3D Heritage Recording using Terrestrial Laser Scanning Techniques

Vassilios D. ANDRITSANOS[1], Michail GIANNIOU[1], Vassilios PAGOUNIS[1*], Maria TSAKIRI[2]

[1] Department of Surveying Engineering, Technological Educational Institute, Athens, Greece, *pagounis@teiath.gr

[2] School of Rural & Surveying Engineering, National Technical University of Athens, Greece

Keywords: Heritage recording, Terrestrial laser scanning (TLS), Geodetic techniques, 3D modeling, Documentation.

Abstract
The importance of heritage recording and documentation with optical ranging sensors is well recognized at international level. The continuous development of new sensors such as terrestrial laser scanning (TLS), data capture methodologies and multi-resolution 3D representations, contributes significantly to the digital 3D documentation, mapping, conservation and representation of heritages. This article discusses the use of TLS for 3D data capture and 3D modeling techniques in the documentation and modeling of two significant heritage sites and monuments.

Introduction
The creation of 3D models of heritage and archaeological objects and sites in their current state requires powerful techniques capable of capturing large volumes of data which are then used to digitally model the fine geometric and appearance details of such sites. Digital recording is demanded as the heritages are globally experiencing natural or human driven deterioration requiring preservation. Furthermore, the digital documentation record is important so that it can be transferred to future generations. Nowadays, remote sensing technologies and methodologies for cultural heritage 3D documentation and modeling allow the generation of very realistic 3D products (in terms of geometric and radiometric accuracy) that can be used for many purposes, such as historical documentation, digital preservation and conservation, cross-comparisons, monitoring of shape and colours, simulation of aging and deterioration, virtual computer-aided restoration, multimedia museum exhibitions, visualization and so on (e.g. Bernadini et al., 2002; Gruen et al., 2004; Doneus and Neubauer, 2005; El-Hakim et al., 2008; Bruno et al., 2010).
Today, state-of-the-art remote, non-invasive optical techniques are available for mapping purposes and digital recording of cultural heritage. Generally, non-invasive optical recording sensors are divided into passive and active systems. Passive sensors (e.g., digital cameras) deliver image data which are then processed with some mathematical formulations to infer 3D information from the 2D image measurements (e.g. Sturm et al., 2011). On the other hand, active sensors (e.g., laser scanner or radar) can provide data directly for 3D information or ranges. Terrestrial active and passive sensors employed to derive 3D shapes are often referred to 3D imaging techniques (e.g. Sansoni et al., 2009).
Almost fifteen years after the introduction into the market of the first TLS, nowadays a great variety of sensors is available. TLSs work from very short ranges (few cm up to a few km) in accordance with surface properties and environment characteristics, delivering 3D data with accuracy from some mm to few cm.
The main challenges in 3D surveying and modeling of large sites or complex objects using TLS arise in every phase, from the data acquisition to the visualization of the achieved 3D results.

3D modeling should be intended as the generation of structured 3D data from the surveyed unstructured data and it consists of geometric and appearance modeling. The geometric modeling deals with data registration and processing (editing, cleaning, meshing) while the appearance modeling deals with texturing, blending and rendering simplification. In general, the 3D modeling pipeline involves the following steps: (i) selecting the appropriate methodology (sensor, hardware, software) and data processing procedure; (ii) designing the proper production workflow, guaranteeing that the final result is in accordance with all the given technical specifications; (iii) speeding up the data processing time with as much automation as possible but always with the accuracy as primary goal; (iv) being able to fluently display and interact with the achieved 3D model. This paper deals with the 3D modeling pipeline as discussed above and gives two examples of 3D surveying and modeling of heritage sites and monuments.

Case Studies

The reported examples show the potentialities of the modern surveying technologies to digitally document and preserve landscape and heritage sites as well as share and manage them. In both case studies TLS systems is the main source for acquiring 3D data.

a) The ancient theatre of Thebes, Fthiotidas, Greece

The ancient theatre of Thebes Fthiotidas, the excavation of which is not yet completed, is located on the east side of the ancient city of Thebes Fthiotidas, on the natural slope of the hill "Castle", east of the village Mikrothives. The ancient theatre is Hellenistic but there is also the Roman phase, which converted it to Arena Theatre. With a maximum capacity of 3000 spectators, the theatre housed ancient drama, music competitions, and during the Roman Era gladiator fights. The theatre was investigated in 1992-93 under a project of the Hellenic Military Aviation. Research in the theatre has not been completed and of the main aims is the 3D documentation of this important monument, which subsequently needs restoration works, in order to make it available to visitors.

