PROCESS EVALUATION OF 3D RECONSTRUCTION METHODOLOGIES TARGETED TO WEB BASED VIRTUAL REALITY

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ABSTRACT:

It is fascinating to look at any digitization project from the scientific, technical and implementation points of view. However, it is necessary to consider the financial perspective as well. In this work we attempt to evaluate two common practices (photogrammetry and laser scanning) for the creation of 3D reconstructions of Cultural Heritage monuments. We question the applicability of these practices either in small or in large budgeted digitization projects. In order to compare these methodologies, a test scenario was designed that involved the digitization of a prime example of Xanthi's architecture previously used as a tobacco warehouse. Detailed plans of the warehouse had to be created in order to lead to a final synthetic solution. The results of our survey indicate that there is a trade off between application, accuracy, experience, complexity, man-hours and budget.

1. INTRODUCTION

Cultural heritage is an inseparable part of a nation's identity. It is a prestigious deposit that has to be protected, preserved and promoted. Promotion of this thesaurus has always played an important role in the dissemination of history, tradition and knowledge. Furthermore, this promotion can be considered as one of the fundamental elements of tourism development, as it results in attracting more visitors, offering solutions to the tourist seasons' problem with alternative forms of tourism and motivates the expansion of tourism infrastructures.

The technological evolution we experience during the last decades, offers entirely new possibilities that have already influenced, although on a limited scale so far, the methods used for the presentation and preservation of cultural heritage. With the advent of the twenty-first century these technologies reached a mature level and can now be used effectively, in collaboration with the traditional scholar research, for the archival, preservation and dissemination of cultural heritage (Alshawabkeh, 2005; El-Hakim et al., 2002; Forte et al., 2005; Lingua et al., 2003; Sgrenzaroli, 2005; Tsioukas et al., 2005; Valzano et al., 2005).

Cultural heritage is primarily promoted over the Internet using digital photographs (Pavlidis et al., 2006). Over the last years, improvements that have been achieved in data transfer speeds over the Web in conjunction with the boost of multimedia technologies broadened the possibilities for an increasing amount of Internet-based 3D applications concerning nearly every sector of interest. The involvement of technology in the dissemination of cultural heritage causes a smooth transition from *subjective* promotion methodologies such as sketched and text based descriptions to more *objective* such as photographs, video and more recently 3D virtual reconstructions (Figure 1). The role of 3D reconstructions is still being considered as supplemental, given the present limitations on bandwidth and real time graphics rendering.

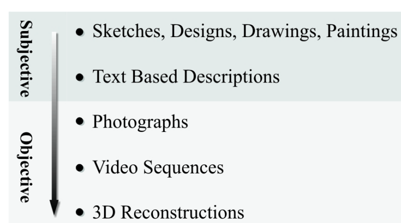

Figure 1. Means for *subjective* and *objective* cultural heritage promotion

Even so, it is safe to allege that a 3D model provides a better perception than a typical photograph or a video sequence. A virtual walkthrough simulates a physical visit by providing equivalent freedom in motion. Additionally, it enhances the user's experience by allowing the examination of the subject from every possible point of view. A virtual walkthrough can be more amusing as the user directs the tour according to his/her choices. Furthermore, the 3D virtual environment offers a dynamic information visualisation platform where supplementary information related to the subject can be presented in more efficient ways.

Over the last years, numerous efforts regarding the implementation of web-based 3D environments targeted to virtual exhibitions have already been reported. A number of surveys arguing the applicability and advantages of such 3D representations have demonstrated that, a realistic reconstruction has a great impact on their visitors and encourage more people to visit the physical exhibitions (Di Blas et al. 2005; Thomas and Carey 2005).

In this paper, we attempted to evaluate two widely used methodologies for 3D reconstructions, digital terrestrial photogrammetry and laser (range) scanning. We tried to identify the trade-offs of using these approaches, with respect to the total cost, the available human resources and the infrastructures (software and hardware) required for web-based 3D reconstructions.

