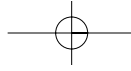


## Preservation of Architectural Heritage Through 3D Digitization

George Pavlidis, Despoina Tsiafakis, Vassilios Tsioukas, Anestis Koutsoudis, Fotis Arnaoutoglou and Christodoulos Chamzas

Continuity and relation to the past are inherent in human nature. The remains of the past constitute culture and cultural heritage. Preservation and dissemination of cultural heritage appear to be, nowadays, a universal priority. Historic/architectural monuments are among the most significant categories of cultural heritage and their 3D digitization appears to be a chief way towards that direction. 3D digitization of architectural heritage is a very specific problem in the digitization domain. Since *size, budget and applicability* are some of the most important factors in choosing an appropriate digitization method, and since *there is not an all-in-one solution* in digitization, this problem cannot be always addressed by using one technique. In this paper we review methods that are available for 3D digitization of architectural heritage and we present two case studies of real-world digitization projects involving monuments and urban areas.



## I. Introduction

“Architecture” is the art or craft –depending on the different time periods– of the “architect”, a word that derives from the ancient Greek “architekton” meaning the “master builder”. To the classical Antiquity, architecture meant much more than construction of buildings. According to the earliest surviving work on the subject, ‘De Architectura’, written by the Roman architect Vitruvius “...Architecture consists of Order, and of Arrangement, and of Proportion and Symmetry and Propriety and Distribution”. Worth of note is also that he adds that the architect should be well versed in fields such as music and astronomy.

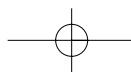
The construction of various types of buildings was one of the earliest crafts appeared in the society in order to cover primary human needs (e.g. shelter, security, worship). Early human settlements were essentially rural. As surplus of production began to occur, rural societies transformed into urban ones and cities began to evolve. Over time the complexity of buildings and their types increased. At the same time architecture was related and reflected different aspects of life and society.

Through monuments, buildings and urban planning the human history and the different civilizations are expressed. Architectural heritage is one of the most important aspects of cultural heritage and of outstanding interest and therefore need to be preserved as part of the world heritage of mankind as a whole.

Aside from the traditional methods in preservation and presentation of architectural structures, new technologies can contribute significantly to that direction. Digital recording of monuments, buildings, sites, and cities may also help in the preservation, presentation and dissemination of architectural heritage.

The necessity for recording cultural heritage monuments is proven by the existence of international organizations that have, as main target, the definition of strict specifications for the monuments’ proper documentation. According to ICOMOS every national and international organization that is responsible for manmade monuments is also responsible to accomplish a proper documentation using appropriate methods: “Such methods might include written descriptions and analyses, photographs (aerial or terrestrial), rectified photography, photogrammetry, geophysical survey, maps, measured plans, drawings and sketches, replicas or other traditional and modern technologies” [A].

Architectural monuments are part of a global but also a local cultural heritage and their digitization in 3D is a specific problem in the digitization domain. Unfortunately, this problem (as almost all digitization problems) cannot be always addressed by using one digitization technique. The plethora of available 3D digitization techniques is the result of three main properties that influence the suitability and the applicability of a method:



1. Complexity in size and shape
2. Morphological complexity (level of detail)
3. Diversity of raw materials

Additionally, *size, budget and applicability* are some of the most important factors in choosing an appropriate digitization method, and since *there is not an all-in-one solution* in digitization, the problem of 3D digitization of architectural heritage cannot be always addressed by using one technique. Various techniques have been proposed and different technologies have been developed: some based on laser scanning, others on surveying-photogrammetric techniques, some using simple empirical methodologies and others based on imaging techniques.

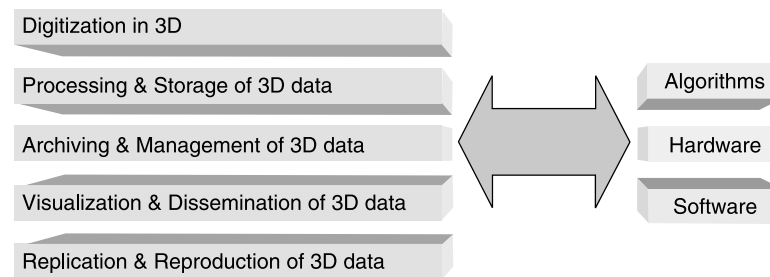
During the last years, numerous 3D reconstruction projects have been crowned with success. Some of them have produced impressive results by introducing the fusion of different digitization methodologies [1]–[8]. The main purpose behind such a combination is no other than acquiring the best of the different approaches. In other cases this fusion aims at the automation of the digitization phase. Nonetheless, it still remains a highly active research area, as there is still no panacea methodology to comply with the multiformity of cultural heritage.

