Innovative Techniques for 3d Digital Survey of the Paphos Theatre

Paola RONZINO, Italy

Key words: Aerial Photogrammetry, Laser Scanning, Integration.

SUMMARY

The research object is the digital acquisition of a complex architectonic monument, integrating two technologies: aerial photogrammetry and laser scanning.
The acquisition process has been applied on the Hellenistic-Roman Theater located in Paphos (Cyprus) that for its extension and complex morphology required the use of both the techniques.
These include a balloon-suspended set of digital cameras (automatic photogrammetry), taking shots of the site from above (30-50 m), which are then processed with special software that provides a model of the surface; and a 3D scanner to acquire details, interiors or parts not visible from top. The single scans from laser scanner and the point cloud obtained from aerophotogrammetry will then be aligned using target points acquired with a total station and geo-referenced using a Differential GPS system.
The outcome of the work consists in a 3D model that will enable different uses, such as archaeological documentation with the possibility to extract maps and sections, for communication and conservation, allowing 3D reconstruction of the original appearance and virtual restoration. It will also be used to test the integration of the two complementary technologies.

SOMMARIO

Lo scopo di questo lavoro di ricerca e` l`acquisizione digitale di monumenti architettonici complessi, attraverso l`uso di due tecnologie: fotogrammetria aerea e laser scanning.
Il processo di acquisizione e`stato applicato al teatro Greco-Romano sito nella citta`di Pafos a Cipro, il quale per l`estensione e la morfologia complessa ha richiesto l`uso di entrambe le tecnologie. Per cio`che concerne la fotogrammetria aerea, un set di camere digitali sospese ad un pallone aerostatico ha permesso di acquisire delle immagini del sito da circa 30-50 metri di altezza. I dati sono stati poi elaborati da un software proprietario, il quale ha restituito un modello 3D della superficie. La seconda tecnica utilizzata e` il laser scanning per l`acquisizione delle parti interne del teatro non visibili dall`alto. Le singole acquisizioni da laser scanner e la nuvola di punti ottenuta con la fotogrammetria aerea sono state successivamente integrate in un unico modello, utilizzando dei punti di controllo a terra, posizionati precedentemente con stazione totale. Il modello finale e`stato poi georeferenziato usando un GPS Differenziale. Il risultato di questo lavoro consiste in un modello 3D utilizzabile per diversi scopi quali: documentazione archeologica, estrazione di piante e sezioni, comunicazione, conservazione, la ricostruzione 3D dell`aspetto originale e il restauro virtuale ed infine come test per verificare l`integrazione delle due tecnologie complementari.

Innovative Techniques for 3d Digital Survey of the Paphos Theatre

Paola RONZINO, Italy

1. INTRODUCTION

Nowadays the use of digital acquisition techniques is widespread in archaeology and in the cultural heritage field, mainly applied for documentation and conservation issues.
This project aims at producing a 3D model of the Hellenistic-Roman Theatre of Paphos in Cyprus, by integrating two different acquisition technologies such as aerial photogrammetry and laser scanning, for documentation, dissemination and for reconstruction purposes and for the test of different technologies involved in the project.
This work is a collaboration between the Science and Technology for Archaeology Research Center (STARC) of the Cyprus Institute (CY), the Institute for Technology Applications to Cultural Heritage of the National Research Council (CNR-ITABC) Italy, the University of Naples "L'Orientale" (CISA), Italy and the University of Sydney-Archaeological mission in Paphos.
The result of the work consists in a 3D model suitable for many uses. It can be viewed and processed with appropriate software, processed with CAD software, visualized in different environments such as Internet, standard monitors, special 3D visualization monitors and so on (N. AMICO *et al* 2010).
The pipeline followed for data acquisition and data processing has an experimental character due to the originality of the adopted instruments (automatic photogrammetry) and because it was never tested before in similar conditions. The outcome gave a satisfactory result with a high level of accuracy and a perfect overlap between the models achieved with the two different techniques.