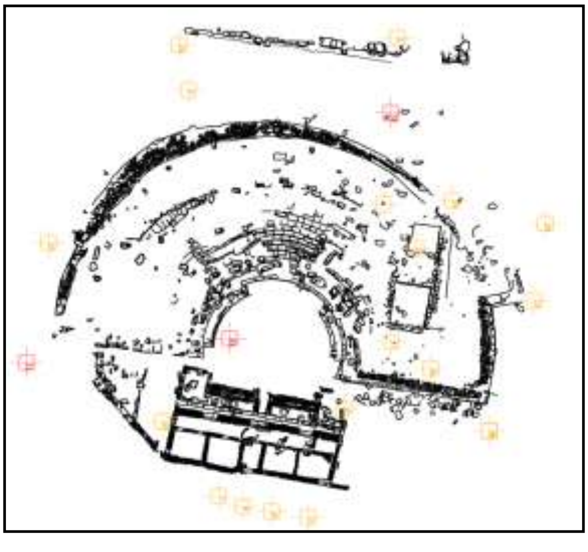

Fig. 1a. The ancient theatre of Thebes Fthiotidas with the positions of the geodetic network (red) and TLS (orange).

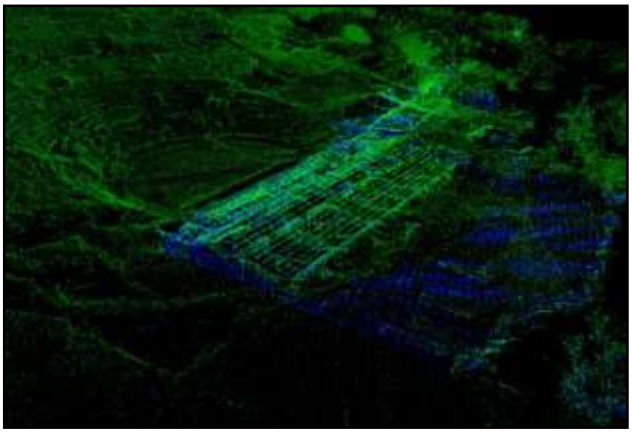

Fig. 1b. Point cloud data of the theatre.

The documentation phase included a combination of geodetic and TLS measurements. Initially, a control survey network was established around the site to provide the reference coordinate system and the necessary geodetic information with an accuracy of 0.7cm in the horizontal and 0.9cm in the vertical component (Fig. 1a). The network establishment was based on GNSS measurements using geodetic receivers and referenced to the national geodetic system (Greek Geodetic Reference System 1987 - GGRS87). Also, a detailed total station surveying data collection was performed for specific sections of the theatre which were compared with the TLS data (Fig. 1b). The TLS documentation required 28 scans and the georeference was achieved using reflective spherical targets at an accuracy of 1cm. The accuracy of the final registered cloud is 1.4cm. Using a CAD environment, the TLS data were imported in order to create a 2D detailed plan of the theatre (Fig.2a) and sections at selected parts (Fig. 2b).

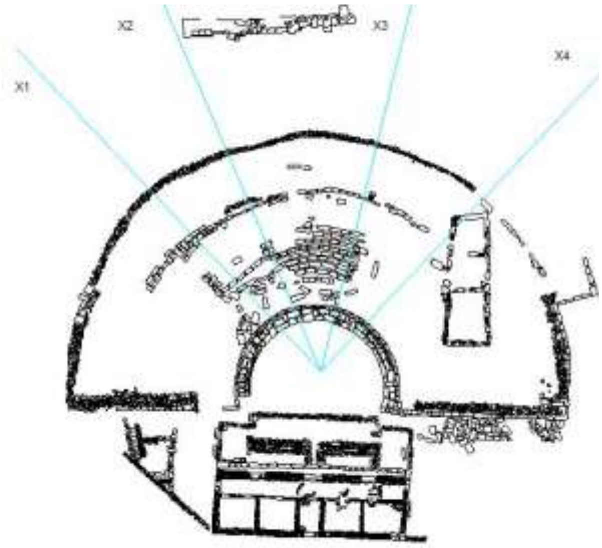

Fig. 2a. The 2D topographic plan using TLS data.