In this paper we present methods that are available today for 3D digitization of architectural heritage and we present two case studies of real-world digitization projects involving two different categories of architecture, monuments and urban areas. The first case study deals with the 3D digitization and representation of two Byzantine churches of Mani in Peloponnesus, Greece. It is a joint attempt of three different Institutions in Greece, the Cultural and Educational Technology Institute, the 5th Ephorate of Byzantine Antiquities and the Department of Architectural Engineering of Democritus University of Thrace. The second case regards the digitization and 3D representation of a part of the old town of Kavala in North-Eastern Greece. It is a collaboration of the Cultural and Educational Technology Institute and the Department of Architectural Engineering of Democritus University of Thrace.

## 2. Three-dimensional (3D) digitization

Complete recording of Cultural Heritage is a multidimensional process. It does not only address the problem of three-dimensional (3D) digitization of monuments but involves all the aspects of this new digital content management, representation and reproduction, thus affecting the whole life cycle of the digital cultural content. Due to the complexity of the digitization needs that emerge from the monuments themselves, it is not possible to identify a single methodology which is applicable to all cases. Five main processes can be identified in digital recording. These processes are shown graphically in Figure 1. Every process requires the usage of advanced algorithms, new hardware and more sophisticated software implementations.

► Figure 1: Complete recording of cultural heritage.



Nowadays, 3D digitization is considered as the first step of a complicated process that leads to the complete recording of a monument. This process consists of multiple steps and exhibits variations in accordance with specific application requirements. Due to the complexity of the digitization needs that emerge from the actual objects, there is a plethora of methods and technologies. The scope of every such technique is to address successfully a particular type or class of monuments, or to fulfill particular demands and needs of a specific digital recording project (i.e. complete recording for archiving, digitization for presentation, digitization for commercial and promotional exploitation).

### 2.1. Digitization of monuments

3D digitization of cultural content can be mainly categorized by the size of objects it is applied to. Due to technical limitations and application requirements, there must be a distinction between the digitization of objects and the digitization of monuments. Digitization of monuments is, in many cases, based on methods that involve traditional surveying techniques (due to scale reasons). In the following paragraphs we briefly review these methods.

#### *Empiric technique*

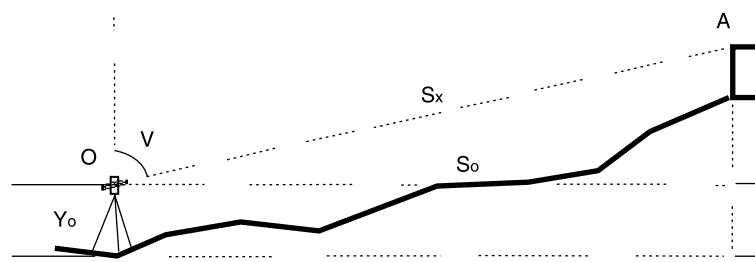
During the recording of monuments by using the empiric technique, measurements of distances between characteristic points on the surfaces of the monument are taken by hand (Figure 2). The coordinates are defined on an arbitrary coordinate system on a plane surface of the monument. This method is *simple, productive, portable* and of *low cost*. On the other hand, it is of *low accuracy* and rather *demanding in terms of time of physical presence on site*. It can be successfully applied when a monument has low façade complexity, or there is a need for recording a sectional plan or sections of the interiors [9].

#### *Surveying technique*

Surveying techniques implement a 3D orthogonal coordinate system by using complicated and high accuracy measuring devices (Figure 3). This method, mainly, uses a Total Station, a device for measuring angles and distances of



◀ Figure 2: Instruments for empiric techniques of 3D digitization of monuments.



◀ Figure 3: Topographic measurements.