2. CASE STUDY: THE PAPHOS THEATRE

The site of the ancient theatre of Nea Paphos is located in the modern town of Kato Paphos. It was built on the southern slope of a hill, which is in the very north-east part of the ancient walled city. It measured 90 × 195 m from side to side and had a seating capacity for over 8000 spectators. The angle of rise of the seating is 26.5 degrees.
The theatre has been built around 300 BC. It is possible to identify at least five major phases of remodelling and rennovation during the its history representing the changing nature of performance during Greek and Roman audiences, and the responses to earthquake damage. At its peak, in the mid-second century AD under the Roman Antonine emperors, when the stage building was façaded in marble, the theatre measured over 90 meters from side to side, and had a seating capacity of over 8000 spectactors.
By the end of the third century AD, probably after the devastating earthquake of 365 AD, the theatre was abandoned and much of the stonework was robbed and later quarried for use elsewhere in the town. After a period of abandonment, the site of the ancient theatre sees renewed activities in the 12th and 13th centuries AD, when the harbour of Paphos became

once again a major economic point of activity, this time for the Crusaders on their way to the Holy Land (BARKER G *et al* 2004).

3. ACQUISITION AND POST PROCESSING

For the digital acquisition of the theatre two innovative techniques were used: aerial photogrammetry with an aerostatic balloon, for the acquisition of the whole extension of the theatre; and laser scanning for the acquisition of the part difficult to reach from above.

	ZF IMAGER 5003	Fly scan
Technology	Phase shift	Automatic Photogrammetry
Range of acquisition	0.40 – 53.5 m	Up to 100 mt above the ground
Scan rate	Up to 500.000 p/s	Undefined number of shots
Field of view	360°x320°	65°
Accuracy	1 mm	1-2 cm
Integrated camera	no	Set of three cameras
Software	JRC 3D Reconstructor	Z-Scan; Z- Map

Tab.1: Specification of the instruments

3.1 Aerial photogrammetry

The ”*automatic photogrammetry*”, is an experimental technique that concerns the acquisition of a sequence of shots from 30-50 meters above the ground. In this case the height was 40 m. The pictures were taken from a set of three cameras (Nikon D80), with 24 mm lens, previously calibrated and lined up, suspended to a balloon with two aluminium (T shaped) bars 2.20 m long. A remote controller was connected for the shooting of the photos.

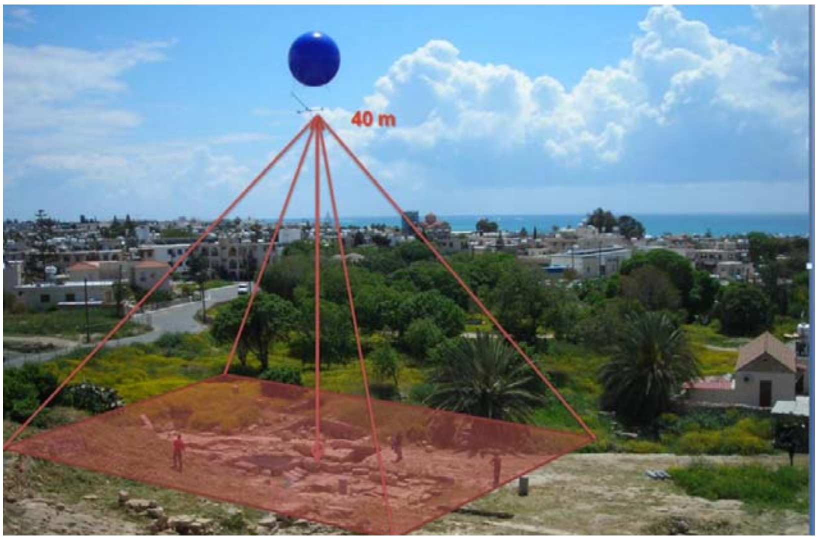

Fig.1: The Fly scan system during data acquisition.

The system (Fly scan) is an innovative device implemented by the company Menci Software, Arezzo, in collaboration with the Institute for Technology Applications to Cultural Heritage of the National Research Council (CNR-ITABC). The diameter of the balloon is about 4,7 m. It is tied to the ground with ropes hold by four operators who drive the system. The balloon is filled with helium.
Beside the pictures from above, two additional sequences of shots were taken from the ground with the same set of three cameras. In the first sequence the cameras were positioned on the bar with the focal at the zenith and in the second sequence with the focal skewed at 45 degrees, in order to acquire the front elevation of the theatre.
More over, in this project, it has been tested a new technolgy "*close range photogrammetry*" for the acquisition of structures of short distance.


Fig.2 : Close range photogrammetry.

