D models of objects or environments with or without appearance modeling are briefly reviewed here. We then present our solution to building a photo-realistic 3D model of the Byzantine Crypt.

4.1 SURVEY OF SOME 3D PROJECTS

At Altamira in Spain and Lascaux in France, one could once admire the caves of our Paleolithic ancestors. Unfortunately, it was found that the carbon dioxide visitors exhaled was making the atmosphere inside the caves more acidic, dissolving the surfaces of the limestone walls and loosening the paintings [17]. Furthermore, all the tourists at Altamira were raising the temperature inside the caves to the point where bacteria began growing on the artwork. In order to protect these ancient illustrations, wide-scale access to cave galleries was stopped about 25 years ago. Hence, close-up experience is no longer available. Efforts in replicating those caves began in the 1980s with Lascaux in France, for which two of the cave's galleries were reproduced using manual measurements and photogrammetry. In Spain, Spanish agencies selected in 1988 a Madrid-based replication specialist to create a facsimile of Altamira [17]. Here, environment modeling and replication was aimed at recreating the experience one would have inside those caves.

After nearly 100 years of displaying the world's first triceratops skeleton, the Smithsonian National Museum of Natural History (NMNH) was forced to disassemble its specimen and replace it with a cast replica to protect the fragile bones from further atmospheric wear and tear. The NMNH scientists also rewrote history by using 3D scanning and stereo-lithography to correct scientific inaccuracies in the original 1905 mounted skeleton. By digitizing its triceratops skeleton with a 3D laser scanner, the Smithsonian was able not only to build a precise physical replica, but also to create an accurate animation of the dinosaur's movements to better understand how it behaved [18]. Here environment modeling and replication targeted both scientific and tourism purposes.

A team of 30 faculty, staff, and students from Stanford University and the University of Washington spent the 1998-99 academic year in Italy scanning the sculptures of Michelangelo. As a side project, they also scanned 1,163 fragments of the Forma Urbis Romae, a giant marble map of ancient Rome. Their goal is to produce a set of 3D computer models - one for each statue, architectural setting, and map fragment they scanned - and to make these models available to scholars worldwide [19]. Bernardini et al. [20] published a good survey of other projects along with their Michelangelo's Pietà project. Miyazaki, D. et al. [21] describe the Great Buddha project. Gaiani et al. [22] present their work on the Coliseum in Rome. Each project tries to optimize some part or all of the modeling phases using custom and commercial tools. Both virtualization of existing sites and recreation of virtual sites (when they no longer exist) are modeled. The digital reconstruction of Olympia and 3D Zeus was presented as an exhibition at the Powerhouse Museum, Sydney in 2000. Entitled "1000 Years of the Olympic Games: treasures from ancient Greece", the exhibit offered a unique opportunity to supplement the traditional experience of the visitor by the introduction of virtual reality components. The rare antiquities, which travelled from Greece for the first time, were enhanced using a full-scale digital reconstruction of Ancient Olympia, and a 3D model of the statue of Zeus from Artemision [23]. Here a mixture of virtual and virtualized environment and object modeling were used to recreate a site which no longer exists.

4.2 BYZANTINE CRYPT: CHALLENGES AND SOLUTIONS

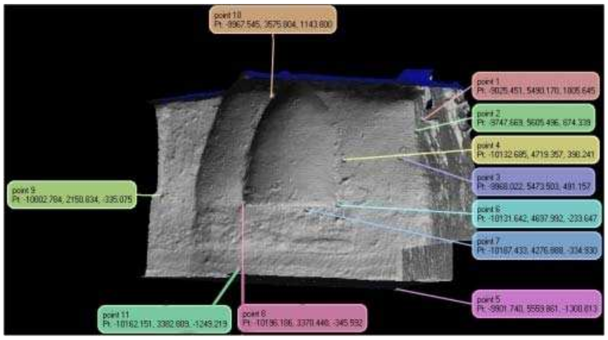
The 3D model was created with the technique implemented in the commercially available software Polyworks™. Regarding texture mapping, though the Mensi provides 2D images from its internal video camera, the resolution and color quality is not acceptable for our application. Furthermore, the laser intensity at each 3D point is not supplied by the scanner and hence can't be used to register 2D images taken with a separate camera. Therefore, what we had to deal with is a 3D model that did not have intensity data attached to it. Below we will explain how the synthetically shaded images created from the 3D scans were used to register our high-resolution 2D images.