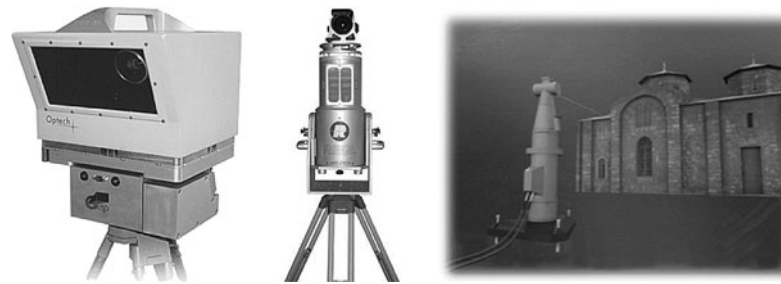
characteristic points on the surface of the monument, which are further on transformed into coordinates in reference to the initial orthogonal coordinate system. The main advantage of such a method is its *high accuracy* and *objectivity of its measurements*. It is not only *reliable* but it also provides an *easy process* of the measuring data. Although the method requires *long periods of physical presence on site*, it is the only one that can be used under challenging situations such as *complex morphology* of the monument and difficulty to access specific areas of the site. It is thought of as the ideal method for producing high accuracy models of scale 1:50 or smaller [9].

#### Laser scanning techniques

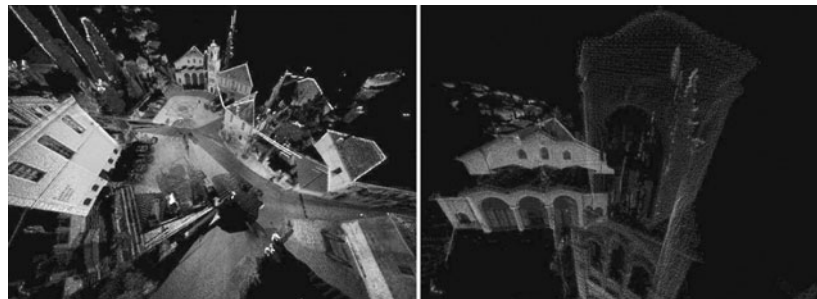
Laser scanners can actually be considered as advanced geodesic stations and can be used to measure topographic quantities. These devices can be used to measure the direction of a fictional optical line joining the characteristic points on a surface of a monument to a reference point on the measuring device (Figure 4). Additionally these scanners can estimate their distance from these points. By applying the known triangulation principle they produce Cartesian coordinates automatically.

The main advantages are *high accuracy* and *productivity*, as well as the *large volume* of produced measurement data in a fraction of time (Figure 5).

► Figure 4: Laser scanning devices and representation of laser scanning process.



► Figure 5: Point clouds (with color information) produced by laser scanning of urban areas (Courtesy Guerra F. and associates, International Conference "Imaging Culture", Xanthi, Greece, March 2006).

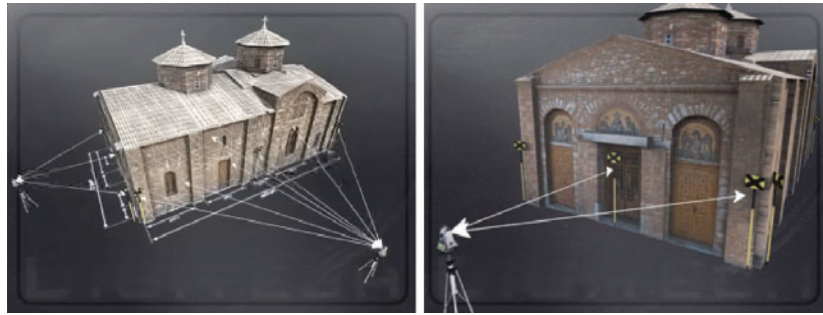


Laser scanning is both *reliable* and *objective*. But it is also considered as a *high cost method* with *portability and autonomy difficulties*. It can be applied on almost any monument digitization project, but, in many cases, the measurements' accuracy is affected by very bright light [10].

#### Photogrammetry

Common digital photos can be used, under suitable conditions, for measurements that can be of the accuracy obtained by the topographic methods. By applying orientation processes and transformations of digital photogrammetry it is possible to deduce 2D or 3D coordinates from one or two photos (Figure 6). The method is *objective* and *reliable* and can be *aided by CAD software*. It is *relatively simple* and of *low cost*. On the other hand it *has to be combined* with topographical or empiric measurements and the final outcome is *a function of the time spent*. It can be used *for complex objects with high surface detail*, but since it is based on photos, there is a need for adequate space (distance from the monument). It is also useful when direct access or contact to the monument is prohibited. It can be used to record stages of the monument during different time periods. When combined with accurate measurements it can produce models of high accuracy for scales of 1:100 and even higher [9],[11],[12].

