# 3D DIGITIZATION AND MAPPING OF HERITAGE MONUMENTS AND COMPARISON WITH HISTORICAL DRAWINGS

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**ABSTRACT:**

The paper presents the integration of different 3D recording techniques and instruments to survey the archaeological area of Paestum (Italy). Paestum was included in the UNESCO World Heritage list since 1998, and still preserves the ruins of Greek and Roman times. Photogrammetry and terrestrial laser scanning (TLS) acquisitions were integrated in order to exploit the advantages of the 3D surveying techniques and produce digital models, orthoimages, maps and other geometric representations useful for archaeological, architectural and cultural touristic purposes. The obtained 3D results are then compared to historical representations to show the high quality of such ancient manual drawings.

## 1. INTRODUCTION

In the field of Cultural Heritage, a reality-based survey is a very important instrument of knowledge, documentation and analysis, preliminary to any work of cataloguing, restoration and 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 (Fig.1) in order to obtain detailed 3D textured models of the site and orthoimages for archaeological needs, conservation and management policies as well as documentation and graphical representations. Protection of existing Cultural Heritage from degradation or its loss is of vital importance. Nowadays the continuous expansion and development of new recording and visualization techniques allow us to produce reality-based 3D models with high geometric accuracy and realistic appearance. The achievable 3D products can then be used for detailed and accurate documentation and digital preservation of existing tangible heritages as well as for new archaeological or architectural studies and analyses, 3D repositories and catalogues, virtual reconstruction, computer-aided restoration, virtual anastylosis, physical replicas, virtual and augmented reality applications, monoscopic or stereoscopic renderings, multimedia museum exhibitions and virtual visits, archaeological prospection, web access, visualizations and so on (Remondino et al, 2011).

### 1.1 The heritage site in Paestum

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. Greeks from Sybaris founded Paestum around 600 BC and Troezen 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 (the *Athenaion*). Instead, the so-called "Basilica" (ca 550 BC, it was the earliest of three temples) and the temple of Neptune (ca 480-450 BC) were placed in the South.


Figure 1: An aerial view in 1989 of the Paestum site (picture courtesy of Otto Braasch) which spans ca 700 x 350 m.

At the end of the 5th century BC, Poseidonia came under the control of the Lucani, a population of Samnite origins, who replaced the Greeks in the government of the city. The conquest of Lucani did not particular 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 transformation of this period involves the organization of the urban space: the Forum was built and the main Greek public monuments (*agorà*, *ekklesiasterion* 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 conducted by the University of Salerno and FBK Trento aims to produce accurate and realistic 3D models and orthoimages for documentation, conservation, preservation, restoration and visualization purposes

## 2. THE PAESTUM PROJECT

The on-going 3D surveying and modelling project is a joint collaboration between FBK Trento and the University of Salerno, Italy. Every year a summer school for knowledge and technology transfer is taking place at Paestum and new technologies or acquisition platforms/sensors are employed and tested. Given the dimension of the area and the characteristics and complexity of the architectures, an integrated surveying approach was selected (Barba, 2012). Photogrammetry and terrestrial laser scanning (TLS) methods were integrated in order to fully exploit the intrinsic advantages of the actual 3D recording techniques.

### 2.1 Aerial surveying and data processing

An UAV platform (Fig. 2a) was used to record aerial views (nadir and oblique images) useful for orthoimages generation and as integration to the terrestrial surveying and modelling (Remondino et al., 2011). The employed quadricopter belongs to the "Laboratorio de Fotogrametría Arquitectónica (LFA) y Documentación, Análisis y Visualización Avanzada del Patrimonio" (DAVAP) of the University of Valladolid (http://157.88.193.21/~lfa-davap). The UAV is a MD4-1000 entirely of carbon fibre with a max payload of 1.2 kg. It was coupled once with an Olympus E-P1 camera (12 Megapixels, 4 micron pixel size) with 17 mm focal length for the oblique images and then with an Olympus XZ-1 (10 Megapixels, 2 micron pixel size) with 6 mm focal length for the nadir images. The flight's endurance of the UAV platform depends on the payload, wind and batteries but can reach, under optimal conditions, ca 70 minutes. The UAV flies with 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 ca 130 m (for the entire site) and ca 70 m (for the single monuments) was respectively used, delivering images with an average ground sampling distance (GSD) of 5 and 3 cm, respectively. 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 block adjustment, dense point clouds were extracted for the successive creation of a geo-referenced orthoimage (Fig. 2e) of the entire UNESCO site. The achieved aerial results were also useful as integration with the terrestrial 3D data (Fig. 2d) in order to produce more complete and detailed 3D models of the monuments (particularly for the upper parts not visible from the ground survey).