2. 3D RECONSTRUCTION METHODOLOGIES

2.1 3D Digitisation of Architectural Heritage

In recent years, 3D digitization has been applied in the recording of architectural heritage with great success. In fact, a lot of research has been motivated by the challenges that arise from such applications. Some of the available methodologies have been identified as more appropriate to handle the morphological complexity while others provide efficient mechanisms for digitising larger areas. Empiric measurements, topographic techniques, terrestrial photogrammetry and *Time-of-Flight* laser scanning (or range scanning) are the most widely used techniques. A sort description of each of these techniques is given in the following paragraphs.

2.1.1 Empiric Technique

During an empiric recording of monuments, measurements are performed by hand. Distances between characteristic points on the surface of a monument are acquired. These coordinates refer to an arbitrary coordinate system on a planar surface of the monument. The technique is considered to be simple, productive, portable and of a low cost. On the other hand, the low accuracy of the measurements and the long periods of physical presence *on-site* may classify the technique as inefficient, especially when the complexity of the monument is high. Nevertheless, it can be successfully applied to monuments with low structural complexity or in cases where sectional plans or sections of the interiors are required (Livieratos, 1992).

2.1.2 Topographic Technique

The topographic technique implements a 3D orthogonal coordinate system by using complicated and high-accuracy measuring devices. This technique involves the usage of geodesic stations (a system for measuring angles and distances of characteristic points on the surface of the monument). These measurements are further transformed into coordinates that are referenced to the initial orthogonal coordinate system. The main advantage of the technique is the high accuracy and objectivity of the measurements. It is characterised by its reliability and easiness in data processing. Once again, the required time of physical presence *on-site* can be considered as a disadvantage. On the other hand, it is referred to as *the only* technique to be used under difficult conditions in terms of physical access to the monument. It is ideal for producing high-accuracy models of scale 1:50 or even smaller (Livieratos, 1992).

2.1.3 Photogrammetry

Common digital photos can be used, under suitable conditions, for geometric measurements of the accuracy obtained by the topographic technique. By applying orientation processes and transformations of digital photogrammetry it is possible to deduce 2D or 3D coordinates from one, two or a sequence of photos. The method is objective and reliable and can be aided by CAD software. It is a relatively simple technique based mainly on software and it is of low cost. 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 for photo shooting. It is also useful when direct access to the monument is not allowed. When combined with accurate measurements it can produce models of high accuracy for scales of 1:100 or even higher (Hanke and Grusenmeyer, 2002; Livieratos, 1992; Tsioukas and Patias, 2002).

2.1.4 Time-of-Flight Laser (Range) Scanning

Commercial *Time-of-Flight* (TOF) digitisation devices allow acquisition rates in the range of 2000 to 15000 samples per second. These measurements are estimated on the surface of a building within a reasonable time and an accuracy of 6-7 millimetres and a distance of 5-8 centimetres between two sequential measurements. These systems usually produce high quality data for a range of distances of 3 to 700 meters or more. The complete data set acquired by such systems is represented as a three dimensional colour point cloud. The acquisition times in combination with the high density of the point cloud characterise the technique as efficient in terms of quality. On the other hand, the cost of such systems is prohibitive for low-budget applications.

2.2 Managing a Digitisation Project or Application specific limitations

Just like in any project, a digitisation project requires extensive planning of all the tasks and procedures to be followed. It is important to identify some aspects such as the:

- main purpose of the 3D reconstruction
- target group to be addressed
- benefits of such a reconstruction
- dissemination platform to be used
- project timeline and deadlines for each task
- required personnel
- required management procedures

Some of these aspects influence the others. One of them, the selected dissemination platform, could eventually influence most of the other aspects. Today, there are many available solutions for the promotion of 3D reconstructed architectural heritage. They are mostly characterised as Internet based/online or desktop/offline:

i. Real time interactive or non-interactive (pre-defined) walkthroughs
ii. Research/Study-oriented real-time interactive applications
iii. Real time interactive walkthroughs as stand-alone educational applications
iv. Photorealistic pre-rendered video sequences