Photogrammetric modeling of buildings having great cultural value is becoming a common task during the last years [13]. It is not only a correct way of buildings' documentation but also a fast and simple way to the restitution of their basic geometric and thematic information.



◀ Figure 6: Representation of the photogrammetric method.

### 3. Case studies: digitization of monuments and urban areas

In this part of the paper we present two case studies of real-world digitization projects involving monuments and urban areas. The first, case study is a joint attempt for the 3D digitization and representation of two Byzantine churches in one of the richest in Byzantine antiquities sites in Greece, Mani (Peloponnesus). The second case study is an attempt of the Cultural and Educational Technology Institute to digitize and represent in 3D a part of the old city of Kavala in North Greece, within the framework of a regional digitization project.

#### 3.1. Monuments: the case of Byzantine churches in Mani, Peloponnesus [3]

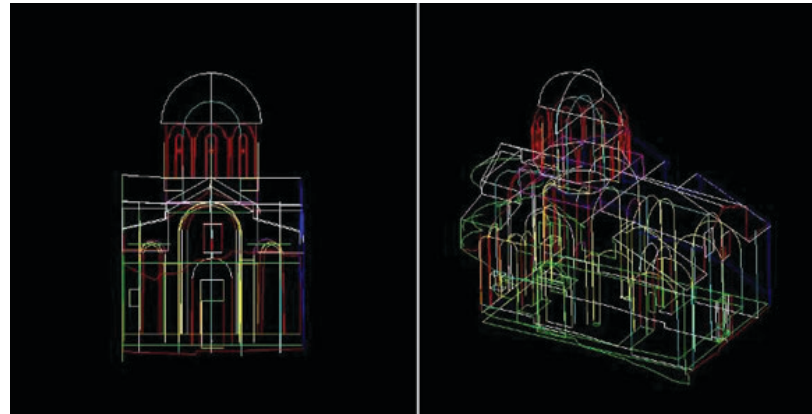
In this case study we present the experience gained and the results of our project of digitizing two Byzantine churches of Mani, Episkopi at Stavri and Agios Nikolaos at Kelefa of Mani, Peloponnesus, Greece (Figure 7). Although laser scanning [10],[14] would be the most appropriate method for the generation of the textured models of the two monuments, the photogrammetric modeling was chosen instead, due to *low budget* and the adequacy for *medium accuracy*.

The 3D model of the outer surfaces of both churches has been acquired by using a set of photographs with two commercial photogrammetric software packages, Photomodeler and 3D Builder. The photo camera that was used for capturing the images was a 6.3 Mpixel NIKON D1X dSLR camera equipped with a 17mm wide-angle lens. The camera was properly calibrated using Photomodeler. Horizontal and vertical measurements of distances between well-distinguished and properly distributed feature points on the 3D objects gave the appropriate control for the registration of the images in the 3D space and the final calculation of the 3D model. The overall accuracy of the derived 3D model was 0.5–0.8%. The generated models were accurate enough for the production of satisfactory solid models that would be the basis of the textured virtual reality models of the two monuments (Figure 8). The surface models were imported into 3D Studio Max for

► Figure 7: The temples are characterized of beautiful decorative constructions and paintings of great archaeological and regional importance. Episkopi above and Agjos Nikolaos below.



► Figure 8: The wireframe model (front and isometric view) of one of the churches.



texture mapping. The final texture images of the planar outer surfaces were produced using Microstation/IRASC. Photogrammetric image processing has also been applied for the creation of the photomosaics of the inner textures.

The photogrammetric processing was carried out rather easily and with no particular problems using a small number of measurements and a bundle of images covering all around the entire objects (Figure 9). Additional measurements gave the appropriate validation points during the photogrammetric processing.

In Figure 10, 3D reconstructions of the exteriors of the two monuments are shown with reconstructions of the surroundings in order to provide a realistic representation of both the monuments and the topology of the area. Accordingly, Figure 11 depicts 3D reconstructions of the interiors of the two churches.





◀ Figure 9: The photogrammetric processing was carried out rather easily using a bundle of images covering all around the entire buildings — here shown for Agios Nikolaos.



◀ Figure 10: 3D reconstructions of the exteriors of the two churches with surroundings — Episkopi (left), Agios Nikolaos (right).