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 images - 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 |
| Neptune | ca 3 cm | 28 oblique images - 1 round |

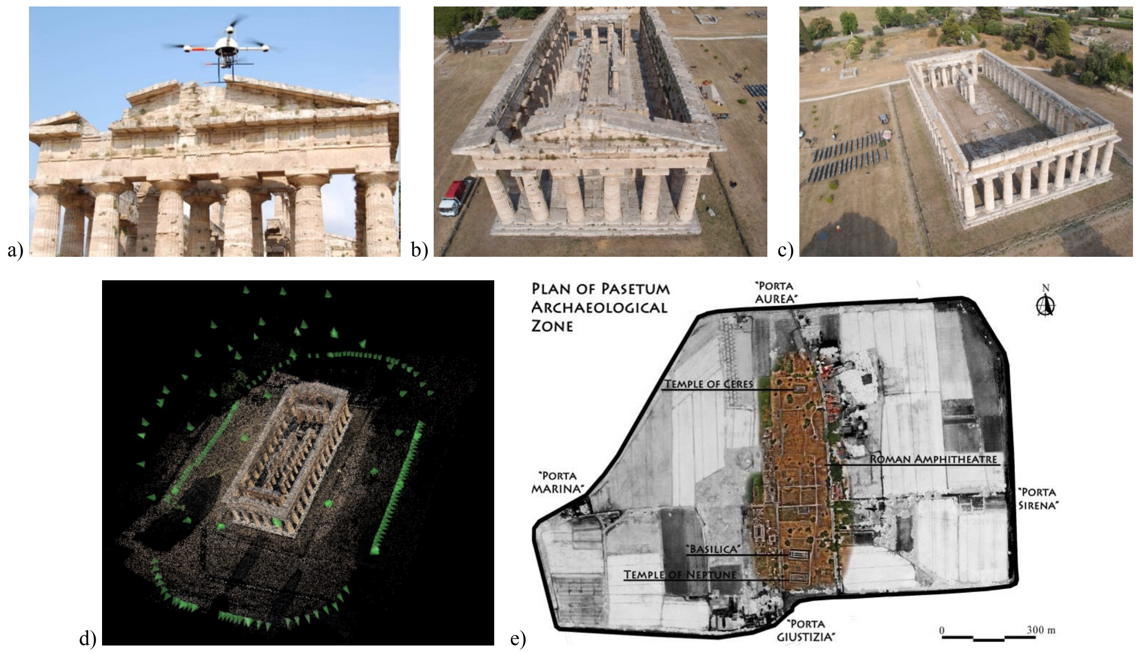


Figure 2: The employed UAV platform (a) and two oblique views of the Neptune (b) and "Basilica" (c) temples. The UAV image block over the Neptune temple integrated with the terrestrial image survey (d). The produced geo-referenced orthoimage overlaid on an old map of entire area (e).

