



Terrestrial Laser Scanning Coupled with UAVs Technologies: The Case of Old Navarino Castle in Pylos, Greece

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Abstract. The archaeological site of Palaiokastro (Old Navarino castle), is located in Messenia on Koryfasio peninsula, at the southern end of the beach of Voidokoilia in the-Navarino Bay, SW Peloponnese. Palaiokastro was built during Frankish rule of the Peloponnese, in the 13th century, over the classical Acropolis of Pylos. The Castle as seen today is a result of additions made by other conquerors, such as the Venetians from 1423 to 1500 and the Ottomans from 1500 to 1686 [14].

The aim of this study is to present the methodology, challenges and outcomes of digital documentation in the remaining of the Palaiokastro castle using a combination of innovative technologies including terrestrial laser scanner (TLS) and aerial photogrammetry using unmanned aerial vehicles (UAVs). TLS and UAV photogrammetry were applied in an integrated design to rapidly facilitate the acquisition of the Main South gate, eliminating all possible obstacles. The TLS was exploited for the acquisition of the facades while the UAV was used to capture the top view of the castle gate. The recent improvement of the post-processing algorithms provides us with the ability to implement fusion methods of TLS and UAV models and also deliver an accurate 3D model of the whole gate.

The combination of photogrammetry from the UAV with the data of the terrestrial laser scanner was used in order to give us a multitude of products such as textured 3D model, orthophotos, 2D floor plans, elevations and sections which are necessary for the complete and accurate geometric documentation of the current situation of the Southwest gate of Palaiokastro in order to identify different construction phases.

Keywords: Terrestrial Lase Scanner · Point cloud · Pylos · Construction phases

1 Introduction

1.1 Historical Information

In the south west region of the Peloponnese Greece, the coastal area along the Ionian Sea surrounding the Bay of Navarino has been traditionally identified as the land that is described in Homer's Iliad and Odyssey as the land of the mythical king Nestor [4].

Situated over the ridge of the Koryfasio hill at the northern end of Voidokoilia beach in the Navarino Bay is the fortification of the Medieval Castle known as Old Navarino. The Castle was constructed by the Franks during the 13th century (ADE1282/1289) over the remains of the classical fortification of Pylos. H. Schlieman in 1874 was the first for searching for Nestor's Pylos with no results (E. Schliemann, 1874). The 1970s the University of Minnesota under the program of the University of Minnesota Messenia Expedition (UMME) and in early 1990s the University of Cincinnati under the program Pylos Regional Archaeological Project (P.R.A.P.) (Fig. 1).



Fig. 1. Palaiokastro, Old Navarino (Google Earth)

The Navarino area according to archaeological findings was inhabited from the Neolithic to the Late Byzantine period (4500 BC-1453AD). Neolithic evidences (4500 – 3100BC) were found in the Cave of Nestor located on the north-east side of Koryfasio peninsula [17, 18] as well as on the northern arm of Voidokoilia Bay where the Tholos Tomb of Thrasymedes, (son of the mythical King Nestor) was built upon the Early and Middle Helladic settlement [15]. The Voidokoilia bay most probably was the palace harbor for the Mycenaean ships. The human activity decreased significantly but never disappeared in the periods followed the collapse of the Mycenaean Palace of Ano Englianos under whose rule the whole area operated.[16].

During the late geometric period a new began with the Spartan rule over Messenia which continued until the establishment of the city of Messene (mid7th century BC – 369BC). During Spartan occupation Pylos occupied the Koryfasio peninsula, now dominated by the Frankish castle [16, 19].

Pylos gained its independence in 365BC and included in the territory of free Messenia (369BC). The city flourished during the Hellenistic and Roman period according to the numerous findings from the extended cemetery excavated along the sandbar that separates the Navarino bay from the Yalova lagoon and minted even its own coinage (ΠΥΛΙΩΝ AD 193-211) [12, 13].

The lack of significant findings in the area that can relate to the Byzantine period point to possible population movement towards the inland perhaps to avoid pirate attacks which was common during the period.