The goal of the procedure, shown below, is to take either a cloud of points of un-registered 3D data or a 3D model, texture map high resolution 2D images that are un-registered between themselves and with the 3D data, and, to create a geometrically correct visually realistic and highly detailed 3D model. The methodology proposed is very flexible and within reach to many people. Therefore, people that are worried about copyright or data ownership can do the work themselves without relying on external help. The methodology uses commercially available software to give the complete realistically looking and geometrically correct 3D textured model. The 2D camera does not have to be rigidly mounted on the 3D camera and therefore 2D images created from digital cameras can be mapped onto the 3D model. These 2D images can be taken specifically for texturing purposes or obtained by other means, e.g., tourist photos, postcard, infrared or ultraviolet images, or even historical photos.

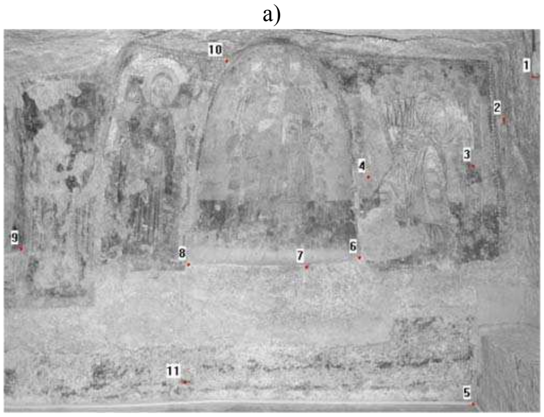
The colorless 3D model is first segmented into mutually exclusive regions (like in Fig. 5a). Each 3D region is mapped onto a region that is a subset of one of the 2D images. Then, features are located on a shaded version of the 3D image using Polyworks (see Fig. 6a) and an ASCII file is created that contains those 3D points. The same features are located in the 2D image, and the relative position between 2D and 3D cameras is found using the photogrammetirc software, ShapeCaptureTM (ShapeQuest Inc.) (see Fig. 6b). The last step required here is a simple mapping that assigns the texture coordinates to each vertex of the 3D model. We assumed that the 2D camera has already been calibrated and that the 3D points generated by Polyworks were imported as control points in ShapeCapture. Pose estimation uses the distortion parameters of the lens computed from the camera calibration (see Fig. 6c). We used a 6-parameter lens distortion model. The calibration can be performed once, before taking the 2D images or if the camera is no longer available, then 3D data points found on the 3D model can be used for the lens calibration.

a) b)

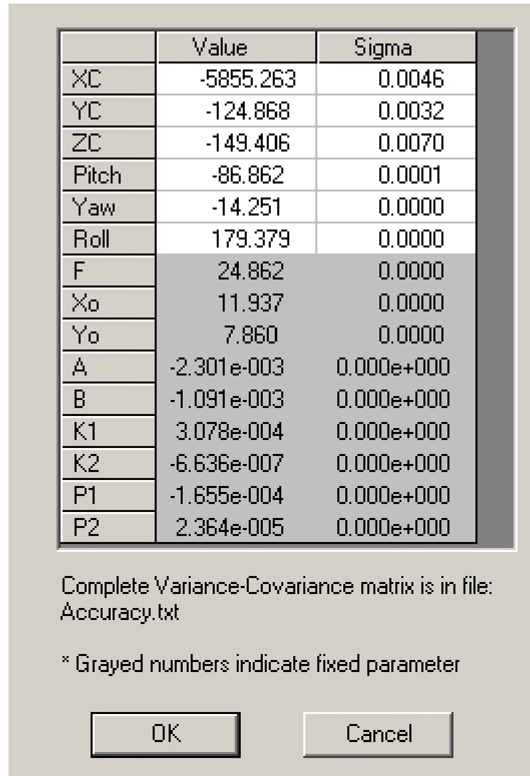
Figure 5. A section of the Crypt, a) synthetic shading replaces one of the colour images, b) the proper colour image mapped with the technique proposed in this paper.



a)



b)