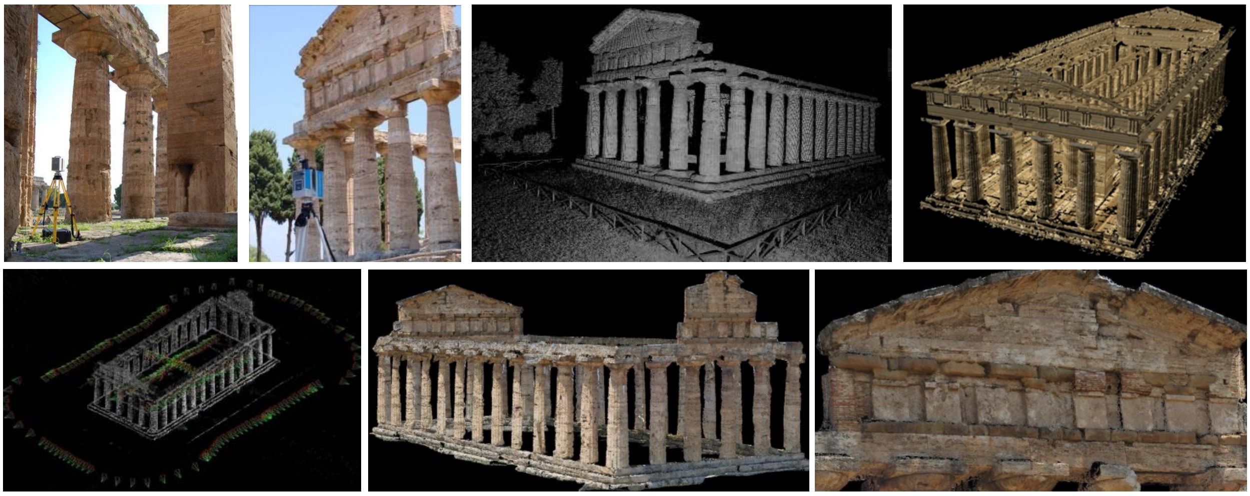

Figure 3: TLS data acquisition, clouds and produced 3D model (above). Terrestrial image-based network and derived 3D data (below).

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

| *Object* | *Technique* | *Instrument* | *Data* |
|---|---|---|---|
| **Neptune** | TLS | Leica HDS 7000 | 48 scans<br>23 int, 25 ext<br>500 mil. points |
| **Neptune** | Photogr. | Nikon D3X | 153 images (ext) |
| **Basilica** | TLS | Z+F 5600h | 28 scans<br>13 int, 15 ext<br>65 mil. points |
| **Ceres** | TLS | Z+F 5600h | 23 scans<br>9 int, 16 ext<br>40 mil. points |
| **Ceres** | Photogr. | Nikon D3X | 214 images<br>99 int, 115 ext |

### 2.2 Terrestrial surveying and data processing

The temples of Neptune and Ceres were surveyed with TOF laser scanner and images while the "Basilica" was digitized only with TOF 3D scanning (Table 2). The temple of Neptune (Fig. 2b) is much more complex: it measures ca 24,3 x 60 m at the stylobate 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. The "Basilica" (Fig. 2c) spans ca 24,5 x 54,3 m at the stylobate (ca 26 x 55 m gat the last bottom step of the *crepidoma*) 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 Ceres has only a series of 6 x 13 columns and measure ca 14,5 x 33 m.
The number of the range acquisitions and stations for each temple depends on dimensions and 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, occlusions or 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 (Fiorillo, 2012). For example, the nominal resolution for the nearest stations and for all scans of the inner part of the 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. For the "Basilica" and the temple of Ceres a minimum and maximum resolution of 0,036° and 0,018° respectively were selected.

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. 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. The processing of the terrestrial scan data faced the well know time-consuming operations (Barba et al., 2010). The photogrammetric processing of the temple terrestrial images (Fig. 3) followed the standard photogrammetric pipeline and investigated some new automated image orientation and matching algorithms available in the open-source domain - out of the scope of this paper. The 3D results are quite satisfactory but further tests and critical analyses are necessary.
The produced 3D models are now the basis for further visualization, interpretation and analyses issues and allowed us to produce orthoimages, sections, maps, segmented representations and other digital deliverable useful for archaeologists, conservators or communicators (Fig. 4).

## 3. HISTORICAL DATA AND COMPARISONS

The comparative study between the results of actual 3D recording methods and the historical drawings of the temples in Paestum, born from the idea to check the dimensional accuracy and the formal correctness of the surveys performed as early as the late 18th century. More precisely, the following three authors (and related products) were considered: G. P. D. Dumont (1720-1791), A. Aurès (1806-1894) and H. Labrouste (1801-1875).