In the early 13th century, the Franks conquered and maintained rule over the Peloponnese peninsula (AD 1205 – 1453). Throughout Moreas, as the region was named by the western conquerors, citadel fortresses were built at strategic places in order to control the territory and the Castle of Navarino was one of them. The Palaiokastro was constructed over the remains of the classical Acropolis of Pylos. The medieval castle named ‘Port de Junch’ was built in 1282/1289 by the Flemish crusader Nicholas II of Saintomer and became one of the most important fortresses during the Frankish rule in the Morea. The castle was attacked on many occasions and changed a number of rulers – due to the strategic importance of its position. It underwent numerous significant structural interventions, modifications of uses and architectural changes, by the different conquerors, which altered its original physiognomy [1, 11, 21].

In the period of the first Venetian rule (1423–1500), during which the construction of the southern enclosure of the castle is attributed, walls were built only on the west and south sides. The east side facing the cliff is naturally fortified. The fortress consists of two enclosures, a smaller polygonal to the north and a larger quadrilateral to the south. The walls of the castle in their largest part are vertical and have been preserved up to the ramparts while they are interrupted by semicircular and rectangular towers (Fig. 2). The central gate on the south side of the castle as well as most of the semi-circular towers that reinforced the earlier walls have structural and morphological features such as the use of plinths and Islamic arches that can be attributed to the first Ottoman period (1500–1686) [1, 11, 22].



Fig. 2. The NW view of the fortification of Old Navarino (https://www.efames.gr/first_gr.html).

During this first Ottoman period a second fortress was built on the southern arm of the Navarino bay, Niokastro (new castle). Following Morozini’s successful campaign against the Peloponnese the Palaiokastro fortress was surrendered to the Venetians and

the Niokastro became of the four capitals of the Venetian Peloponnese during the second Venetian period (1686–1715). In 1715 the Ottomans reacquired the region and maintained their rule until the naval battle of Navarino, 1827 that determined the outcome of the Greek Revolution (Fig. 3) [1].



Fig. 3. Picture of New Navarino and Old Navarino proximity (Google Earth)

The several conquests of the fortress, are reflected in the interventions and additions to the initial erection. The Castle's layout of trapezoid shape includes two fortified enclosures, separated by a transverse wall which communicate with each other via a stone-paved path. It is considered that the inner enclosure, which covered the highest point of the northern part of the fortress, is located on the borders of the ancient acropolis and the Frankish castle of the 13th century, while the outer enclosure is the work of the Venetians of the 15th century and the Ottomans after the conquest of 1500 [11].

The Central South Gate of the Castle

The central South gate of the castle with its pointed arched roof is located on the ground floor of a rectangular tower that consists of a ground floor and the roof. The interior of the gate consists of a semi-cylindrical brick dome, which has been covered with brick, while traces of a retractable door are preserved from an earlier building phase. It was protected by a barricade, located on the south side of the enclosure. Access to this main entrance was served by a path, starting from the southernmost point of the Koryfasio peninsula. The fortress was built with mudstones and limestones, while partly use of bricks is seen after the 16th century. Internally preserved ruins of the buildings of the

settlement have been identified in the Governor's quarters, houses, churches, wells, as well as large cisterns.

Three main building phases can be distinguished in the architectural structure of the fortification. The initial Frankish construction phase seems to use the engraving and the remains of the ancient fortification in several places. During the period of the Venetian occupation, the walls were repaired to adapt to the requirements of the new fortifications and a type of early cannon portholes were used with a circular opening on the outer side of the wall and a channel-like plan with a widening towards the inner side. At the same time, the enclosures are strengthened by the creation of a new zone of ramparts, which are rectangular with a dovetail ending. The Ottoman period which followed included extensive strengthening projects to the fortification such as raising the walls, construction of the central gate of the southern enclosure and the construction of two small semi-circular towers for cannons [16].

2 Methodology

The aim of this study is the documentation of the current situation of the medieval castle of Palaiokastros and initially the structural documentation of the South Gate applying innovative technology including terrestrial laser scanning (TLS) and aerial photogrammetry using unmanned aerial vehicles (UAVs). TLS and UAV photogrammetry has been used in an integrated design to rapidly facilitate the acquisition of the whole gate, eliminating all possible occlusions.