	Value	Sigma
XC	-5855.263	0.0046
YC	-124.868	0.0032
ZC	-149.406	0.0070
Pitch	-86.862	0.0001
Yaw	-14.251	0.0000
Roll	179.379	0.0000
F	24.862	0.0000
Xo	11.937	0.0000
Yo	7.860	0.0000
A	-2.301e-003	0.000e+000
B	-1.091e-003	0.000e+000
K1	3.078e-004	0.000e+000
K2	-6.636e-007	0.000e+000
P1	-1.655e-004	0.000e+000
P2	2.364e-005	0.000e+000

c)

Figure 6. Pose calculation, a) 3D points selection in Polyworks using the shaded images, b) selection of homologous points in 2D image with ShapeCapture, c) rigid transformation with lens parameters fixed by initial calibration.

a)

b)

c)

Figure 7. Texture mapping, a) setup used to acquire 2D texture images, b) the preferred method maps those texture images onto the 3D model hence are easier to use for possible virtual restorations, c) texture map for the color per vertex method.

We have experimented with two approaches for the construction of a texture-mapped simplified model, again with the goal of maximizing the use of commercially available software tools. The first method prepares the data so that it can be entered into the model compression and texture mapping process available in Polyworks (Fig. 7c). This technique requires a triangulated geometric model with a color value assigned to each vertex. More details are found in [2]. The second method, which we ultimately adopted, simply uses the manually assigned pairings between subsets of 3D triangles and individual 2D images. Because the triangles are relatively small, no perspective correction was applied to the mapped texture triangles. With this method, the original high-resolution 2D images (Fig. 7b) are always available for processing. Once modified for a given task, e.g., like virtual restoration, a simple reload of the VRML file in the viewer updates the model. There is no need to re-compute the projection or go through the modeling procedure.

The realistic looking nature of the model comes from the fact that a calibration of the 2D camera guarantees the geometric quality of the mapping; the mapping uses all the texture data present in the 2D image, and a dense 3D model. Therefore, a user can select the level of resolution for an application and then map the texture on a high-resolution 3D model or a compressed version of it. Though full automation may seem a legitimate goal as a way to reduce the time to create a model, experience shows that some involvement by the user can make a huge difference in the final quality or realism of the digital model. For example, automatic hole filling in a 3D model might imply modifying the intentions of the creator of the work of art. Therefore, proper knowledge by the user can assist a semi-automatic hole-filler in cases like these. The matching between 2D and 3D data is performed interactively. We could include in the features detection part of the solution a module that does segmentation and matching between 2D and 3D imagery [7]. We don't rely on automatic best view computations at this point. If 3D points are occluded then at this point we don't remove the texture mapping around that point. Presently we rely on the ability of the user to take the 2D snapshots and to pick the best point of views when segmenting the 3D model. However, all of these features can be added. Figure 8 presents a view of the Crypt taken from the final model.