v. Virtual museums and virtual cities

Choosing the Web as dissemination platform introduces a number of limitations regarding the volume of data and the computer graphics technologies that can be used. Even today, with broadband connections being a standard for the average home user; there is still a need for organising and compressing the data so that they can be efficiently transferred over the Internet.
The Virtual Reality Modelling Language (VRML) plays an important role in promoting 3D content over the Web since 1997, when it became an international standard (ISO/IEC 14772-1:1997). The usage of open source software allows the generation and merging of VRML97 worlds into websites that can be combined with other multimedia elements like video, sound, animation and include an adequate level of interaction [5]. On the other hand, the limitations of VRML are more than obvious today, in terms of presenting realistic real time graphics, providing reasons for the its replacement by X3D. X3D is the ISO standard (ISO/IEC 19775-1) for real-time 3D computer graphics, the successor to VRML. X3D features extensions to VRML (e.g. Humanoid Animation, NURBS, GeoVRML), the ability to encode the scene using an XML syntax, as well as the Open Inventor-like syntax of VRML97, and enhanced application programmer interfaces (APIs). Advanced techniques like multiple lightmaps and double texturing, bump mapping, programmable shaders will be available to the Web through the X3D standard.

3. WEB-ORIENTED 3D RECONSTRUCTION OF ARCHITECTURAL HERITAGE

The primary objective of the project was the application of new technologies for the creation of a web-based interactive tourist brochure. A practical solution would be the implementation of a website to combine text, photographs, 3D reconstructions and fundamental principals of non-immersive virtual reality. We planned to use and compare two of the most commonly used methodologies for the generation of 3D reconstructions for architectural heritage, terrestrial photogrammetry and range scanning. The comparison covers important factors including, total costs, man-hours, on-site and post-processing work.

3.1 The Tobacco Warehouse

The old city of Xanthi located in North-eastern Greece, is a masterpiece of traditional architecture based on raw materials such as mud, brick and stone. During the 19th century and till the beginning of the 20th, the city thrived as one the greatest centres of tobacco trade. Industrial complexes were constructed to support the increased market needs; complexes that could be characterised, today, as industrial monuments. Lack of interest, on behalf of the government, in preserving those monuments resulted in their gradual decadence.

The warehouse that was selected for this project, shown in Figure 2, is such an example. It was constructed about 120 years ago but there are no records concerning its history. Nevertheless, it is known that the building has been used for the last 40 years as a carpenter's workshop, resulting in several structural changes of the interior. The pillars were supported by additional wooden constructions that were painted over and over again during this period, resulting in noticeable structural deformations. Moreover, the abandonment and decay of the building are evident both in the bearer and bearing elements (roofs and floors).

Figure 2. The tobacco warehouse facade

3.2 Digitisation of the Warehouse

The building was digitised with the use of a RIEGL laser scanner from six different positions covering 360^0 horizontally and 270^0 vertically. The scanning rate was 12000 points per second and the final colour point cloud of the warehouse after processing and removing the noisy measurements was reduced to 6598357 points. Figure 3 depicts the textured triangular mesh produced automatically by Geomagic Studio. The simplified 3D model consists of 26793 vertices that correspond to 28318 triangles that lead to the generation of a VRML file of 1.91 Mbytes (or 430 Kbytes gzipped, geometry only).

Figure 3. Triangular Mesh produced automatically from the coloured point cloud using Geomagic Studio 9

The building was also digitised with photogrammetry. During this process we have used a monoscopic rectification procedure, based on vanishing points geometry, leading to the creation of rectified fa•ades images. The fa•ades' texture images were then mapped on the 3D model provided by empirical measurements and the final textured model was generated in a 3D visualization environment. The accuracy of the resulted model was inferior compared to the one achieved by the laser scanning approach. It has though succeeded in the generation of a pseudo 3D model of adequate accuracy for web-based applications. With the use of additional control points more accurate rectified fa•ades' images could be acquired. Those images could be used for a more detailed and accurate recording in order to document the building for architectural purposes (in 1:50 or greater restitution scales). The derived fa•ade plans can be used in a conservation and restoration study concerning the building.

3.3 Process Evaluation

The major phases during a digitisation project can be summarised as:

- Planning
    - Equipment preparations
    - Area study
    - Scanning/Photo shooting viewpoint identification and selection
    - Scanning/Photo shooting workflow scheduling
- Data Acquisition
    - Collection of measurements
    - Photo shooting
- Data Processing
    - Geometry structures generation from raw data
    - Alignment and merging of partial geometry structures
    - Data Filtering
    - Texture maps generation and mapping
    - Data optimisation for Internet transmission

In order to compare the two approaches one has to take into consideration the several operational differences of laser scanning and photogrammetry. In general, both approaches follow the previously described phases.

