The use of geodetic techniques in the documentation of the Amykles archaeological site

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SUMMARY

The aim of this study is to present the documentation results of the archaeological site of Amykles in Sparta, Greece using different types of geodetic techniques. The site of Amykles includes a large number of important findings. For the documentation of the site, data from land surveys (total station surveying, Global Navigation Satellite Systems -GNSS surveying), terrestrial laser scanning (TLS), and aerial digital images from UAV are collected in two different epochs (2015 and 2017). The data are georeferenced into a common reference system. From the data, digital surface models of the archaeological site are produced and a geometrical comparison of the surface models is made in order to establish the progress of the excavations. The paper describes the methodology followed for the data collection and data processing pipeline and discusses on the practical aspects and difficulties for such types of documentation projects and reports on the produced results.

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1. INTRODUCTION

An archaeological excavation is usually a rapidly evolving environment with a number of constraining factors such as weather, costs, and permissions imposing the work to be concentrated in a limited period. Moreover, excavating is an operation which constantly modifies the state of the site. Since most of the interpretation is performed in a second stage, it is necessary to collect a massive amount of documentation data (images, sketches, notes, measurements) in a short period of time.

The common method of archaeological documentation implemented mainly by the archaeologists is the so-called direct survey, which involves measuring in direct contact objects, or excavation units, using a caliper or tape measure. Clearly, the survey of this type is highly time-consuming and not so accurate. The following methods refer to using surveying instrumentation and related techniques such as total stations, Global Navigation Satellite System (GNSS) and 3D optical instruments, which offer several advantages over the direct acquisition techniques. The advantages include shorter time to perform the survey and with higher accuracy and they are contactless avoiding possible damages to archaeological objects. The third method refers to the digital 3D documentation generally performed by means of passive techniques (image-based methods) such as photogrammetry or active sensors (range-based methods) such as laser scanner or by integration of active and passive techniques. The best and most appropriate technique depends on the type of project.

In archaeological excavations, due to time and resources required in producing an accurate documentation of any intermediate steps during the excavation stages, it is often impractical for time and resources constrains to be able to obtain a sufficiently time-dense documentation. One method is represented by recent dense reconstruction technologies, which are able to obtain a 3D model of a scene starting from a set of uncalibrated images. Their main advantage stands in the fact that a simple digital camera can be used, and no preliminary calibration of the camera or of the scene is needed. However, the use by archaeologists and the algorithm complexity discourage an intensive field use by non-experts (e.g. Callieri et al., 2011; De Balestrinie and Guerra, 2011).

An alternative and recognised method is the 3D scanning technology with the ability to precisely capture the geometry of the excavation, thus, preserving an intermediate state of the site. This technology has been largely applied in this field because of its easiness to use. Despite the still high overhead cost of the instrumentation, the gain in terms of richness of information is incomparable. The integration of this technology with classic archaeological documentation procedures is manageable and without apprehension for replacing the standard documentation pipeline. Also, this method is well suited to integrate with the known documentation procedures such as photogrammetry, thus making it easier to deal with by the archaeologists (e.g. Barsanti et al., 2013; Hermon et al., 2010; Guidi et al., 2009).

In this work, geodetic techniques including GNSS (Global Navigation Satellite System) surveying, terrestrial laser scanning (TLS) and drone images were used to obtain a time-dense, detailed 3D documentation of the excavation site at the Mycenaean sanctuary of Amykles in Sparta, Greece. The acquisition of its evolution was performed in two years (2015 and 2017).The test case, in the context of the archaeological excavation of Amykles, was the search for the further investigation of the outer and inner encirclement of the sanctuary (Section 2). All the time steps were processed using dedicated softare solutions, trying to define a simple pipeline which could be replicated in the general case. In order to be able to compare, measure and present the evolution of the excavation, the acquisitions were put in a common reference (Section 3.2). Moreover, preliminary experiments to improve the model and integrate heterogeneous data were performed. The obtained 3D data is then used to produce effective and precise documentation of the excavation, easy to integrate in the normal documentation framework carried out by archaeologists during a field work (Section 3.2.3). Finally, concluding remarks are given (Section 4) in order to discuss the 3D models and the visualization tools directly used by archaeologist to analyze the site and the 3D data from the surveys of the excavation. Therefore, the objectives of this work are to use 3D data to create maps and sections that provide information useful for archaeological excavation purposes such as the investigation of construction phases and to draw broader conclusions about the applicability of photogrammetry and laser scanning for documenting and analyzing ancient walls within a particular set of environmental circumstances.