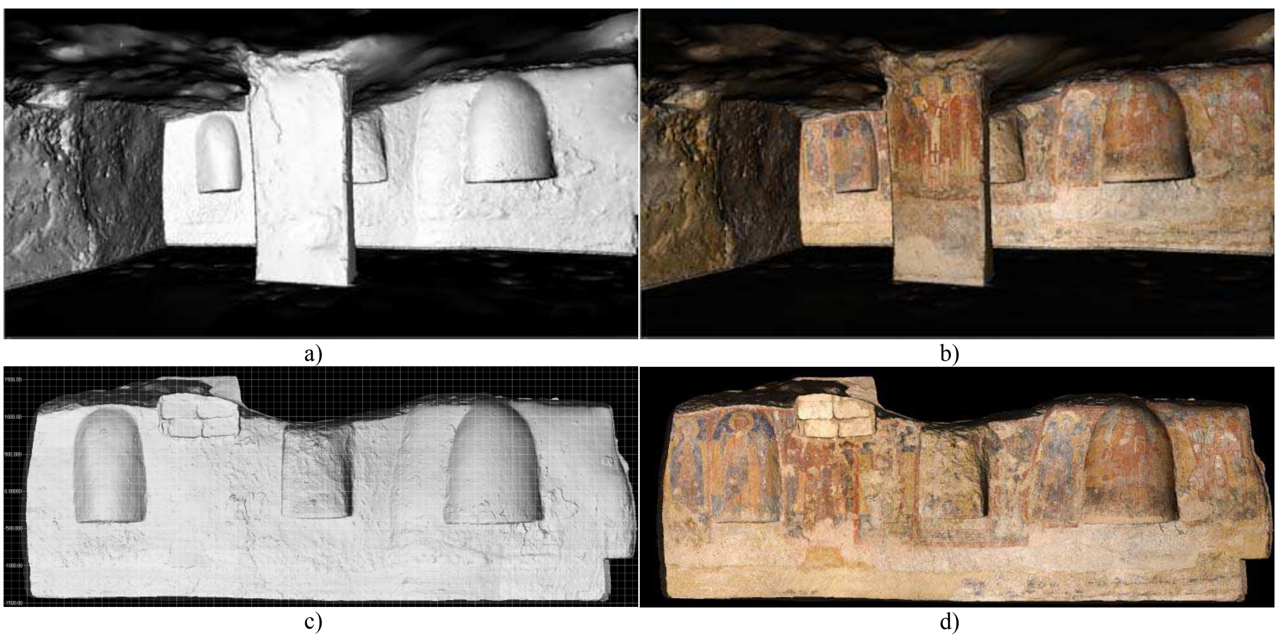
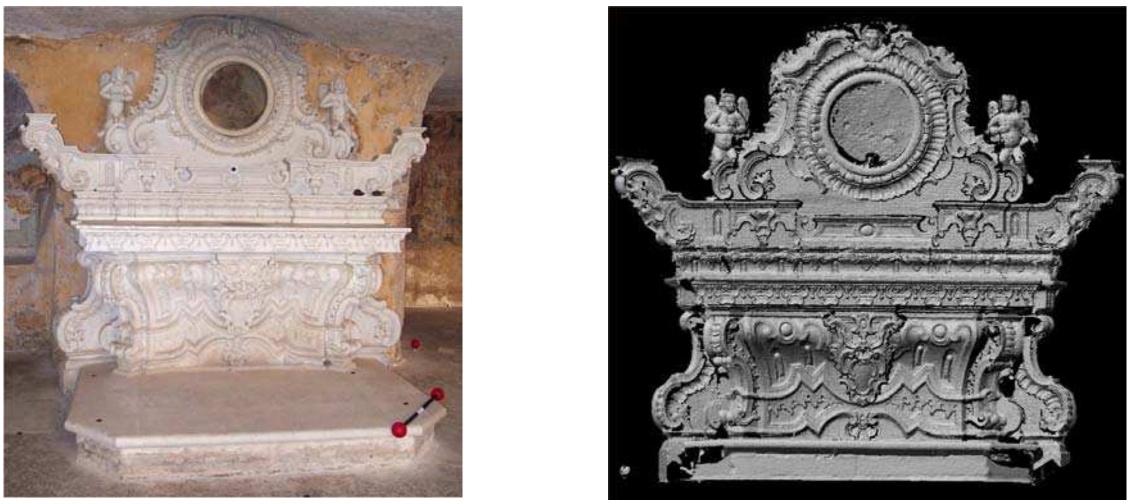


Figure 8. Texture mapping result, a) portion of the Crypt shown with synthetic shading, b) same portion after texture mapping showing a higher level of realism, c) orthophoto generated from 3D model – shaded view, d) orthophoto generated from 3D model.

