3d Surveying and modelling of the Archaeological Area of Paestum, Italy

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Resumen

El objetivo del presente trabajo interdisciplinario es la integración de diferentes técnicas de levantamiento 3D e instrumentos para el estudio de la zona arqueológica de Paestum (Italia), con el fin de obtener modelos tridimensionales digitales de las principales estructuras y templos del yacimiento arqueológico.
La antigua ciudad de Paestum, Patrimonio Mundial desde 1998, es uno de los yacimientos históricos más importantes de Italia, ya que conserva vestigios de las épocas griega y romana, entre ellos tres templos dóricos. La toma de datos se ha realizado a través de técnicas de fotogrametría y láser escáner terrestre (TLS), con el objetivo de aprovechar plenamente las ventajas intrínsecas de las técnicas de levantamiento en 3D basadas en objetos reales.

Palabras Clave: *LÁSER ESCÁNER, FOTOGRAMETRÍA, LEVANTAMIENTO ARQUEOLÓGICO, MODELO 3D, VISITA VIRTUAL*

Abstract

The intention of this interdisciplinary work is the integration of different 3D recording techniques and instruments to survey the archaeological area of Paestum (Italy) and obtain digital models of the main structures and temples of the site. The ancient city of Paestum, included in the UNESCO World Heritage list since 1998, is one of the most important archaeological sites in Italy, preserving the vestiges and ruins of Greek and Roman times, including three Doric temples. Photogrammetry and terrestrial laser scanning (TLS) acquisitions were integrated in order to exploit the intrinsic advantages of the actual 3D surveying techniques and produces digital models, orthoimages, maps and other geometric representations useful for archaeological, architectural and communication needs.

Key words: *LASER SCANNER, PHOTOGRAMMETRY, ARCHAEOLOGICAL SURVEY, 3D MODEL, VIRTUAL TOUR*

1. Introduction

A reality-based survey can be an essential instrument of knowledge, documentation and analysis, preliminary to any work of cataloguing, restoration and heritage conservation. The aim of the presented interdisciplinary work is the integration of different 3D recording techniques and instruments (REMONDINO, 2011) to survey the archaeological area of Paestum (Italy) in order to obtain detailed 3D textured models of the site for archaeological needs and graphical representations.

The ancient city of Paestum preserves ruins of Greek and Roman times and three very well preserved Doric temples. Paestum is one of the most important archaeological sites in Italy and was included in the UNESCO World Heritage list in 1998. Paestum was founded around 600 BC by Greeks from Sybaris with the name of *Poseidonia* and it presents the urban space divided into sacred, public and private areas. The central area of the city was designated for public use and during the Greek period was occupied by the *agorà*. In the North was located the sanctuary of Athena (ca 500 BC) known as the temple of Ceres. Instead, the so-called "Basilica" (ca 550 BC, it was the earliest of three temples) and the temple of Neptune (ca 450 BC) was placed in the South. At the end of the 5th century B.C. *Poseidonia* was defeated by the *Lucani*, a population of Samnite origins, who replaced the Greeks in the government of the city. The conquest of *Lucani* did not introduce changes in the organization of urban cities, only the defensive walls were built. In 273 BC the city became a Roman colony and took the name of *Paestum*. The most important transformations of this period involves the organization of the urban space: the Forum was built and the main Greek public monuments (*agorà*, *ekklesiasteiron* and *heroon)* were eliminated. The city was then abandoned during the Middle Ages and the archaeological area remained submerged under marshes and brushwood for a long time. With the rediscovery of the temples in the 18th century, Paestum came into knowledge again. Systematic archaeological investigations started at the beginning of the last century and they are still on-going.

A detailed and reality-based 3D recording of the area is not yet available, therefore the project aims to produce accurate 3D data and orthoimages for documentation, conservation, preservation, restoration and visualization purposes. In order to fully exploit the intrinsic advantages of the actual 3D recording techniques, photogrammetry and terrestrial laser scanning (TLS) surveying were integrated during a 6-days field campaign (2 days to complete the UAV aerial surveying, 4 days for the terrestrial surveying, based on TOF laser scanning and photogrammetry).