### 3.1 Paestum survey's history

The attention paid by researcher to Poseidonia/Paestum dates back to a period of rediscovery of antiquity, defined by the interest developed within the Illuminist culture of the eighteenth century and the socio-cultural phenomenon of the Grand Tour. Despite the three temples and the walls were already known in the Renaissance period, it is only with the Enlightenment period that, around the same time of the discoveries of Herculaneum and Pompeii, the remains of the ancient city of Paestum were highly re-considered, thanks to the studies of architects, painters and etchers. The Paestum monuments rose to *exempla* within the cultural imagination of the time, often forming the artistic and architectural basis of the time.

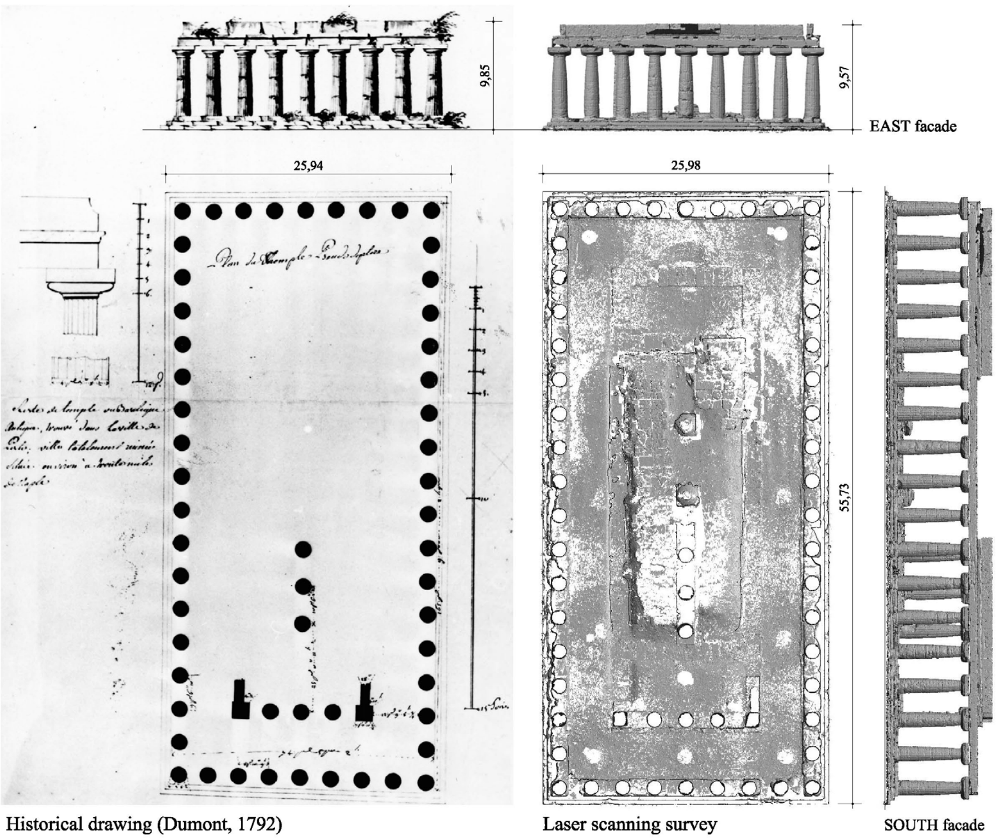


Figure 4: Plan and facade of the “Basilica”: comparison between the results achieved from the laser scanning data and those produced by historical surveys (Dumont, 1792).