◀ Figure 11: 3D reconstructions of the interiors of the two churches — Episkopi (left), Agios Nikolaos (right).

Three versions of the reconstruction have been produced, in order to provide bandwidth compatibility for the efficient transmission of the 3D data over the Internet. These versions include a high, a medium and a low quality texture representation in order to significantly reduce the required

► Table 1: Size of texture and geometry for the three versions of the 3D reconstructions.

|                         | High (bytes) | Medium (bytes) | Low (bytes) |
|-------------------------|--------------|----------------|-------------|
| Episkopi                |              |                |             |
| Textures                | 85 732 105   | 9 431 862      | 4 497 559   |
| Geometry (VRML-gzipped) | 746 440      |                |             |
| Agios Nikolaos          |              |                |             |
| Textures                | 117 374 211  | 29 239 068     | 6 453 587   |
| Geometry (VRML-gzipped) | 276 833      |                |             |

transmission time. Table 1 lists the sizes of texture and geometry for the three versions. Textures represent the greatest percentage of the data that have to be transmitted, and as of this, the textures are reduced both in terms of compression and resolution. Geometry, which is in the form of VRML (textual form), it is compressed using the typical *gzip compression*, that is supported by the standard.

Data reductions lead to reductions in quality, which is typically measured by metrics such as the PSNR [15]. For this case study, the strategy for measuring the PSNR is as follows: screenshots are taken from the same viewpoints of each of the three versions and PSNR measurements between the medium and low against the high quality version are collected. The overall average PSNR of the medium compared to the high quality was 36.64943 dB for Episkopi and 37.03971 dB for Agios Nikolaos, while the overall average PSNR of the low compared to high quality was 34.00286 dB for Episkopi and 31.18902 dB for Agios Nikolaos. Typical download times are listed in Table 2. It should be noted that the medium and high quality of both the 3D models were produced mainly for offline usage, due to the need for detailed presentation of the inner structures and wall paintings.

### 3.2. Urban area: the case of a part of the old city of Kavala

In this case study we demonstrate the usage of a low-cost open-source based 3D digitization pipeline of a small part of the old town of the city of Kavala (Eastern Macedonia, Greece). It is a picturesque area with cobbled roads that lead to an appealing example of Turkish house architecture of the

► Table 2: Typical ideal download times over different networks.

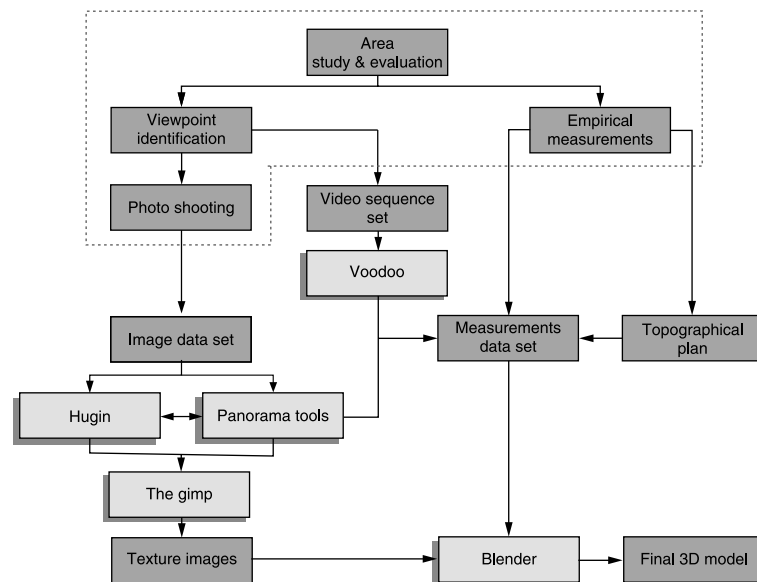
|                | 56 Kbps<br>PSTN | 64 Kbps<br>ISDN | 128 kbps<br>ISDN | 512 Kbps<br>DSL | 1 Mbps<br>DSL | 2 Mbps<br>DSL |
|----------------|-----------------|-----------------|------------------|-----------------|---------------|---------------|
| Episkopi       |                 |                 |                  |                 |               |               |
| Low            | 00:11:22        | 00:09:56        | 00:04:58         | 00:01:14        | 00:00:37      | 00:00:18      |
| Medium         | 00:23:06        | 00:20:13        | 00:10:06         | 00:02:31        | 00:01:15      | 00:00:37      |
| High           | 03:24:46        | 02:59:11        | 01:29:35         | 00:22:23        | 00:11:11      | 00:05:35      |
| Agios Nikolaos |                 |                 |                  |                 |               |               |
| Low            | 00:16:01        | 00:14:01        | 00:07:00         | 00:01:45        | 00:00:52      | 00:00:26      |
| Medium         | 01:10:16        | 01:01:29        | 00:30:44         | 00:07:41        | 00:03:50      | 00:01:55      |
| High           | 04:40:07        | 04:05:06        | 02:02:33         | 00:30:38        | 00:15:19      | 00:07:39      |