2. Aerial surveying

Given the dimension of the area (ca 1x0.6 km) and the characteristics of the temples, an UAV platform (Fig. 1) was used to record aerial views useful for orthoimages generation and as integration to the terrestrial surveying.

The employed quadricopter belongs to the "Laboratorio de Fotogrametría Arquitectónica (LFA) y Documentación, Análisis y Visualización Avanzada del Patrimonio" (DAVAP) of the Valladolid University, directed by Juan José Fernández Martin (http://157.88.193.21/~lfa-davap). The platform is a MD4-1000 entirely of carbon fibre and can carry up to 1.2 kg. It was coupled once with an Olympus E-P1 camera (12 Megapixels, 4 □n pixel size) with 17 mm focal length and then with an Olympus XZ-1 (10 Megapixels, 2 □n pixel size) with 6 mm focal length. The flight's endurance of the UAV platform depends on the payload, wind and batteries but can reach, under optimal conditions, ca 70 minutes.

Figure 1. UAV surveying with the MD4-1000.

Figure 2. Example of an oblique image of the site.

The UAV flies under a remote control or autonomously, with the aid of a GPS Waypoint navigation system.

For the surveying of the site and monuments, a relative altitude of 130 m (for the entire site) and 70 m (for the single monuments) was respectively used, delivering images with an average ground sampling distance (GSD) of 5 and 3 cm, respectively (Fig.2).

Table 1. UAV surveying of the archaeological monuments and site - collected images and average ground resolution.

Area	**Average GSD**	**Number of images**
Entire site	ca 5 cm	60 vertical image - 4 strips
"Basilica"	ca 3 cm	15 vertical images - 3 strips
"Basilica"	ca 3 cm	25 oblique images - 1 round
Neptune	ca 3 cm	14 vertical images - 3 strips

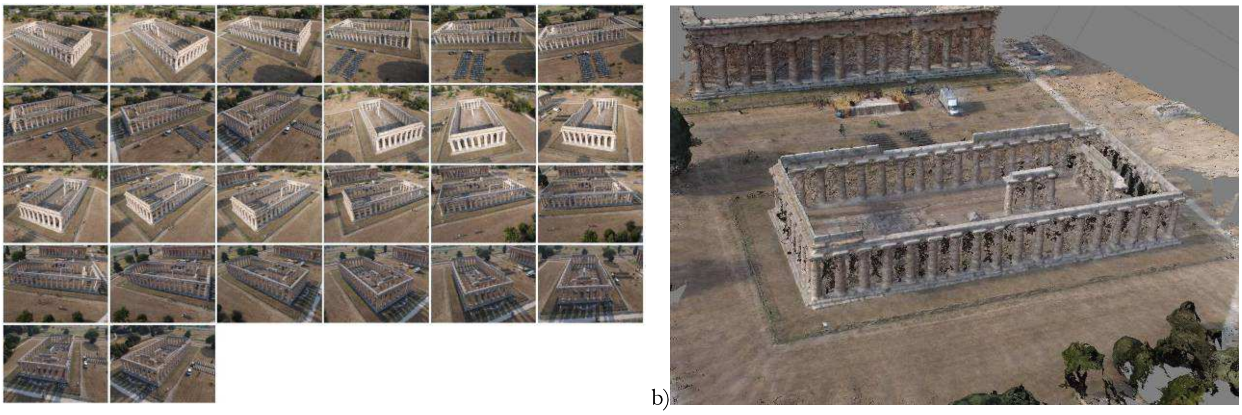
a)

b)

Figure 3. Oblique UAV images over the Basilica temples (a) and derived surface model of the heritage (b).

The processing of the acquired aerial images (Table 1) followed the standard photogrammetric pipeline. After the image triangulation by mean of automated tie points extraction and a photogrammetric bundle adjustment, a dense point cloud and surface model (Fig. 3) were generated for the successive creation of a geo-referenced orthoimage (Fig. 4) of the entire UNESCO site. Later on, the achieved aerial results will be integrated with the terrestrial 3D data in order to create a more complete and detailed 3D model of the area with geometric representations useful for archaeological, architectural, communication and preservation issues.