2. HISTORICAL BACKGROUND

The Mycenaean sanctuary of Amykles extends in a north-west direction of a hill about 5 km south of Sparta, where during the archaic and later times the sanctuary of Hyacinthus and Amykles Apollo was constructed (Fig. 1). The first traveler who recognised the existence of the sanctuary of the Amykles Apollo was the French archaeologist Charles Lenormant, a member of the French scientific mission of Morea, who passed through the area in 1829. During the period 1830-1850, Wilhelm Leake identified the low hill where the sanctuary of Apollo once stood. It is considered that the sacred site of Amykles is the first organized sacred site in Greece. In 1878 the German archaeologist Furtwangler recognized that the nearby church-built architectural members were pieces of the throne once belonged to the sanctuary.

The first excavator of the sanctuary was the Greek archaeologist Christos Tsountas, where during the chronological period 1889-1890, the greatest part of the sanctuary's enclosure and the foundations of the circular altar were revealed and attributed to the throne of Apollo. In 1904, an investigation by Furtwaengler and Ernst Fiechter followed, which identified the real ruins of the throne. In 1925 the excavation of Ernst Buschor and Massow followed. The remaining archaeological evidence from the site includes the retaining walls, circuit walls, evidence of foundations dating to various periods, and a circular altar. The retaining walls around the sanctuary were made of local conglomerate stone, and are architecturally designed to work with the steep slopes of the hill. The precinct indicates that there have been extensions and repairs made to it, as well as general measures of maintenance carried out during the Roman and Byzantine periods. Found at the site is also archaeological evidence of the Throne of Apollo Amyklaios.

Fig. 1. The sanctuary of Amykles Apollo, Greece

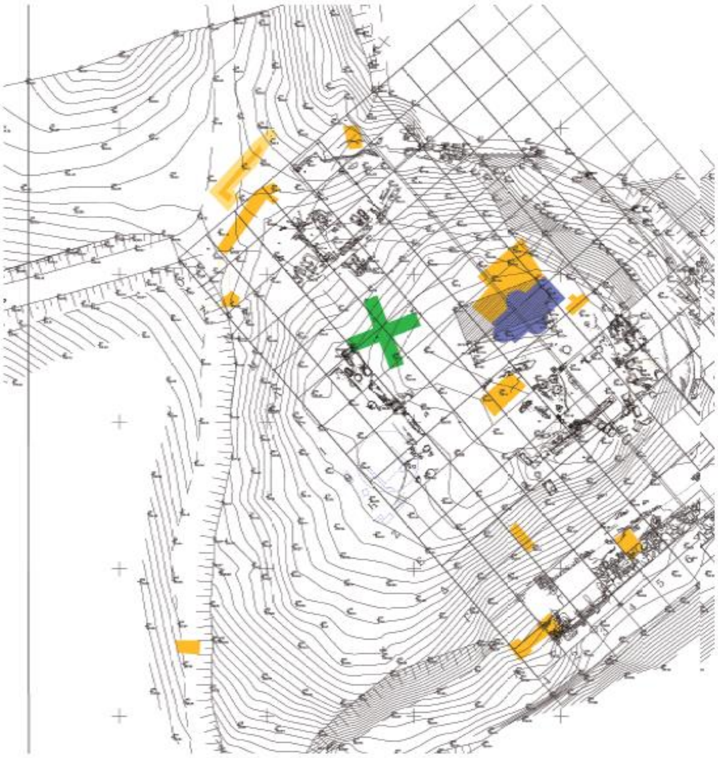


Fig. 2. Plan of the Amykles sanctuary as in 2010 (after Vlizos, 2011)

Fig. 3. Architectural members of the sanctuary

In the period 2005-2010 the excavations were continued by a scientific team headed by Angelos Delivorrias under the supervision of Stavros Vlizos. Based on the above excavations of the archaeologists, the overall topographic plan up to 2010 is shown in Fig. 2. The excavation work extends up to the summer of 2017 and involved the collection, recording, documentation and depiction of the scattered architectural members of the ancient temple, the partial restoration of the throne and altar of the sanctuary, the further investigation of the outer and inner encirclement of the sanctuary (Fig. 3). Functional objects and votive offerings were also found covering chronologically throughout the period of use of space from antiquity to modern times (http://amykles-research-project-en.wikidot.com/reports).