Previously, a set of targets was laid on the entire surface of the theatre and acquired with the total station Trimble 5600. The point set was then geo-referenced using a Differential GPS system, in order to enable the assembling of the sequence of pictures. The targets were A4 black paper with white cross (to reduce the sun glare) visible also from above.
The triplets of pictures generated with each shot were elaborated with a dedicated software (Z-Scan) for the generation of the point clouds and for a first elaboration of the three-dimensional data[1]. A second software (Z-Map) was used for cleaning, filtering, texturing and merging of point clouds and for the creation of orthophotos, cross sections and maps. The outcome is a *textured color per vertex* model.

[1] The software uses an algorithm that identifies the pixels with the same colorimetric characteristics creating a point cloud.

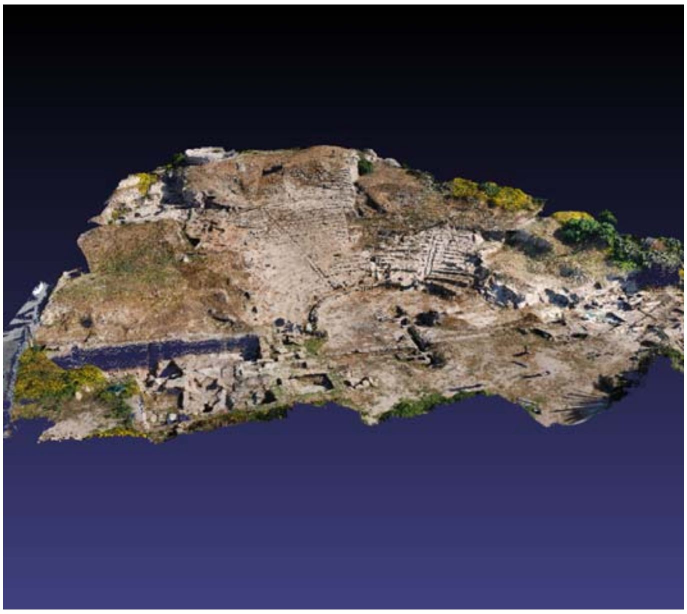

Fig.3: Point cloud of the whole area of the Theater from aerial photogrammetry.

3.2 Laser scanning

The survey described above was integrated by means of the digital acquisition of some parts of the theatre with a phase shift 3D scanner (Z-F IMAGER 5003).

Fig. 4: Laser Scanner Z-F IMAGER 5003

Twenty-five scans (ten for the *summa cavea* and fiftheen for the *parodos*) were necessary to gather all the details of interiors parts and the vertical face of the theatre not visible from the top. Targets were laid also in these areas in order to help the alignment of the scan range.

Two days were necessary for the acquisition on the field and one week in the laboratory for scans cleaning with the application of various filters. The single meshes were than merged together and aligned.
During the acquisition process with Z-F IMAGER 5003 scanner, data is acquired both in spatial coordinates x,y,z, and in the reflectance value (tones of gray that represents the response of the material to the laser beam). In order to assign the texture to the point clouds, another step is necessary. A set of picture was taken with a resolution of 3488x2616 pixels and then they were applied to the point cloud using the ground control point (GCP) as reference target.
The software used was JRC 3D Reconstructor that enables to export the outcomes in all standard format file.

4. INTEGRATION PROCESS

The next step involved the integration of the outcomes. Using the ground control point, the point cloud generated from aerial photogrammetry and the scans from the laser scanner were aligned, with an error of 6 mm. The final model has been georeferenced to the same absolute coordinate system, according to 3 points measured with a Differential GPS.