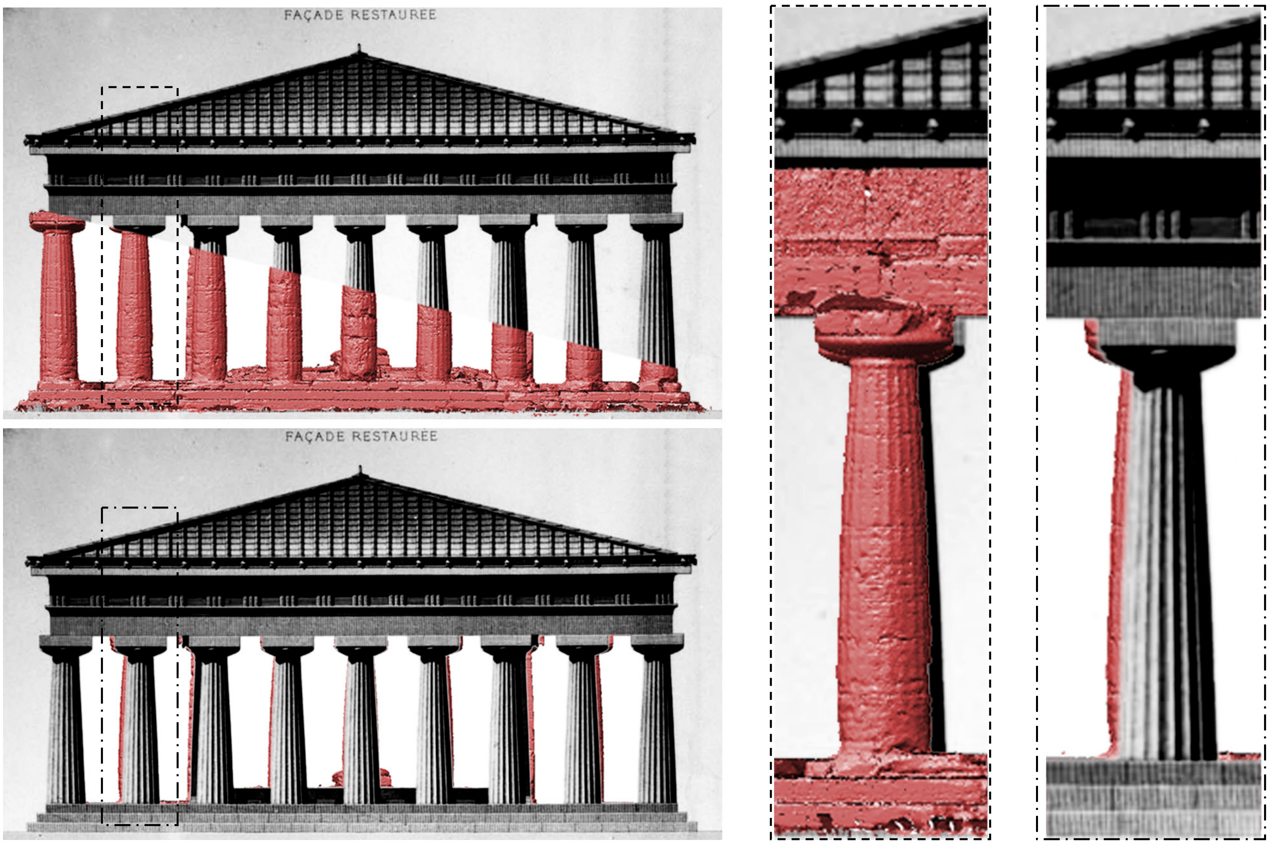


Figure 5: Facade of the “Basilica” (and two closer views): the laser scanning survey (in pink) overlapped on a historical drawing and reconstruction (Labrouste, 1877). Very few discrepancies are notable.

The earliest productions of drawings and views were characterized by fashion and taste for ruins, with no real attempt to create realistic/metric plans and representations of monuments. The first interpretations, often erroneous, of the structures and their stylistic characteristics were diffused by famous specialists, such as J. J. Winckelmann and Th. Major. The first cognitive intervention was operated by Felice Gazola who commissioned, between 1734 and 1740, the architectural survey of the three major temples, part of the walls and of the few visible structures, attempting to represent and read the monuments, in a way that was considered valid at least until the end of the 19th century. The drawings were published in 1764 by Jacques G. Soufflot and then by Morghen (in 1765) and completely by P. A. Paoli (Raspi Serra, 1986).

In 1750, together with Jacques G. Soufflot, the architect Gabriel-Pierre Dumont also visited Paestum. In this occasion, the first drawings of the temples were produced onsite, using scientific methods. These surveys were purely theoretic and were aimed almost exclusively to the illustration of the basic principles of architecture. Interesting is the contribution of C. M. Delagardette, who did at the end of the 18th century a first review of all drawings and surveys. Throughout the 19th century the cognitive activity and recording of data is strongly influenced by the studies of classical architecture and art historical research. With this respect, we may recall the work of H. Labrouste, based on the measurements of the “Basilica”, made between 1826 and 1828 and published posthumously in 1877. His drawings are interesting for a very few colour reconstructions, performed in a time when the debate on the polychromy of ancient architecture had just started. However, the reconstruction of the temple as a *stoà* open on all sides and with a four slopes roof which indicates that H. Labrouste was not updated on the latest interpretations related to the building as the temple of Hera. In the second half of the 19th century the engineer A. Aurès, a prominent member of the Académie de Nîmes (France), concentrated his research on the study of ancient metrology, performing surveys of the so-called temple of Neptune (Aurès, 1868).