Initially a UAV was used to obtain the high-precision photos of the entire area of the Castle and its surrounding. The aerial pictures are processed using specialized photogrammetry software in order to produce a high resolution georeferenced basemap which in turn is used for planning the TLS scans (Fig. 4) [2, 20].

Following the aerial survey field inspection, the optimal route of the occupation points (OP) for the laser scanner were determined. Scan points were planned along a traverse path by setting the point from which to perform the scan ("Occupation point" or "OCC point") and from which to measure the previous scan point ("Backsight point" or "BS point"). In this way, each scan is automatically registered with the previous and the next one, in an operator-defined reference system, even without large overlapping areas. This is an important requirement for a site with many barriers and complex structures and in cases where standard approaches (scans with high percentages of overlap) are difficult to use. Optimal scan positions are selected by criterion of minimizing the number of scans while at the same time achieving maximum coverage and accuracy. Each OCC point was measured during the routing procedure in order to overcome logistical difficulties using the GR5 GNSS GPS by Topcon. The GR5 receiver uses Real Time Kinematic (RTK) method ensuring optimal accuracy of the geodetic measurements. The GPS receiver with absolute positioning moves along a path to the specific scan positions and directly calculates the coordinates (X, Y, Z) of each point. The GLS-2200 allows users to import scanner station coordinates before starting the process of scanning. Thus, each scan has known coordinates in the predefined reference system.

A total of 8 scan stations were placed on the perimeter of the castle surrounding the gate and inside the gate (Fig. 5). All scans acquired with the Topcon GLS2200 were



Fig. 4. Study areas orthophoto

carried out with a full dome field of views (360° in horizontal direction and 270° in vertical direction) and an average sampling step of 6 mm at 10m. Each scan lasted 10 min and the highest scan density was selected. Before starting each scan, high-resolution color panoramic (360°) photos were captured by TLS producing a colored point cloud with real RGB values [5].

The scans were transferred from the TLS to a computer and processed using Magnet Collage software to register and integrate the data of the generated point cloud files, so as to compose the integrated 3D model of the Old Navarino Gate. Magnet Collage is a software compatible with the GLS2200 scanner which enables users to process and manage the raw data of the scanner with automated procedures, such as the registration of already georeferenced point clouds, the possibility of removing unnecessary information (noise) and the data export in different formats, etc. As shown in Fig. 6, the overall workflow consists of the acquisition of the point cloud data on the Paliokastro Gate using terrestrial laser scanning and the 3D modeling process.

The TLS survey of the Old Navarino Gate was carried out to document current situation of the whole Gate and the surrounding area. The TLS survey was carefully planned, taking into account several factors that characterize the morphology of the archaeological area [10].

The reference system used throughout the survey is the Greek Geodetic Reference System EGSA'87 carried out entering the three-dimensional coordinates of the scan positions. In this way, each cloud of points that is created, has its real coordinates from the beginning. All scans acquired along the traverse were automatically registered and a

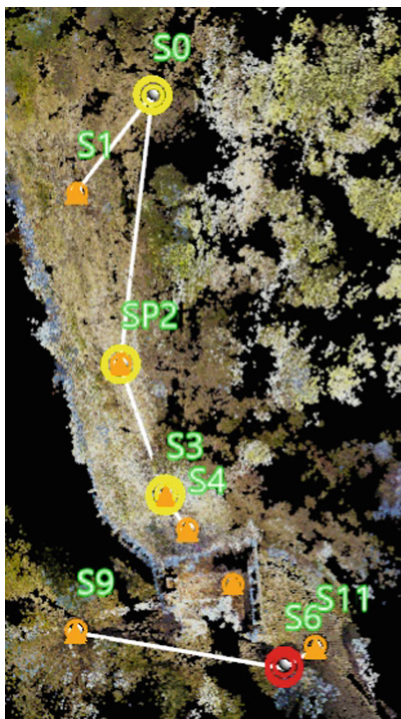


Fig. 5. The scheme of scan points inside and outside of Palaiokastro Gate

reference point cloud for the Gate about 13,500,000 points was achieved. Single GLS-2200 scans were also imported in Magnet Collage and registered with a cloud-to-cloud approach with the reference point cloud. The accuracy of the registration was verified on the scans points coordinates RMSE. Values are of about a few millimeters for east and north coordinates [3].