3. GEODETIC DATA COLLECTION AND PROCESSING

3.1 Data Collection

The starting point of the work in the site of Amykles was the collection of both photogrammetric and laser scanner data of the site. First, a survey was made with a total station Leica 202+ and GNSS receivers (Javad Triumph-1) using static and RTK surveying to acquire ground control points to geo-reference and bring the two models into a common reference system. Second, a laser scanner survey was made on the entire site. Third, image data were collected using an Un-manned Aerial Vehicle (UAV) survey for the entire site that would be enhance the 3D modeling purposes.

To collect range data, a Leica Scanstation 2 laser scanner was used (Fig. 4). Based on TOF measuring principle, this scanner allows a wide field of view (360° H x 320° V) and the acquisition of max of 1 million points per second with millimetric resolution and accuracy. In total, 13 scans in 2015 and 25 in 2017 were acquired, resulting in a dataset of ca. 100 million points. The first scans, captured an external perspective of the site, and the remaining scans captured data inside the site in order to acquire more details of the structures, and collected data with an average sampling distance of 4-25m. These values were chosen as an acceptable compromise between level of detail of the final 3D model and computing resources needed for data processing. The laser scanner data will be used for the creation of archaeological sections of the site and the 3D model.

Fig. 4. TLS data collection at Amykleon site and sample point cloud

Fig. 5. Example images from the UAV survey

The UAV survey was performed with a Quadcopter comprising a compact camera mounted onboard. The image resolution was set at 3648 x 2736 pixels, and about 20 images were acquired (Fig. 5). The UAV did not have any GNSS or INS on-board and it was manually piloted leading to a flight altitude variable between 15 and 25 m. The aim of the UAV data is to create an overview orthoimage of the site and produce and up-to-date map of the site.

3.2 Data Processing

3.2.1 Registration

The TLS captures several millions of points, making it necessary to process them using specialized software programs. In total, 13 different scans were collected and were processed using initially the proprietary software suite Cyclone. The registration of the clouds into a common coordinate system (i.e. the projection of the Greek reference datum EGSA87) was performed in Cyclone by the registration procedure.

For the implementation of the initial stage of registration, the procedure followed was based on the selection of a pair of sequential scans, which are in the same reference system, and specifically in EGSA87. In practice, the individual scans were merged partially and the individual sections at the end of each other. Therefore, when the registration was established between the selected scans, two ScanWorlds were added to join (from Menu-ScanWorld-Add ScanWorld). Then the commands “Cloud Constraint-Add Cloud Constraint” are used and in order to optimize the alignment between the clouds, the command “Cloud Constraint-Optimize Cloud Alignment” is used. It should be noted that this method is based on the knon ICP algorithm, which merges successively clouds, computing each time the similarity transformation parameters without the scale. Thus, with the iterative process, the new parameters are calculated each time. For the execution of the algorithm, in “Menu-Cloud Constraint-Edit Parametres” the number of repetitions as set equal to 150 and the percentage of points to be used was set equal to 60% of the overlapping portion. The process stops when it is checked that the average square error satisfies the precision criteria that have been defined and the program has declared that the georeference is successful. It is worth noting that the algorithm improves the final precision, which was maintained in all scans, and was less than 1cm.

Following the point cloud registration, the georeference of the stations belonging to an independent reference system was performed. The stations in each scan should exhibit a degree of overlap between the scans, so that their association with the model is performed using homologous points. The homologous points in the overlapping area must be evenly distributed (non-coherent) covering the whole surface to ensure the best possible accuracy. Specifically, the solution requires the parameters of a transformation (3 turns and 3 shifts). Therefore, it is necessary to select at least three homologous points. In practice, however, a number of selected 4-5 points is considered more appropriate. Finding these points is more difficult compared to the corresponding process in digital images because the color of the clouds is of low quality as well as the localization of characteristic points. The error of the homologous points between the scans is desirable to be less than 1cm. It is worth mentioning that the accuracy registration of individual scans is distributed to all other stages of the process, thus affecting the accuracy of the final product. The following table (Table 1) shows the individual errors of the scans. Based on the results shown below, it can be seen that the accuracy of the final registration is better compared to the merging of the original clouds. This is because the final scans exhibit the greatest overlap with the most tie points.