3.3.1 Planning

Equipment preparations involve procedures related to the operating status of systems during the data acquisition phase. Laser scanners might require additional power supply devices in order to achieve uninterrupted operation on site due to their long acquisition times. The latter also affects the placement of the device in public locations (e.g. roads and crowded places). On the other hand, the equipment used in photogrammetry is less demanding in terms of power supply, acquisition times and placement requirements.

The selection of camera lenses with appropriate characteristics such as field of view (FOV) in combination with the need of achieving an adequate baseline for a particular level of accuracy increase the complexity of planning during a photogrammetric approach. In many cases, the spatial restrictions introduced by the actual environment dictate the selection of appropriate camera lenses as well as the appropriate photo shooting viewpoints in order to achieve the required baseline. Similarly, spatial restrictions also affect a laser scanner especially when its field of view is limited and the measuring surfaces are located outside its constant operational range.

Additionally, camera lenses must be calibrated in order to eliminate different types of lenses distortions, occurring for various focal lengths when using photogrammetry. Nevertheless, modern photogrammetric software provides automated procedures for camera calibration and high accuracy internal parameters estimation. On the other hand, a laser scanner is a pre-calibrated device ready to be operated at any point within its operational range. Recalibration is a procedure that such system requires after extended usage in varying weather conditions.

Table 1 summarizes the planning phase issues.

Planning	Photogrammetry	Laser Scanning
Autonomy	High (>300 photo shots/charge)	Low (<10 low resolution scans/charge, usually requires additional power supply)
FOV limitations	High : Depends on lens selection	Low : Support panoramic scan acquisition
Range limitations	Theoretically None	Varying from 2m up to 2.500m
Space Occupancy Requirements	Low (can be handheld operated)	High (Tripod is required for most cases)
Calibration	Yes for each lens	Rarely (once a year)

Table 1. Planning Issues comparison

3.3.2 Data Acquisition

The comparisons during this phase involve the evaluation of the required time, data density and accuracy. Laser scanners are able to acquire three dimensional measurements with a single shot. The scene can be completely captured if it is within scanner's range. Photogrammetry though, uses at least a calibrated pair of images. In photogrammetry, despite the fact that a scene is captured by a digital camera, the disparity levels, at high distances, do not allow the extraction of 3D information resulting the need to perform multiple photo shooting in order to cover the same range.

Acquisition times required in photogrammetry are less when compared with laser scanning because photo shooting is almost instant. On the contrary, laser scanning systems and especially those based on TOF technique perform data acquisition in times varying from a couple of minutes up to a couple of hours. The fact is that the density of measurements captured by such a system cannot be achieved practically by following present photogrammetric approaches (manual, semi-automated and fully-automated significant target point correspondence).

In photogrammetry, details of the scene are easier to be identified on the digital images when high resolution cameras are used. However, the time spent to model all these details is increased *in a linear way*, making the technique inefficient for very complex scenes. Furthermore, accuracy in the case of photogrammetry is affected by numerous factors including *baseline distance*, *target selection* on multiple images, *lens calibration*, *image resolution*, camera's *FOV*. The accuracy of a TOF system is affected by the *reflectivity* of the scanned surface. In such systems, the accuracy of measurements is considered to be within the error limits specified by the manufacturer (usually less than an average of 10mm) and it is also not affected by the selection of scanning viewpoints. The discriminating power (identifying details) of modern TOF 3D laser scanners is inferior when compared with *high-resolution* digital cameras. This is a result of the *noise* appearing along the range data, the *spatial distance of adjacent measurement points* and the *spot size* of the laser beam, which increases according to the distance between the scanner and the target. In some occasions the spot size is much bigger than the detailed features of the scene.

When using a laser scanner, colour data are captured with the use of an additional external digital camera (required by most of the commercially available systems) which increases not only the total cost of this approach but also the acquisition times.