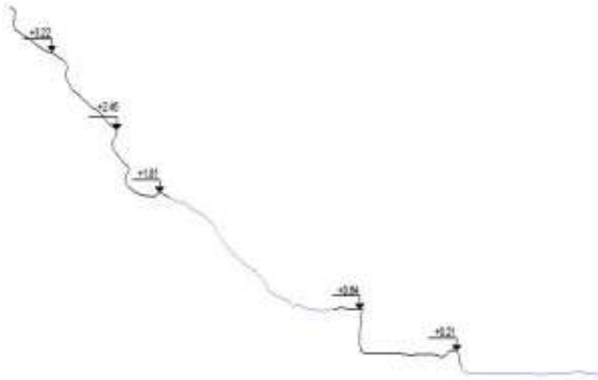

Fig. 2b. Detail of a 2D plan derived from TLS data.

b) The ancient tower of Agia Marina, Kea, Greece

The ancient monument of Agia Marina is a five-storeyed, square tower around 20m high and is a UNESCO protected heritage. It is made of local schist and marble in the Hellenistic period. The north side of the monument is preserved in very good condition but the rest has collapsed and required restoration. For this reason, a detailed 3D model was created using TLS data.

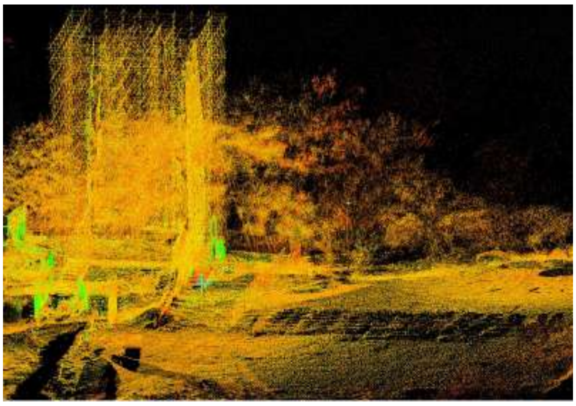

Fig. 3a. The TLS data of the monument (with scaffoldings).

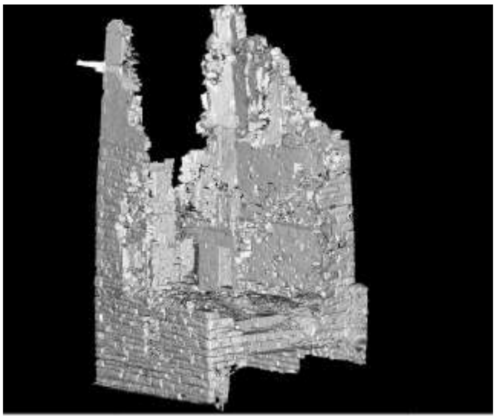

Fig. 3b. 3D model derived from TLS data.

Prior the TLS data acquisition, a control survey network was established using GNSS techniques. A total number of 16 scans were acquired due to the fact that the monument was surrounded by scaffoldings (Fig 3a). Using the Cyclone software the data registration was achieved at 1cm (www.leica-geosystems.com). The data were cleaned from the noise with the point cloud having about 95 million points (Fig. 3b). Using the 3D Reshaper software (www.3dreshaper.com) the cleaned registered point cloud was then used to create a 3D model (Fig 3b). During the TLS data acquisition, digital photos were also taken which were used to create a rendered 3D model (Fig 4a). This was performed in the 3D Reshaper software using the relevant texture map facilities. The final product was an orthophoto mosaic which gives not only the true geometric description but also provides in detail the current appearance of the monument so it can be used for restoration and preservation purposes (Fig. 4b). Finally, a virtual walking through video was also created which can be used for visualization purposes.