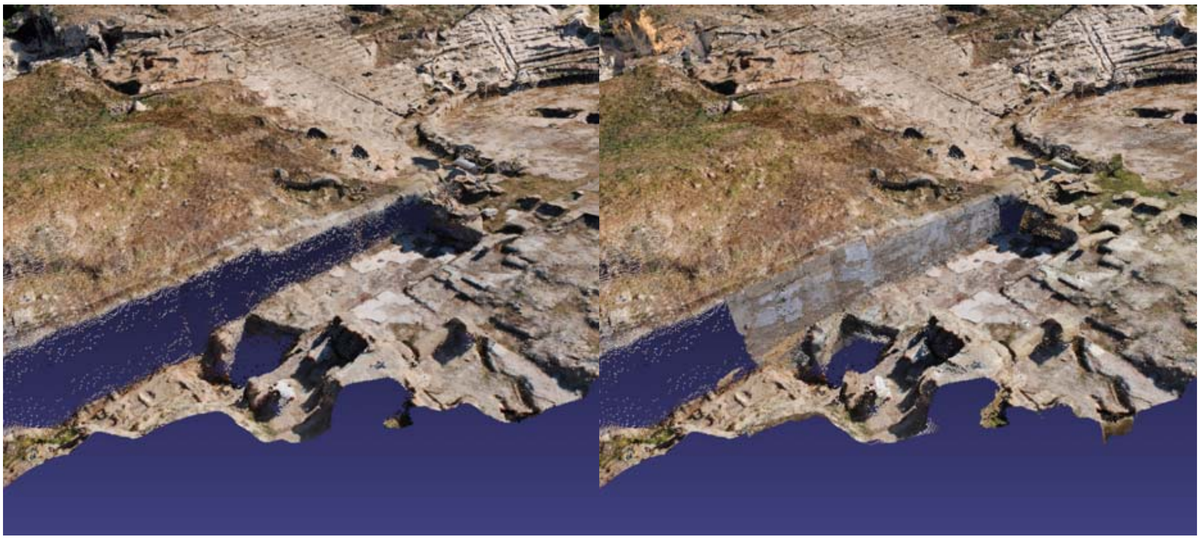

Fig.5: Integration of the point cloud from aeria photogrammetry (left) with a point cloud from laser scanner (right).

5. CONCLUSIONS

The final result is a model generated from the integration of the two techniques (photogrammetry and laser scanner). It is satisfactory because the different parts fit with an high accuracy (error less than 6 mm).
Each of the two tecniques has of course pros and cons.
For example the Fly Scan System is less expensive than a laser scanner, but has a stronger reliance on atmospheric conditions: e.g wind, sun light (a strong sun light causes the lost of a lot of informations). These factors does not affect the acquisition with the laser scanning .

With the aerial photogrammetry it is possible to gather a large amount of data without having the problem of the laser scanning, for which the size of the outcomes is too heavy to be managed. The aerial photogrammetry guarantees a faster acquisition process in the field (in this case one day for the acquisition of the whole area) compared with the laser scanning (two days for twenty-five scans) and an easy processing of the photos with intuitive software (one week), giving the possibility to modify the resolution of the point clouds during the processing phase according to the final use.
On the other hand, the first phase of the Fly Scan set up takes a longer time than setting a laser scanning. Another constraint is the availability of helium to fill the baloon, not easily available everywhere.
The outcomes suggest to integrate the two techniques in order to achieve a complete and accurate documentation of the object of study, using photogrammetry for large scale acquisition, but with lower resolution (1-2 cm), and laser scanning for the acquisition of fine details with higher resolution (1 mm).
The research goal of the work and the expected results are in sum the key factors to decide which tecnologies to use.

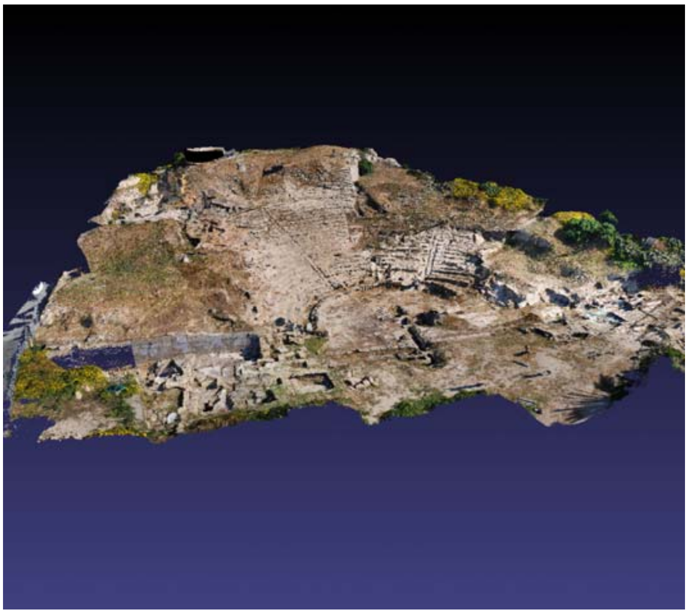

Fig. 6: The final integrated 3D model.

ACKNOWLEDGEMENTS

The survey was carried out in April 2009 by the CNR-ITABC team (Nicola D’ Amico and Andrea Angelini) led by Dr. Roberto Gabrielli and the CISA team (Giancarlo Iannone) led by Dr. Andrea D’ Andrea. The STARC team included the author of the present paper.
This research in partially supported by the European Commission under the 7th Framework Programme throught the 3D-COFORM project, grant 231809.