C. Lenormant, R. Koldewey and O. Puchstein also worked in this period. The development of an attention to the entirety of the city’s architectural and urban data started only from the early decades of the 20th century: the interventions of V. Spinazzola and the activity of A. Maiuri and A. Marzullo are symptom of this new impulse to the knowledge. In this time, there was a trend to document with drawings and surveys – unfortunately not always accurate – a large number of structures brought to light. We can therefore note an increasing need to document and record the reality of the archaeological and architectural data with more refined and precise graphic media. F. Krauss produced numerous drawings in order to publish a monograph on the three temples of Paestum. At the basis of these surveys, there was the idea of a reconstruction as faithful as possible of the ancient monument, using however only a certain number of measures that were then repeated for all the compositional elements. Unfortunately it was published only the documentation of the Ceres temple. The work of Krauss was carried out by D. Mertens, who, over the years, has surveyed the other main structures, reaching a remarkable degree of accuracy and optimizing the documentation, using also photogrammetry, for the purpose of a realistic lecture and interpretation of the architectural remains (Mertens, 1993).

Between 1972 and 1999 the research conducted by E. Greco and D. Theodorescu provided, also through the systematic publication of findings, a fundamental summary for the knowledge on the organization of the urban plan of the city at various stages of life (Greco et al., 1980-1983-1987-1999). Thanks to the interpenetration between the architectural data and archaeological information, it was possible to reconstruct the material and structural essence of mutilated evidences, often apparently unreadable. Thanks to this experience, the idea of a significant restoration of the sacral monuments of the city was spreading in this time, later carried out between 1988 and 2003 (Cipriani et al., 2010).

Researchers have made large use of the results of Krauss and Mertens, by using the old surveys and producing new ones in order to create a mapping of evolutionary phenomena and the deterioration of monuments. The graphic documentation has become one of the main tools of investigation, demonstrating necessary of detailed and accurate surveying for the knowledge of monuments. In the last decade, it has provided an impressive graphic documentation of the city wall was produced, particularly along the walls ranging from the *Porta Sirena* to *Postierla 47*, in order to know its structural characteristics and evolution.

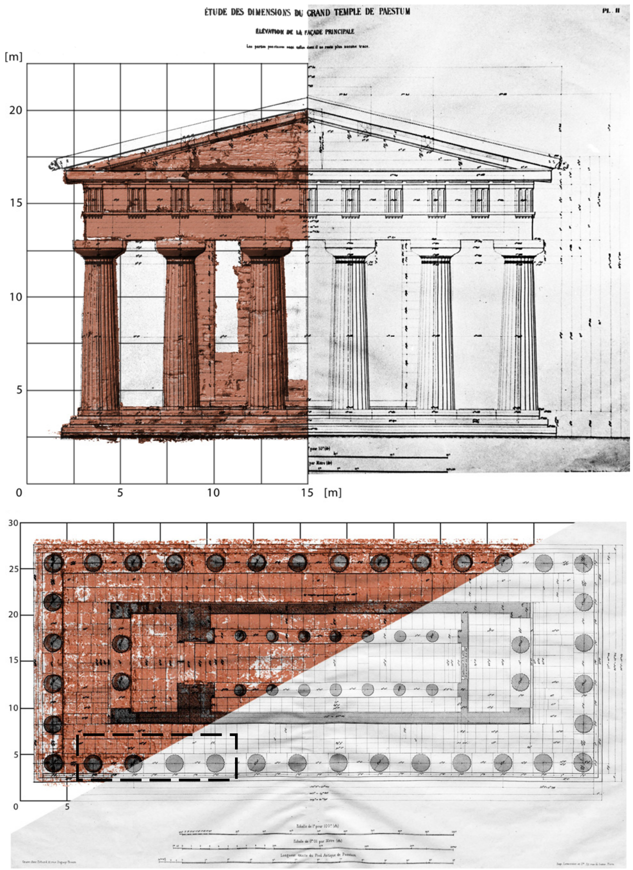


Figure 6: Facade (up) and plan (down) of the Neptune’s temple: the laser scanning survey (in brown) overlapped to the historical drawing of Aurès (1868).