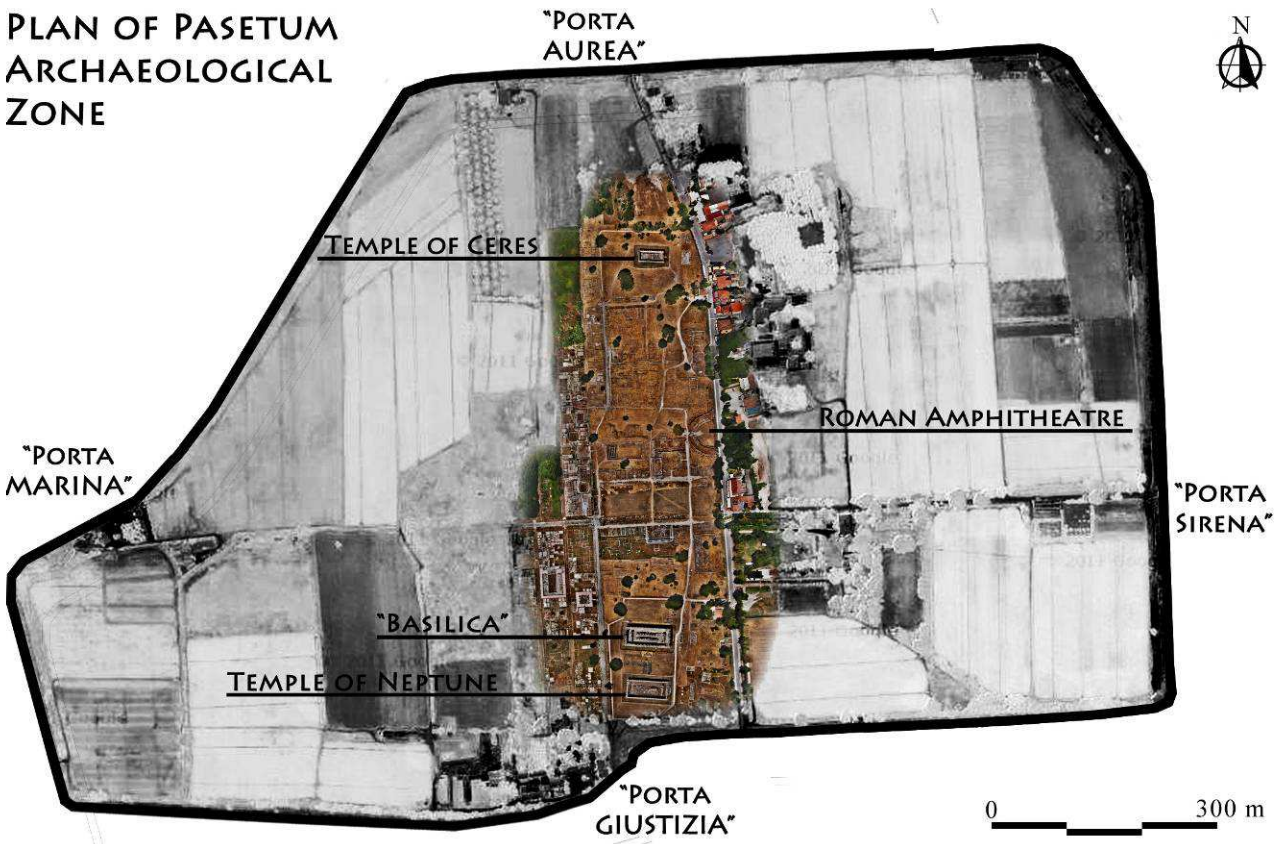


Figure 4. The produced geo-referenced orthoimage overlaid on the map of entire heritage area.

3. Terrestrial surveying

The temple of Neptune and the "Basilica" were surveyed with TOF laser scanners, while the Ceres temple was digitally recorded with images as well as 3D scanning. The "Basilica" (Fig. 5a) spans ca 24,5 x 54 m (at the stylobate) and it features 18 columns on the long side and 9 on the short one, while the interior part has a line of 3 columns. The temple of Neptune (Fig. 5b) is much more complex: it measures ca 24,5 x 60 m and consists of 6 frontal and 14 lateral columns while in the interior area has two rows of double ordered columns that divide the *naos* in three parts. While the temple of Ceres (Fig. 5c) has only a series of 6 x 13 columns and measure 14,5 x 33 m.