Table 2 summarizes the data acquisition phase issues.

Data Acquisition	Photogrammetry	Laser Scanning
Number of shots/scans	• 2	• 1
Time required per shot/scan	Almost instant (ms)	10 minutes – 2 hours
Number of 3D measurements	Practically less than a couple of hundreds of points per scene due to time consuming manual processing	From a couple of thousand points up to millions
Measurement accuracy	Highly affected by multiple factors	Theoretically constant within the specified range
Level of detail	High levels of details can be captured	Relies completely on the system specifications

Table 2. Data Acquisition comparison

3.3.3 Data Processing

Presently, all 3D range scanners provide point cloud data sets. These are dense and require vast amounts of processing power, available memory and high-end 3D graphics accelerators. The usual workflow of such data sets involves procedures like *filtering, noise removal, alignment of partial scans, hole-filling, merging, triangulation, polygon mesh simplification, texture generation* and *texture map processing.* Those procedures are performed using specialised commercial software, which is usually not provided with the scanner and contributes to the total cost of the system.

Modern software solutions provide a set of algorithms to allow the sophisticated simplification of the geometry data in order to be optimised in terms of computer resources and bandwidth utilisation. These processes play an important role when web is considered as the publication medium. The characteristics of present low bandwidth networks and protocols limit the amount of transferred data, leading to low quality three dimensional representations. This quality is determined by the number of polygons that describe the scene and the resolution of the images that compose the texture maps data set.

Table 3 summarizes the data processing phase issues.

Data Processing	Photogrammetry	Laser Scanning
Hardware Requirements	Low	High
Mesh Modelling	Produces directly triangular mesh	Point cloud to triangular mesh transformation required
Texture Mapping	Can be achieved automatically in both cases	
Data Optimisation	None	Heavy
User effort for 3D representation generation	High (Affected by the required degree of detail)	Medium

Table 3. Data Processing comparison

Photogrammetry software solutions allow the generation of triangulated textured meshes that can be characterised as *web-friendly 3D representation* due to their coarse 3D measurements (small number of polygons in mesh). However, the generation of the 3D model is much more time consuming and still manually performed. Procedures such as merging different reconstructed elements need to be followed as well. Computer hardware requirements are lower than those required by laser scanning data set processing software.

4. CONCLUSIONS

In this paper, we have attempted to evaluate two of the most commonly used techniques in 3D reconstructions of buildings. The case study of the tobacco warehouse proved to be more *photogrammetry friendly* due to its low structural complexity. The necessary time for the total completion of the project following the two approaches is given in Table 4.

The scale of the specific case study does not reflect the need of using a laser scanning system. However, in larger scale projects the efficiency of the laser scanning technique is more obvious as it allows faster and denser 3D measurements and it is only then where it justifies its high cost.

Phase	Photogrammetry	Laser Scanning
Planning	1	1
Data Acquisition	4	5
Data Processing	6	2 (not considering the time of the automated data processing)

Table 4. Comparison of different phases' duration (in man hours)

The data produced by laser scanning carry much more structural information that could be dynamically decimated in order to satisfy the needs of present or future network bandwidths and processing requirements (real time graphics cards capabilities). On the other hand, current photogrammetry software can produce highly accurate 3D models but of a lot lower geometric complexity. Current research on photogrammetric techniques such as *shape-from-video*, are able to extract more dense polygonal meshes that are still considered as *web-friendly*.

Since now, web-oriented 3D reconstructions cannot be generated automatically. The specific requirements of such applications introduce the need for processing the vast amount of scanned 3D data. This is still a very time consuming process and requires further development of software. Further research and software development could decrease the data processing time by introducing automated algorithms for the simplification of point clouds and the extraction of planar areas within the point cloud in order to generate polygonal meshes with multiple levels of quality.

Additionally, there is yet to be developed an all-in-one 3D digitisation technique to address all the requirements for accurate, high resolution and high quality 3D scanning. Photogrammetry and range scanning are both very efficient and are widely used for recording architectural heritage. They both have their advantages and their weaknesses, either in terms of cost and man-hours or in terms of the final outcome for specific applications.