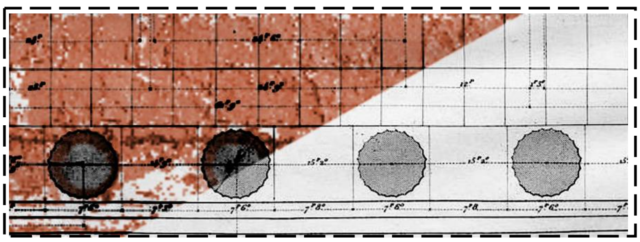

Figure 7: Detail view for Figure 6 of the laser model (in brown) overlapped onto the historical drawing.

### 3.2 Comparison outcomes

The comparison between the graphical restitutions from modern 3D surveys and the historical drawings allowed deepening the knowledge of proportions that characterize the geometry of the "Basilica" and Neptune temples. After the digitization of the historical material, a polynomial best fitting transformation was applied in order to correctly overlap this material with the respective modern products.
The first results (Fig. 4) show how Dumont's designs of the "Basilica" are consistent to the laser scanner restitution. In addition, the comparative study confirmed the already known proportions: (i) the long sides of the cell are aligned with the third and the seventh column of the facades; (ii) the front of the pronaos is aligned with the third column; (iii) the front of the cell is aligned with the fifth column; (iv) the bottom wall of the cell with the fourteenth and the closure western of the adyton with the sixteenth column.
The comparison of the manual drawing and reconstruction of the facade of the "Basilica" by H. Labrouste with the digital model (Fig. 5), has highlighted a maximum deviation of about 15-20 cm. Regarding the temple of Neptune, the superimposition of Aurès manual restitution with the outputs of the digital 3D surveying has shown a satisfactory accuracy of the old drawings and the related alignments of the columns (Fig. 6 and 7). The temple's cell is closely related, along the width, to the east and the west fronts: the outer edge of the *antae* of the pronaos and opisthodomus coincides exactly with the axis of the second and fifth column of the facades. It is not possible to find, however, the same symmetry in the direction of length. In fact, the front of the pronaos coincides with the second half of the distance of the long sides, the east portico of the peristyle is therefore large a wheelbase and an half. The front of the opisthodomus falls at a third of the penultimate distance of the long sides: the west portico of the peristyle is therefore less extensive than the eastern one. This means the continuation of a design typical of the colonial era, which tends to favour the front entrance of the building.

## 4. CONCLUSIONS

The article presented the 3D surveying and modelling of the archaeological area of Paestum, with its large and complex monuments. Photogrammetry and laser scanning were employed and integrated, in order to exploit the intrinsic advantages of each technique. The obtained 3D results were used to produce orthoimages, maps and sections of the site and single monuments and to check the quality of historical surveying and drawings.
The performed comparisons tend to show a sufficient dimensional coherence of the historical drawings, with the H. Labrouste restitutions being less accurate than the others. It should be underlined that the analyses were performed on raster scans of the historical drawings. This means that to the original errors of the tables due to 'graphicism' and those due to the digitization process should be added. The employed polynomial transformation might not have been sufficient to model possible deformations, therefore it will be necessary to continue the research activity implementing a methodology to reduce these aberrations and thus recover the metric of the original works.
Therefore, an appropriate "calibration" phase will be soon carried out, using a suitable cross-linked grid, to determine the distortions associated with the scanner used for the digitization of the ancient drawings. Even more, the use of homologous points, clearly identifiable and properly distributed (de San Antonio Gomez et al., 2008), will enable a more scientific approach and it will be possible to establish a direct comparison of the three levels of information: the historical drawings, its raster image - correct from the distortion - and the digital outputs of the 3D surveys.

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