5. PRACTICAL ASPECTS

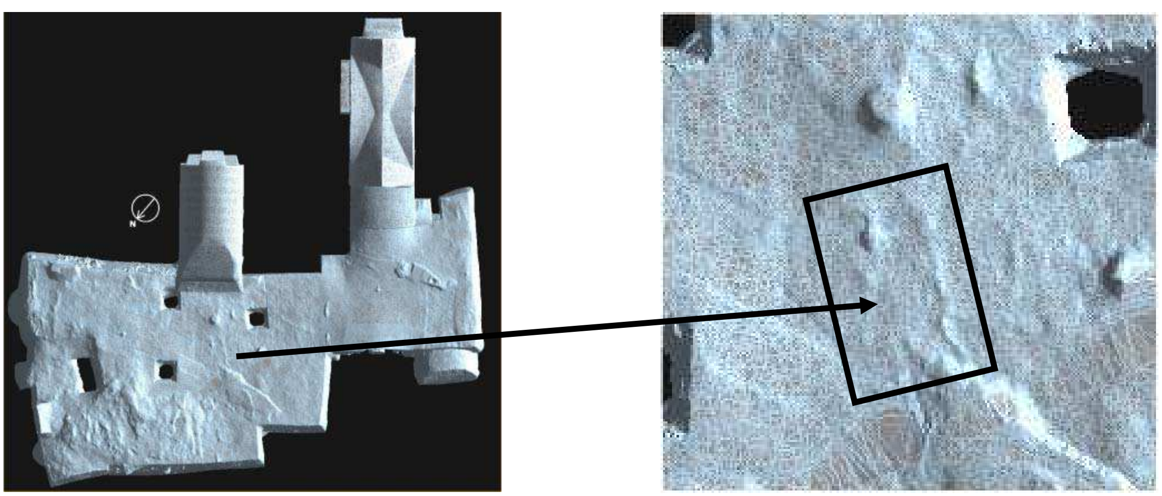
Realistic estimate of the time to acquire the range images, build a 3D model and the determination of the required quality of model is very critical for such a project. The starting point is usually general information found about the site. The procedure outlined in [4,24] allows estimating with good certainty the time it takes to acquire and model an object starting from the scan time of a single 3D image. For this site, the estimate is fairly close to that for an object. With an average scan time on the walls of 80 minutes per 3D image, a total of 92 hours were spent in the Crypt. During that time, fifty 3D images were acquired for the Crypt along with thirty 3D images for the altar (Figure 9a). The total modeling time is significantly affected by the scanning time. The 3D model was created over a period of one month. That time was also used to test and verify the data-driven and the spheres-based registration methods. The acquisition of the texture took 3 days and the actual mapping was done in 4 days. A number of models with different levels of complexity were created from the original data. A total of 6.3 million 3D points (excluding the altar Figure 9b) were acquired. The spatial resolution on the wall is about 5 mm and on the ceiling and floor, 15 mm. We are currently working with 3 models: one 4.6 million-polygonal un-textured model (10 mm resolution) of the complete Crypt, a 12.8 million-polygon fully textured model (5 mm resolution) of the section of the Crypt that contains the two apses, and, a lighter textured model with 0.4 million polygons. These different models were used in their raw form or as transformed representations in a CDROM about that Crypt. All of these representations are aimed at showing the three-dimensionality of the site and visualize artifact that are not visible (Figure 10a and b) in a typical visit to the site. A movie called "Carpiniana" showing a fly through of the Byzantine Crypt was prepared



a) b)

Figure 9 Altar in typical Baroque style, a) Photograph, b) 3D model displayed using synthetic shading.

Finally, periodic verification of the accuracy of the scanner using the stadia provided by the manufacturer gave an average uncertainty of 0.85 mm and a bias of 1.5 mm (0.2%). There is either a scale error, the stadia has a different length, or fitting routine problems! The fitting routines were verified with metric standards, and results were very good. We are verifying with the scanner manufacturer if there is an actual scale error in the data or the stadia. The stadia could be the source of the scale error because it did not come with a certification that is traceable to a National Standard. The range uncertainty was estimated at 0.8 mm.



a) b)

Figure 10 Use of artificially shaded 3D model to highlight areas of historical significance, a) top view showing ceiling from outside the Crypt, b) close-up showing probable location of pillar that collapsed in the 18^{th} century.

6. CONCLUSIONS AND FUTURE WORK

The potential of modeling as-built reality in heritage opens-up applications such as virtual restoration or as an input to virtualized reality tours. It was demonstrated with a Byzantine Crypt. A high degree of realism can be attained by those techniques and the context in which the artifacts were discovered or were used can be recreated. Real world acquisition and modeling is now possible [26]. Technological advances are such that difficulties are more of a logistical nature than technological per se. Many techniques exist to digitize small objects with both a high-resolution 3D surface and a view independent surface texture with perfect registration between them. Models of large objects, structures and environments are possible but as demonstrated here require the combination of a number of techniques. Many papers in the literature explore both modeling and texture mapping onto dense 3D models but the results are not necessarily accessible to everyone interested in applying this technology. The problem we addressed in this paper is the creation of tools and methods that work with commercial devices and software in order to be used in rich multimedia presentations.

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