It is worth noting that the results and therefore the accuracy of the merging of the “singles” point clouds largely depend on the overlap percentage of the point clouds with each other, on the number and geometry of the homologous points. During the scanning process, all distances between the scanner and the object did not exceed 110 m, i.e. they are within the limits where the laser beam of the scanner has the minimum diameter to achieve the best possible accuracy. The 3D point cloud has its color information, enriching the scan data with the image from the camera that the laser scanner itself has taken. As a result of this process 2D drawings of sections and elevations were produced.

The aspect examined in this paper was the construction phases in Palaiokastro Gate. The study of historical sources as well as careful observation of the monument helped us to identify the historical phases of the monument. The different building phases of the gate, which obviously contain different materials and a different way of building, are presented with corresponding plans of views, sections of their representation.

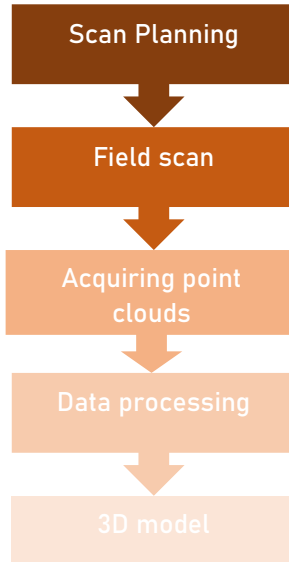


Fig. 6. Workflow of integrated 3D modeling using terrestrial laser scanning (TLS)

Zias and Kontogiannis (2004) give a description of the construction phases of the specific monument and specifically for the central south gate of the castle. Two construction phases are mentioned, which are chronologically placed as follows: A Construction Phase-Venetian (1423–1500), B Construction Phase – Ottomans (1500–1686).

The 3D Laser scanner is a very important tool for documentation cultural heritage due to its accuracy, speed and flexibility. It was used for the geometrical and visual documentation of the existing state of the gate.

The creation of a three-dimensional point cloud, which resulted from the merging of the individual clouds, provide us the geometric and color information of the object to be captured. The aligned point cloud is a three-dimensional representation that can be used to generate traditional two-dimensional drawings or orthoimages. The higher the density and resolution of point clouds, the greater the accuracy and detail orthoimages can provide [8].

Pointcab software was used for the 3D documentation of the Gate, due to its capability to create orthophotos from the 3D point cloud. Taking advantage of the software's ability to create orthophotos of views and sections of the 3D point cloud, we respectively orient the axis parallel to the side we want, creating the appropriate views and sections. The images below show details (snippets) of parts of the 3D model, untextured and textured (Fig. 7) [7].

The observation of the arch's morphological elements of the inner building layer of the southern gate suggest that gate reinforcement works were done at the ottoman period. New masonry was added to the interior chamber of the gate that was covered by a barrel vault made completely out of brick. This masonry layer had niches and a small rectangular guard post inscribed in the walls, a reinforcement of the south door's frame with successive recessed arches (Fig. 8) [9].