The number of the range acquisitions and stations for each temple depends on the dimensions and on the complexity of the monument. The positions of the different acquisitions have been organized to cover the entire volume of the monument, taking account of shadows, obstacles and undercut. The geometric resolution of the scans has been chosen depending of the distance instrument-object in order to ensure a sampling fairly constant and sufficient to reconstruct all the necessary architectural details and degrade. For example, the nominal resolution for the nearest stations and for all scans of the inner temple of Neptune was set to 0,018° (one point for every 3 mm at a distance of 10 m), while for the most distant scanner position a higher resolution, equal to 0.009° (1,6 mm at 10 m), was chosen. Instead, for the Basilica and the Temple of Ceres a minimum and maximum resolution of 0,036° and 0,018° respectively were selected.

Table 2. Terrestrial surveying of the archaeological monuments in Paestum.

Object	*Technique*	*Instrument*	*Data*
Neptune	TLS	Leica HDS 7000	48 scans 23 int, 25 ext 500 mil. points
Basilica	TLS	Z+F 5600h	28 scans 13 int, 15 ext 65 mil. points
Ceres	TLS	Z+F 5600h	23 scans 9 int, 16 ext 40 mil. points
Ceres	Photogr.	Nikon D3X	214 images 99 int, 115 ext

a) b) c)

Figure 5. Range data acquisition and shaded clouds ("Basilica", Neptune and Ceres temples, respectively).

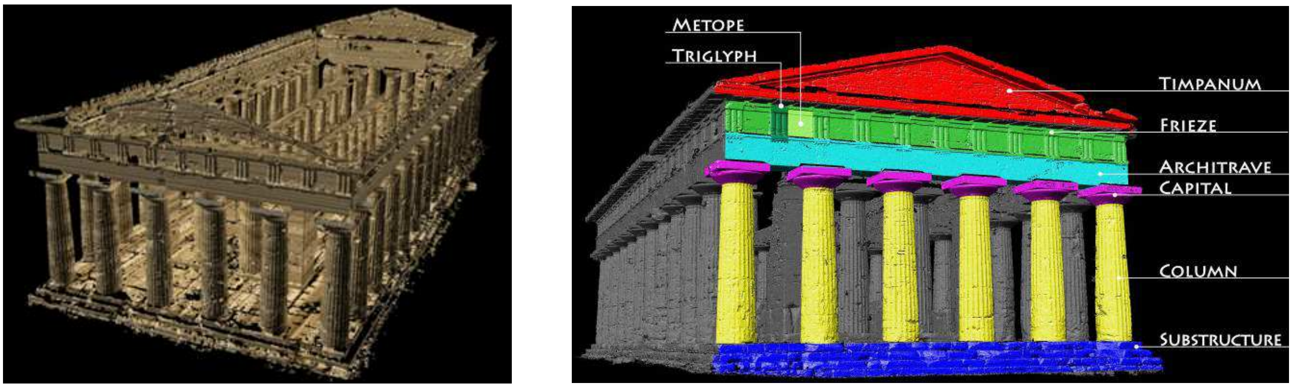


Figure 6. Range-based textured 3D model of the Neptune temple (ca 87 million polygons) and the segmentation of the archaeological elements.

The employed laser scanners are a Z+F IMAGER 5600h and a Leica HDS 7000, both based the phase-shift measurement principle which guarantees a very high sampling step, fast scanning operations and good geometric accuracy (SAN JOSÉ ALONSO et al., 2011). The Z+F scanner was coupled with the motorized camera M-Cam (5 Megapixels, 55° FOV, 4.8 mm focal length) in order to simultaneously capture the radiometric information of the surveyed scene. For the Neptune temple, in order to obtain a textured 3D model (Fig. 6a), terrestrial images were also acquired.

Before starting the meshing of the acquired point clouds, the range data needed to be aligned and edited (BARBA & FIORILLO, 2010).

The produced polygonal model is now the basis for further modelling issues and allows us to produce orthoimages, sections, maps, segmented representations and other digital delivering useful for archaeologists, conservators or communicators (Fig. 6).