18th century (where Mehmet Ali Paşa, founder of the last Egyptian royal line was born) and a Christian Orthodox church dedicated to Virgin Mary. Both monuments are located within the walls of a Byzantine castle.

The proposed pipeline includes the usage of the following tools:

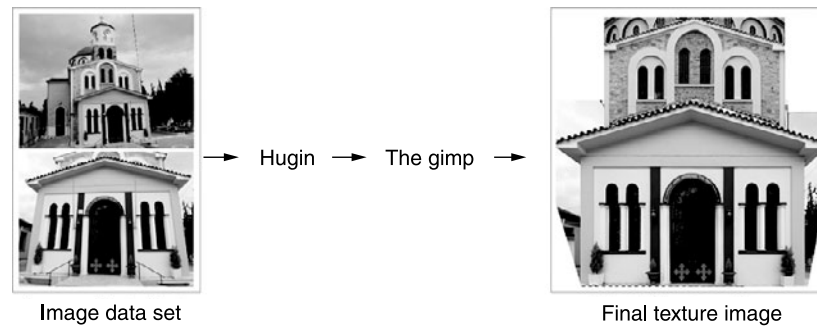
- *Panorama Tools*: a collection of free software programs for creating panoramas from multiple images. The core software was originally written by Professor Helmut Dersch of the Fachhochschule Furtwangen.
- *Hugin*: a cross-platform open source panorama photo stitching program developed by Pablo d'Angelo and others. It is, actually, a GUI front-end for Panorama Tools.
- *The GNU Image Manipulation Program or just the GIMP*: a raster graphics editor for creating and processing raster graphics with support for vector graphics. The project was initiated in 1995 by Spencer Kimball and Peter Mattis and is now maintained by a group of volunteers, licensed under the GNU General Public License.
- *Blender*: an open source software for 3D modeling, animation, rendering, post-production, interactive creation and playback. Available for all major operating systems under the GNU General Public License.
- *Voodoo Camera Tracker*: a camera tracking tool for the integration of virtual and real scenes. This non-commercial software tool is developed for research purposes at the Laboratorium fuer Informationstechnologie, University of Hannover.

The reconstructions that can be produced within the framework defined by these tools are to be considered *mainly for promotional purposes and not for digital archival or scientific study*. Figure 12 depicts the phases of the pipeline.



◀ Figure 12: The pipeline for 3D digitization and reconstruction of urban areas based on open source tools.

► Figure 13: Image rectification.



The data acquisition phase (defined by the dashed line) denotes the actual fieldwork. At this phase a thorough study of the target field is required in order to decide on which of the geometric features of the buildings and surroundings are going to be modeled as well as to decide on the measurements and photo shooting.

The photographic dataset, formed during the photo shooting, should cover as much as possible visible information. The purpose of this dataset (including video) is twofold. *Hugin* can be used for image rectifications [16] (Figure 13).

*Panorama Tools* can provide a low density triangulated mesh based on the *shape-from-stereo* technique [17],[18] — which is usually used for deducing the 3D geometry of objects by exploiting two cameras or photos from different angles — by using the *ptpicker* and *ptstereo* software components. The output mesh doesn't reflect real dimensions but only relative distances. The measurements acquired according to the empirical method aid in transforming those relative quantities to real-world dimensions. *Voodoo Camera Tracker* can provide a denser 3D point cloud based on feature points automatically detected and extracted from a video sequence. Both 3D data sets provide valuable information as they can be imported into *Blender*.

A 3D approximation of the area can be modeled by combining data from the empirical method, a topographical plan and the point clouds. Finally, the rectified images are used for texture mapping.