Scans	RMS(m)
S_1-S_2	0.01
S_1-S_2-S_7	0.01
S_1-S_2-S_7-S_8-S_3	0.014
S_1-S_2-S_7-S_8-S_3-S_4	0.014
S_1-S_2-S_7-S_8-S_3-S_4-S_5	0.017
S_1-S_2-S_7-S_8-S_3-S_4-S_5-S_6	0.019
S_1-S_2-S_7-S_8-S_3-S_4-S_5-S_6-S_9	0.016
S_{10}-S_{11}	0.011
S_{10}-S_{11}-S_{13}	0.010
S_{10}-S_{11}-S_{13}-S_{14}	0.015
S_1-S_2-S_7-S_8-S_3-S_4-S_5-S_6-S_9-S_{1L}	0.009
S_{10}-S_{11}-S_{13}-S_{14}-S_{14L}	0.008
S_1-S_2-S_7-S_8-S_3-S_4-S_5-S_6-S_9-S_{1L}-S_{3L}	0.010
S_1-S_2-S_7-S_8-S_3-S_4-S_5-S_6-S_9-S_{1L} -S_{3L}-S_{4L}	0.010
S_1-S_2-S_7-S_8-S_3-S_4-S_5-S_6-S_9-S_{1L} -S_{3L} -S_{4L}-S_{7L}	0.008

Table 1. Registration errors between scans

3.2.2 Sections

After the necessary cloud processing in Cyclone was completed, the registered cloud was exported to AutoCAD. In order to do this, sections are cut from in the form of a slice (Slice) having a range defined by the user. Depending on the needs of the geometric documentation, it is important to choose every time the borders of the sections. For the needs of this project, the sections were cut at the top of the stones so that each stone is digitized separately (Fig. 6). To ensure optimum precision, the defined “Slice” was selected as thin as possible. At the same time, in those areas where there were occlusions, the digitization of the stones was realized through drone images. A similar procedure was followed for the production of appropriate sections to create the final drawings of the monument. Thus, it is possible to view the details of the archaeological site. Specifically, two longitudinal and two transversal sections of the merged cloud were produced, orienting north-south and east-west, respectively. The scale of drawings in all cases is 1:50. The following illustrations are examples of the above procedure.

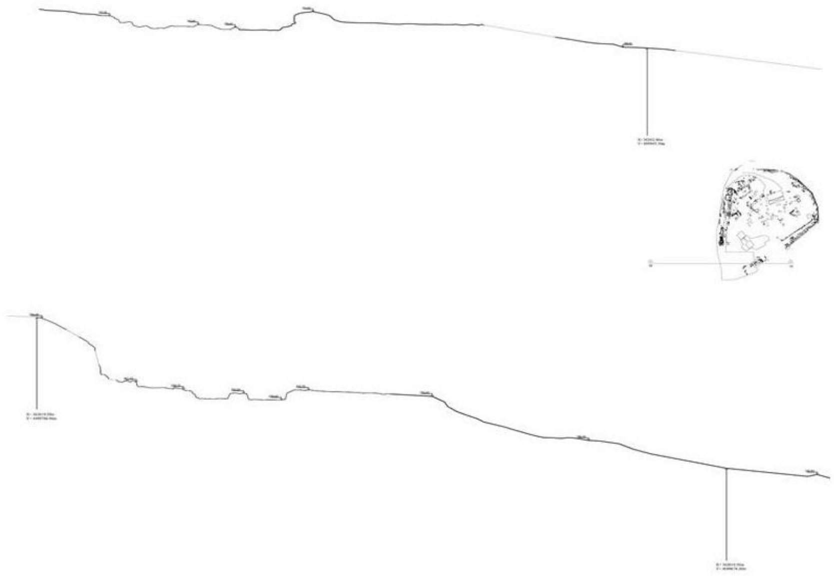


Fig. 6. Example images of sections

3.2.3 Modelling

The 3D surface modelling of the scanned archaeological site was performed using the Geomagic software. The created model is considered to be a continuous mathematical surface, depicting physical and artificial objects of space, in which measurement capabilities are provided in three dimensions. Initially, the process of removing noise, closing the holes and triangulation of the merged cloud points must first take place. It is worth noting that the software cannot handle large numbers of digits in the coordinates, which is the case in the projection coordinate values of EGSA87. In order to allow for the joining of surface models, it was necessary to deduct two digits by X and three Y digits in the coordinate values.

As a first step, from the Cyclone program the area of interest is selected (Fence-Copy Fenced to New ModelSpace) and this is export in .pts file format. By inserting this file into Geomagic Studio (vs 2013), the geometry of the object is visualized and the color of Point Cloud is enhanced through the “Shading-Shade Points” command.