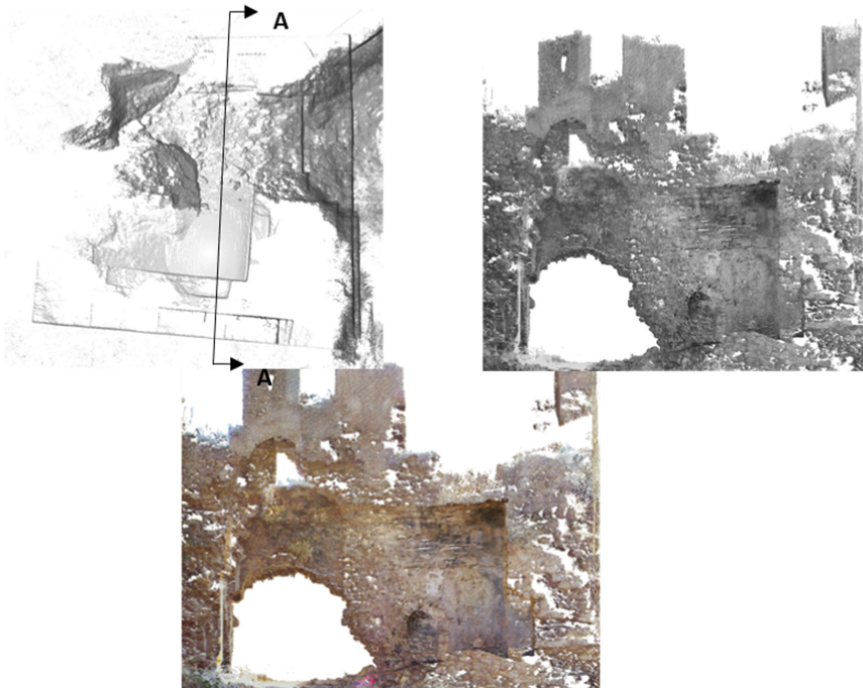


Fig. 7. Point cloud cross section (A-A) of the Gate



Fig. 8. Orthophoto from point cloud viewing the cross-section A-A with visibility to the interior of the Gate, including the Ottoman period construction phases (orange)

These facades are useful because it is possible in this way to control the preservation of the walls, to identify the different construction phases in order to create a phase map.

All these data are important tools for the protection of the site and for future intervention of conservation.

3 Conclusions

TLS technology is the fastest data acquisition technology for large scale and complex (archaeological) environments. At the same time, the necessity to entirely record archaeological sites, with spatial and shape complexity, device optical limitation and spatial constraints, requires multiple scans to completely acquire the scene of interest slowing down both the acquisition and postprocessing phase. In addition to the requirement for a complete documentation, some logistical issues, related to the site, have to be overcome, such as the irregular shapes and the narrow spaces of the archaeological complex, the insufficient environment lighting, the orientation and registration of single scans inside the Gate [6]. The technical issues created by the landscape and the site condition are confronted uniformly as part of the methodology of the project.

In this study, a 3D model and the associated digital documentation of the Old Navarino Castle Gate was established by using terrestrial laser scanning. The precise determination of the coordinates was ensured by using GPS and the RTK method. RTK GPS positioning provides high accuracy without the need for establishing local GPS control networks, thus reducing the time, and man power, required to provide positional control.

The use of the 3D model gave the possibility to examine the existing condition of the Gate from every necessary angle and focus in specific areas of interest. The removal of the texture layer provided the opportunity to examine a clearer model by showing only geometric data and focusing on the immediate relation of the monument and the surrounding landscape.

Terrestrial laser scanner survey produced very accurate geometrical data. The Magnet Collage software was used for processing the total datasets in order to integrate all scans. A complete 3D model of the whole Gate was achieved (Fig. 9). Using the coordinates of topographic points, the final 3D model was georeferenced.

The paper presents the results of the TLS survey carried out to document the remains of the archaeological site of Old Navarino Gate, known as Palaiokastro, which is located in Messenia Greece. This project is part of an overall attempt to digitally recreate the Old Navarino Castle in Koryfasio, the first digital surveying approach for the specific monument using TLS and aerial photogrammetry. The methodology highlights the application of new technologies in acquiring structural data in remote areas, here for the South Gate of the monument. Aerial photogrammetry assisted in planning the TLS survey of the surrounding area of interest. Using a topographic approach for scan registration; the scan acquisition process was optimized.

The produced 3D model can be used further creating a multitude of products such as orthophotos, 2D floor plans, elevations and sections which are necessary for the complete and accurate geometric documentation of the current situation of the Southwest gate of Palaiokastro.



Fig. 9. The exterior east side of Palaiokastro Gate, registered point cloud from Magnet Collage.

The significance of our study, it the fact that textured 3D models of archaeological sites are necessary tools for visualization, assisting archaeologists in identifying structural phases, construction techniques, sequences, restorations, etc. Additionally, in order to carry out further investigations of the site for conservation and preservation policies.

Acknowledgements. This project was implemented within the scope of the “Exceptional Laboratory Practices in Cultural Heritage: Upgrading Infrastructure and Extending Research Perspectives of the Laboratory of Archaeometry”, a co-financed by Greece and the European Union project under the auspices of the program “Competitiveness, Entrepreneurship and Innovation” NSRF 2014–2020.

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