REFERENCES

AMICO N., ANGELINI A., D`ANDREA A., GABRIELLI R., IANNONE G., 2010, Integrating 3D data acquisition techniques for comprehensive study of the ancient Hellenistic-Roman Theatre of Paphos, Cyprus. (In press).

ANGELINI A., FRANCHI R., DRAPP P., GABRIELLI R., 2008 Antica rete idrologica di Petra. Studio e restauro nell'ottica della conservazione dei beni architettonici. In *Archeologia e Calcolatori '08* (2008), vol. 19, pp. 323-341.

BARKER C.D., "Excavations at the Site of the Hellenistic-Roman Theatre of Nea Paphos in Cyprus, 2007-2008", *The Australian Archaeological Institute at Athens Bulletin*, Volume 5, 2007/2008, 40-47.

BARKER G., S. GABRIELI., GREEN R., 2004. *Fabrika: an ancient theatre of Nea Paphos*, Nicosia.

BITELLI G, GIRELLI V A, TINI M A, VITTUARI L., ZANUTTA. A., 2003. Laser a scansione terrestre e fotogrammetria digitale nel rilevamento dei Beni Culturali. In *Atti 7° Conferenza Nazionale ASITA,* vol 1. pp. 345-350

BITELLI G., 2002. Moderne tecniche e strumentazioni per il rilievo dei Beni Culturali. In *Atti della 6° conferenza Nazionale ASITA*, vol. 1 IX-XXIV, , pp. 180-185.

CAMPANA. S., FRANCOVICH R.; 2006 Laser scanner e GPS ; paesaggi archeologici e tecnologie digitali. pp.341.

D'ANDREA A., IANNONE G., SAFFIOTTI L., 2008. Metodologie Laser Scanner per il rilievo archeologico: metodi operativi e standard di documentazione, in *Atti del Workshop L'informatica e il metodo della stratigrafia 11,* pp. 123-134

HERMON S., NICCOLUCCI F., D`ANDREA A., 2005, Some evaluations on the potential impacts of Virtual Reality on the Archeological Scientifich Research, in Thawaites H. (ed.), Proceedings of the Eleventh International Conference on virtual System and Multimedia, VSMM 2005, (October 3-7, Ghent), Budapest, pp 105-114.

SCOPIGNO R., 2006, Gestione efficiente dei dati prodotti dai sistemi di scansione tridimensionale, in CAMPANA S., FRANCOVICH R., (eds.), Laser Scanner e GPS. Paesaggi archeologici e tecnologie
digitali1., *I Workshop (Grosseto, 4 marzo 2005), Quaderni del Dipartimento di Archeologia e Storia delle Arti. Sezione Archeolgoia- Universita` di Siena, Firenze,pp 41-68*

SGRENZAROLI M.,VASSENA G.P.M. (eds.) 2007, *Tecniche di rilevamento trdimensionale tramite laser scanner, Vol.1 – Introduzione generale*, Brescia.

PELOSO. D., 2005.Tecniche laser scanner per il rilievo dei beni culturali in Archeologia e calcolatori n°XVI pp. 199-224.

WENDT A., 2007. A concept for feature dased data registration by simultaneos consideration of Laser Scanner data and Photogrammetric images. ISPRS journal of Photogrammetry & Remote Sensing, 62, pp.122 – 134.

BIOGRAPHICAL NOTES

Born in Nardo`(LE) Italy the 12/05/1980.
Actual position: Research assistant at the Cyprus Institute (Cy)
Formerly: Marie Curie- Early Stage Training at Ben-Gurion University of the Negev, Department of Bible, Archaeology and Ancient Near Eastern Studies, Israel, 2008.
Education: Course in "digital integrated technologies applied to Cultural Heritage: from data acquisition to the communication through virtual reality systems"- Institute of Technologies Applied to Cultural Heritage (CNR) Rome 2008; Master Euromachs "European Heritage, Digital Media and Information Society" 2006-2008 with courses followed at University of Coimbra 2007; MA in Conservation of Cultural Heritage Course in Archaeology 2005. Diploma of Surveyor in the 1999.
Research Interest: Digital integrated technologies applied to Cultural Heritage, GIS analyses, topographic survey.

CONTACTS

Paola Ronzino
Research assistant
The Cyprus Institute-STARC
Guy Ourisson Bldg- Athalassa Campus
P.O. Box 27456, 1645 Nicosia, Cyprus
CYPRUS
Tel. + 357 22208672
Fax + 357 22208625
E-mail: p.ronzino@cyi.ac.cy