The photogrammetric modelling of the Ceres temple investigated new automated image orientation and matching algorithms available in the open-source domain (mainly Apero and MicMac - PIERROT-DESEILLIGNY et al., 2011). The 3D results are quite satisfactory (Fig. 7) but further tests and critical analyses are necessary.

3.1 Virtual Tour of Paestum

With a different purpose, a panoramic head (GigaPan) was used to capture a series of high-resolution images of the archaeological site. The single shots were assembled into unique panoramic gigapixel images in order to create immersive photography for virtual tour applications and allow the exploration of the archaeological area of Paestum even on-line (using any browser). The panoramic images can be enriched with illustrative videos, text information and digital 3D models of artefacts (REMONDINO, 2011). Therefore, a virtual tour application allows not only to visit "virtually" distant places, but also to have access to additional media content and information that facilitate and enhance the knowledge of the site or help education and promotion. In this way, the virtual tour becomes a container of data of different types for different purposes and may represent a suitable solution for the organization, divulgation and sharing of the collected information.

4. Conclusions and outlook

The article reported the preliminary results of the Paestum project, an on-going collaborative and interdisciplinary 3D modeling project. The aims of this project are (i) to develop reality-based digital models of the main structures and temples of the archaeological site, (ii) to compare 3D surveying and modelling methodologies concerning costs, reliability, processing time and final accuracy and finally (iii) to deliver metric and accurate results for archaeological, architectural, conservation and communications needs. The produced 3D models can be used (i) to extract maps, plans, cross-sections, orthoimages for a technical public or for conservation issues, (ii) to allow the use of 3D models on the web, using innovative techniques of visualization (ABATE et al., 2012) and virtual reality and (iii) to produce material for informative and educational purposes. The next steps of the project will be the integration of the aerial and terrestrial 3D data and the generation of a seamless 3D model of the entire heritage area

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Figure 7. Derived camera poses (214 images) and 3D model for the Ceres temple.

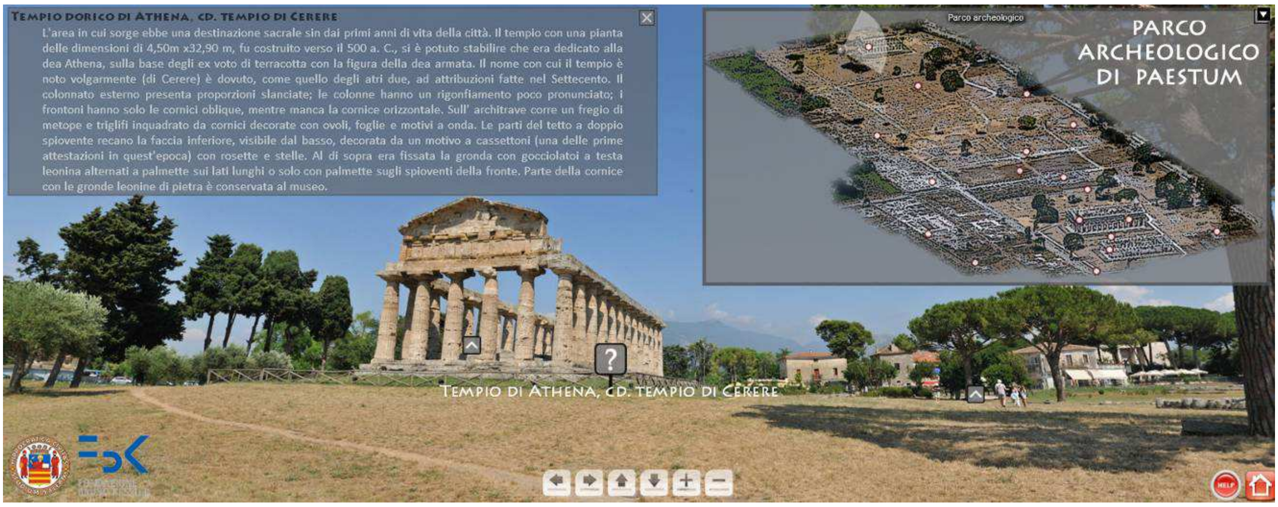

Figure 8. Virtual Tour of the archaeological area of Paestum.

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