Subsequently, removing the unnecessary information, i.e. points that are not useful for modeling the surface of interest, the polygonal model is created. By removing the elements that are not necessary for the performance of the object and the noise elements, the size of the initial cloud point can be reduced to a significant extent relative to the original one. After removing the noise, the “Flip Normals” of the object part must be reversed in order to match the internal and external side of the model. At the same time, there is a lack of modeling, as in some places the object is occluded causing holes in parts. To correct these, a series of processes are performed by the “Menu-Fill Holes”. In particular, to fill the voids on relatively flat surfaces, the “Fill Single” command as used by choosing the “Flat-Complete” parameters. Additionally, to accommodate the larger gaps the same command was selected by activating the “Tangent-Complete” parameters, as they present deformation deformations. Continuing, through the “Mesh Doctor”, a cloud of points is converted to a continuous surface by triangles. An important advantage of using polygonal meshes is the significant reduction in the volume of data required to describe the 3D geometry. It is worth noting that the density of the Mesh depends on the complexity of the surface. This method is mainly applied to objects that are irregular in shape and cannot approach geometric surfaces such as architectural objects and historical monuments. The method “Decimate” is the most effective way to create triangles between pairs of points. The vector data model of the grid has three key elements: the nodes (with X, Y, Z coordinates), the lines (connecting the nodes to the triangles) and the triangles forming the continuous surface. Examples of the 3D model are given in Fig. 7.

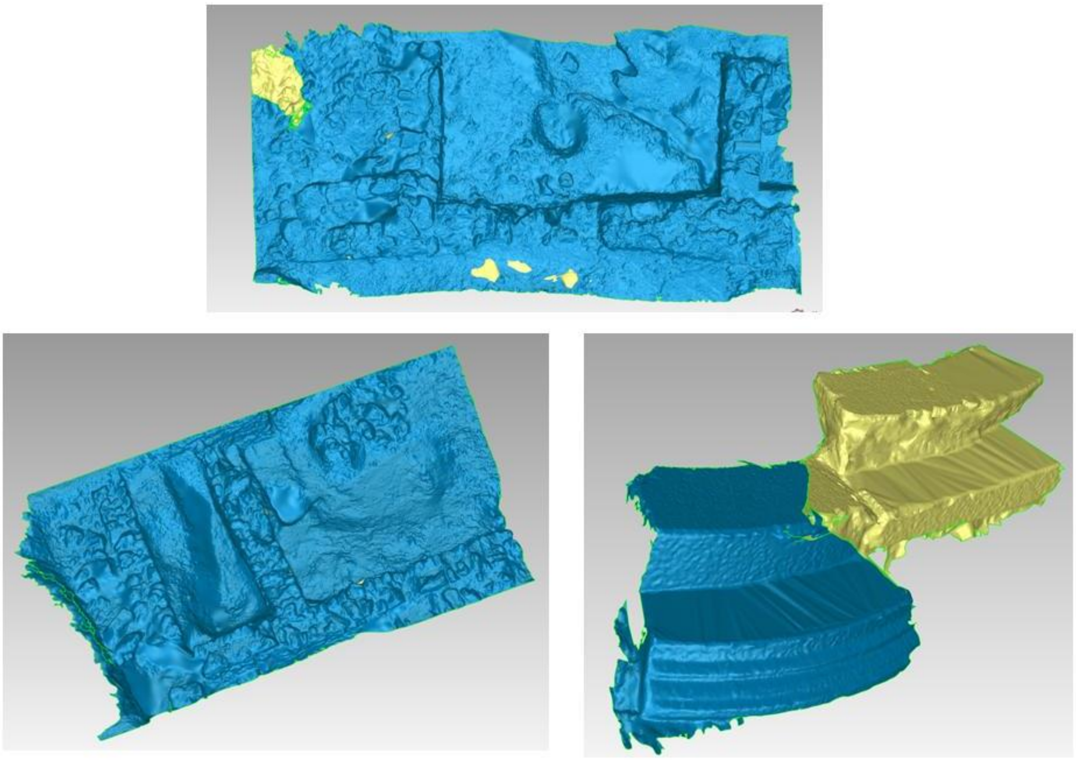
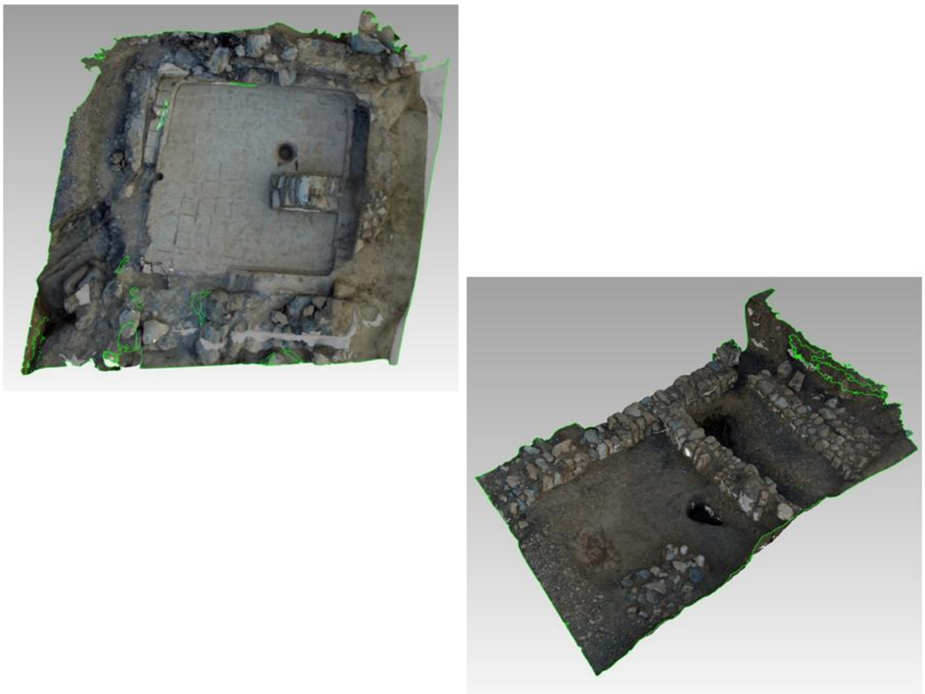
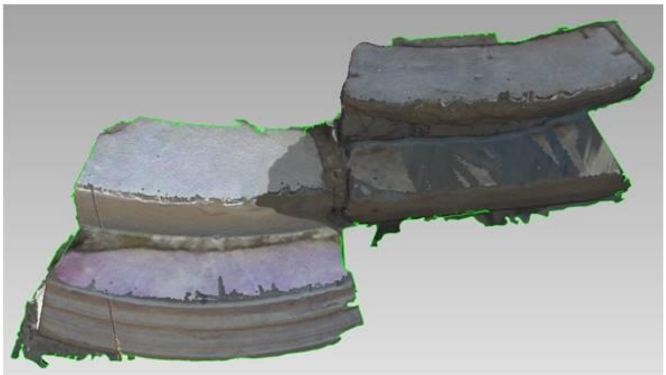