REFERENCES

Alshawabkeh Y.,2005. Using Terrestrial Laser Scanning for the 3D Reconstruction of Petra – Jordan. Photogrammetric Week ’05, Wichmann, pp. 39-48.

Di Blas, N., Gobbo, E. Paolini P., 2005. 3D Worlds and Cultural Heritage: Realism vs. Virtual Presence, International Conference on Museums and the Web 2005, Vancouver, British Columbia, Canada, online at:
http://www.archimuse.com/mw2005/papers/diBlas/diBlas.html . (accessed 8 Jun. 2007).

El-Hakim S., Beraldin, J.-A., Picard M., 2002. Detailed 3D Reconstruction of Monuments Using Multiple Techniques. In Proceedings of the ISPRS Commission V, Symposium, Corfu, Greece.

Forte M., Pescarin S., Calori L., Camporesi C., Guidazzoli A., Imboden S., 2005. Open Heritage: an Open Source Approach to 3D Real-Time and Web Based Landscape Reconstruction. VSMM 2005, 11th International Conference on Virtual Systems and Multimedia.

Hanke, K., Grusenmeyer, P., 2002. Architectural Photogrammetry: Basic theory, Procedures, Tools, Tutorial of Architectural Photogrammetry, Corfu.

Koutsoudis, A., Arnaoutoglou, F., Chamzas, C., 2007. On 3D Reconstruction of the old city of Xanthi, *Journal of Cultural Heritage*, 8(1), pp. 26-31.

Lingua A., Piumatti P., Rinaudo F., 2003. Digital Photogrammetry: A Standard Approach To Cultural Heritage Survey, In Proceedings of the ISPRS International Workshop on Vision Techniques for Digital Architectural and Archaeological Archives, Ancona, Italy.

Livieratos, E., 1992. Empiric, topographic or photogrammetric recording? Answers to properly phrased questions, in Proceedings of the congress, "Terrestrial Photogrammetry and Geographic Information Systems for the documentation of the National Cultural Heritage".

Pavlidis, G., Tsiafakis, D., Koutsoudis A., Arnaoutoglou F., Tsioukas, V., Chamzas, C., 2006. Recording Cultural Heritage, In Proceedings of the 3rd International Conference of Museology, Mytilene, Greece.

Pavlidis G., Koutsoudis A., Arnaoutoglou F., Tsioukas V., Chamzas C., 2007., Methods for 3D digitization of Cultural Heritage *Journal of Cultural Heritage*, 8(1), pp. 93-98.

Pollefeys, M., Proesmans, M., Koch, R., Vergauwen, M., Van Gool, L., 1998. Flexible 3D reconstruction techniques with applications in archaeology, 26th Int'l Conf. on Computer Applications in Archaeology.

Sgrenzaroli, M., 2005. Cultural Heritage 3D Reconstruction using High Resolution Laser Scanner: New Frontiers Data Processing. In Proceedings of the CIPA 2005 XX International Symposium, Torino, Italy.

Thomas, W. A. Carey, S., 2005. Actual/Virtual Visits: What are the Links?, International Conference on Museums and the Web 2005, Vancouver, British Columbia, Canada, online at:
http://www.archimuse.com/mw2005/papers/thomas/thomas.html (accessed 8 Jun. 2007).

Tsioukas, V., Patias, P., 2002. Low cost 3D visualization and measuring ‘tool’ in the service of archaeological excavations, in Computer Applications and Quantitative Methods in Archaeology Conference, "The Digital Heritage of Archaeology".

Tsioukas, V., Tsirliganis, N., Pavlidis, G., Arnaoutoglou, F., Chamzas, Ch., Mpakourou, E., Mexia, A., 2005. Photogrammetric Modelling of Byzantine Churches, In Proceeding of the XX International Symposium of CIPA, Torino, Italy.

Valzano, V., Bandiera, A., Beraldin, J.-A., Picard, M., El-Hakim, S., Godin, G., Paquet, E., Rioux, M., 2005. Fusion of 3D Information for Efficient Modelling of Cultural Heritage Sites with Objects. In Proceedings of the CIPA 2005 XXth International Symposium: Cooperation to Save the World’s Cultural Heritage. Turin, Italy.

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