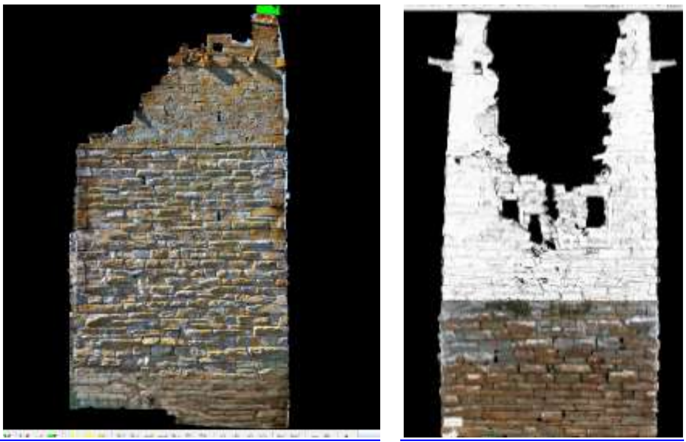

Fig. 4a. View of the rendered model.

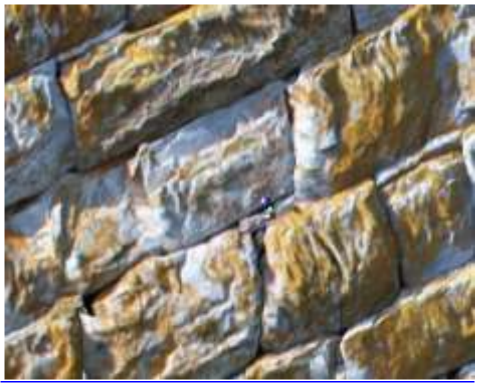

Fig. 4b. Detail of the orthophoto.

Concluding Remarks

This article discussed the use of 3D measurements sensors and specifically TLS techniques used for surveying, mapping, digital documentation and 3D modeling applications in the heritage field. The 3D modeling pipeline was also reported through two examples from heritage sites. Despite the fact that the 3D documentation is not yet widely used in the heritage field, the reported examples show the potentialities of the modern surveying technologies to digitally document and preserve sites and monuments as well as share and manage them. Clearly, the wide access of archaeologists to geospatial technologies can aid for more effective decisions.

References

Bernardini, F.; Rushmeier, H.; Martin, I.M.; Mittleman, J.; Taubin, 2002, Building a digital model of Michelangelo's Florentine Pieta. IEEE Comput. Graph. Appl. 22, 59-67.

Bruno, F.; Bruno, S.; De Sensi, G.; Luchi, M.L.; Mancuso, S.; Muzzupappa, M., 2010, From 3D reconstruction to virtual reality: A complete methodology for digital arch. exhibition. J. Cult. Herit. 11(42-49).

Doneus, M.; Neubauer, W., 2005, 3D Laser Scanners on Archaeological Excavations. Proc.CIPA 2005 XX International Symposium, Torino, Italy, 26 Sept.–1 Oct., Volume 34(5/C34/1), pp. 226-231.

El-Hakim, S.; Beraldin, J.; Remondino, F.; Picard, M.; Cournoyer, L.; Baltsavias, E., 2008, Using Terrestrial Laser Scanning and Digital Images for the 3D Modeling of the Erechteion, Acropolis of Athens. Proc. DMACH Conf. on Digital Media and Applications in Cultural Heritage, Amman, Jordan, 3–6 Nov, pp. 3-16.

Gruen, A.; Remondino, F.; Zhang, L., 2004, Photogrammetric reconstruction of the Great Buddha of Bamiyan. The Photogrammetric Record 19, 177-199.

Sansoni, G.; Trebeschi, M.; Docchio F., 2009, State-of-the-art and applications of 3D imaging sensors in industry, cultural heritage, medicine, and criminal investigation. Sensors *9*, 568-601.

Sturm, P.; Ramalingam, S.; Tardif, J.-P.; Gasparini, S.; Barreto, J., 2011, Camera models and fundamental concepts used in geometric Computer Vision. Found. Trend. Comput. Graph. Vis., *6*, 1-183.