Alternatively, *Panorama tools* and *Hugin* can be used to create image panoramas that can be mapped on planar surfaces which act as backgrounds or as areas where modeling is not possible. The versatility of the pipeline allows different approaches to be followed during the modeling phase.

A total time of 500 person-hours over a two month period was allocated for the project. Since, the development of the 3D model was focused on producing a web based virtual walkthrough of the cultural district, greater efforts were put to the construction of medium geometry models with high texture details. As known, texture maps can provide the illusion of details in low geometry models [19]. Experiments have shown that pictorial realism plays an important role in an immersive VR system [20].



◀ Figure 14: Screenshots during a virtual tour inside reconstructed area.

The main problems faced during the photo shooting were:

- Viewpoint limitations and occlusion
- Lenses distortions due to the need for wide angle lenses
- Weather conditions (heavy shadow casting and high contrast)
- Long times of physical presence (field work)
- Unexpected events, like distractions from locals

A total of 900 photos were taken using an 8 Mpixel digital camera along with 192 measurements based on empirical method. Additional topographical and historical information were also collected and related with the architectural elements of the area. The final model of the reconstructed area (Figure 14) includes a total of 11673 vertices that define a set of 17832 facets. Such geometric complexity can easily be handled even by low-end graphics cards.

Once again, in order to provide bandwidth compatibility for the efficient transmission of the 3D data over the Internet, three versions of the reconstruction have been produced. These versions include a high, a medium and a low quality texture representation in order to significantly reduce the required transmission time. In Table 3, the sizes of texture and geometry are listed for each of the three versions. As shown, textures represent the greatest percentage of the data that have to be transmitted, and as of this, the textures are the target of data reduction both in terms of compression and resolution reduction. Geometry, which is in the form of VRML (textual form), it is compressed using the typical *gzip compression*, that is supported by the standard.

These data reductions, as expected, lead to reductions in quality, which is typically measured by metrics such as the PSNR. For this case study, the

|                         | High (bytes) | Medium (bytes) | Low (bytes) |
|-------------------------|--------------|----------------|-------------|
| Textures                | 28 630 685   | 5 519 871      | 2 266 882   |
| Geometry (VRML-gzipped) | 208 089      |                |             |

◀ Table 3: Size of texture and geometry for the three versions of the 3D reconstructions.

► Table 4: Typical ideal download times over different networks.

|        | 56 Kbps  | 64 Kbps  | 128 kbps | 512 Kbps | 1 Mbps   | 2 Mbps   |
|--------|----------|----------|----------|----------|----------|----------|
|        | PSTN     | ISDN     | ISDN     | DSL      | DSL      | DSL      |
| Low    | 00:05:53 | 00:05:09 | 00:02:34 | 00:00:38 | 00:00:19 | 00:00:09 |
| Medium | 00:13:38 | 00:11:55 | 00:05:57 | 00:01:29 | 00:00:44 | 00:00:22 |
| High   | 01:08:39 | 01:00:04 | 00:30:02 | 00:07:30 | 00:03:45 | 00:01:52 |

strategy for measuring the PSNR is as follows: screenshots are taken from the same viewpoints of each of the three versions and PSNR measurements between the medium and low to the high quality version are collected. The overall average PSNR of the medium compared to the high quality was 38.89640 dB, while the overall average PSNR of the low compared to high quality was 31.41654 dB. Typical download times are listed in Table 4.

#### 4. Conclusion

3D digital recording of Cultural Architecture is a multi-dimensional process, which depends on various factors and as well as the main purpose of recording. Main aims of 3D recording are in the preservation and promotion of the cultural content. In this work we made an attempt to summarize most of the methods available today for 3D digitization that can be applied to cultural architecture recording. Two case studies were provided in order to share the knowledge and experience gained by two 3D digitization projects, one for monuments and one for urban areas.

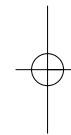
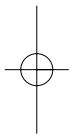
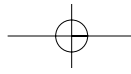
#### Notes

A. Text ratified by the 11th ICOMOS General Assembly, held in Sofia, Bulgaria, 5-9 October 1996.

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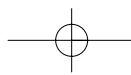
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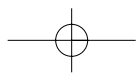
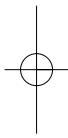
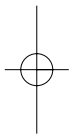
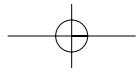
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# Conservation of Architectural Heritage: The Role of Digital Documentation Tools: The Need for Appropriate Teaching Material

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