Fig. 7. Examples of the 3D surface model

Having the information of points with X, Y, Z coordinates as well as the lines in which there is a sudden surface change, the software takes into account the above data as well as other parameters and creates an optimal network of triangles. The ability to combine two-dimensional and three-dimensional information is extremely important in places of cultural interest. Thus, the polygonal mesh is a more realistic rendering of the object when texture mapping is applied on it. To apply this command, the homologous points from the “Tools-Texture Maps-Project” are selected and then “Texture Maps-Generate Texture Maps” is applied. Then, by selecting ”Register”, the transformation of the image is made so that it is inserted into the surface model. Upon completion of the processes, the final 3D textured surface model was produced which is an orthoimage. Typical examples of the generated orthoimages are given in Fig. 8a, b.



(a)



(b)

Fig. 8. Examples of generated orthoimages (a) from site (b) architectural details

4. CONCLUDING REMARKS

Archaeological investigations require 3D models such as orthoimages, detailed site maps, sections for ancient walls, and segmented high-resolution 3D models in order to derive metric data that are useful for analyses that may include construction techniques, sequences, restorations, etc. Textured 3D models of archaeological sites are also useful for visualization purposes to engage the public and assist archaeologists in historic interpretations.

The use of geodetic techniques offers the necessary accuracy and detailed information to produce the above metric products. In this work, a combination of TLS and images has been used. TLS is a well established method, straightforward in data acquisition bur requires time and experience for the data processing. To obtain different geometric levels of detail and achieve more accurate and complete geometric surveying for modelling it is almost necessary to use additionally other types of data.

This work highlighted how the use of 3D data in monitoring and documenting an archaeological excavation site radically increases the perception of the site and its evolution.

The availability of a time-dense representation of the evolution of the excavation as a series of georeferenced 3D models, aids in the interpretation of the site. Moreover, the typical documentation material (notes, images, sketches, plans) can be easily integrated with the 3D models in a spatial archaeological database to enrich the analysis experience. This is an on-going task with the specific archaeological site and future work will concentrate on the development of this database.

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