

PAPER • OPEN ACCESS

3D Integrated Survey for the Study of Archaeological Sites: the Case Study of Euryalus Castle in Siracusa

To cite this article: R Valenti and E Paternò 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **767** 012015

View the [article online](#) for updates and enhancements.



ECS The Electrochemical Society
Advancing solid state & electrochemical science & technology

239th ECS Meeting with IMCS18

DIGITAL MEETING • May 30-June 3, 2021

Live events daily • Free to register

Register now!

3D Integrated Survey for the Study of Archaeological Sites: the Case Study of Euryalus Castle in Siracusa

R Valenti¹, E Paternò¹

¹ Special Educational Structure of Architecture, DICAR, University of Catania, Syracuse, Italy

ritam.valenti@gmail.com, patermanu@hotmail.it

Abstract. The present article deals with the results of a recent study conducted by the Laboratory of Representation at the University of Catania regarding the 3D modelling process of the archaeological site of Euryalus Castle in Siracusa. The purpose of the research was to discuss the survey methods implemented in the archaeological field, considering each methodology as a singular or as a multi-sensor approach. Digital integrated survey (range-based and image-based methods) and, in particular, the UAS system (Unmanned Aerial System) reduce the problems connected with the survey of complex or large objects and increase capability exposure thanks to the high quality of 3D photorealistic technology. The traditional survey systems applied to the area around Siracusa and to the archaeological site have been integrated, in the present case study, with UAV (Unmanned Aerial Vehicle) photogrammetric survey for the acquisition of nadir and oblique imagery. The research shows that modern survey technology contributes to the digital 3D monitoring and documentation of cultural heritage.

1. Introduction

1.1. Motivation and aim

The protection of archaeological heritage should be made the subject of a widespread environmental knowledge especially of all those works of art and nature which have contributed to shape the geomorphological aspect of landscape and which, for their importance, represent the socio-political events and the reasons that determined them. Archaeological remains, often in the form of ruins, have increased their value in the course of time. Their original value implies the recognition that their value is intrinsic to their specific impact on the topos. Undoubtedly, the lack of resources greatly affects the management and strategic planning of restoration interventions on cultural heritage. In view of a sustainable development of these areas where archaeology and landscape become a single thing, the aim of research is that of facing ethical issues of great complexity focusing on the implementation of innovative technology to protect cultural heritage and enhance visitors' experience. The 3D processing of the archaeological investigated site is necessary to give shape, dimension, physical consistency and colour to archaeology contributing to its promotion for future generations and preservation of collective memory. The main purpose of the present research is to provide a 3D digital documentation of archaeological remains in situ for their virtual reconstruction. A significant development is represented by advances in survey technology. 3D modelling has definitely become a methodological approach for the understanding, analysis and interpretation of structures. In particular, modern



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

surveying technologies offered by Geomatics are efficiently employed during the data acquisition phase of survey operations. Actually, in archaeological survey, too, considerable work has been undertaken on the adaptations of existing instruments to specific and consolidated methods for documentation. It is necessary, then, to develop strategies of investigation appropriate to the statutory teaching programme in surveying, able to combine knowledge and dissemination.

In particular, the research conducted by the Laboratory of Representation at the University of Catania deals with the archaeological site known as Euryalus Castle, located around the area of Siracusa, a big town in Sicily. (Figure 1)



Figure 1. The archaeological site of Euryalus Castle.

The architectural artefact represents a real historical and geographical context structured according to an architectural and geographical dimension from the spatial point of view and, according to a historical dimension from a temporal point of view. A witness of the signs impressed in the place by the events occurred in the course of more than two thousand years. The majesty of such archaeological context implies a dynamic and explorative attitude towards knowledge in order to fully grasp the fortifications and the fortress known as Euryalus Castle: converging point of northern and southern lines of the corresponding system of the castle towers built by the tyrant Dyonisius between 402 and 397 b.C.. The complex structure presents some lower and higher elevations, partly visible from the ground, along the Castle towers. In some points, especially along the eastern side of the third moat, it develops in a network of corridors dug in the rock.

The intention of translating these concepts into a living heritage supported by 3D documentation led to a collaboration between the Laboratory of Representation and the Parco Archeologico in Siracusa which authorized survey activities giving full support in the campaign.

1.2. Related works

The implementation of advanced technology in the field of architectural and archaeological survey for 3D image processing of cultural objects has become a consolidated practice in scientific literature. The selection of the appropriate methodological approach is based on different criteria such as the dimensions of the analysed object, its morphological characteristics, the final purpose, the budget for the research program, the administrative support for the development of the project, the available time, the local regulations concerning airspace restrictions. More specifically, over the last ten years, the consolidated 3D data acquisition system with laser scanning technology (TLS) has been supported and, in some cases, even surpassed by aerial and terrestrial photogrammetry, especially with the introduction of SfM (Structure from Motion) which is automatically able to achieve good results with the reduction on digital data acquisition and processing time. In particular, photogrammetry based on Unmanned Aerial System (UAS) allows rapid and accurate mapping of cultural heritage.

Flight planning and the combination of nadir and oblique photogrammetry enlarges the application field from the local scale to the architectural and archaeological one. Such non-invasive methodology

reveals to be very effective especially in the archaeological field. It reduces acquisition time, improves colorimetric values of the final 3D model and requires cheaper instruments than the traditional LIDAR systems. These advantages are reported in lots of case studies [1], [2], [3] which analyse UAV application for the digital surveying of the archaeological heritage. However, different researches show that a multi-sensor approach for high-quality digital product rendering is needed, due to the morphological characteristics and complexity of the examined archaeological sites [4], [5], [6]. The proposed research focuses on the use of different survey methodologies and their combination for the digital modelling of cultural sites and examines the UAV implementation for the case study of Euryalus Castle.

2. Materials and methods

2.1. Study case: Euryalus Castle

The extraordinary Euryalus Fortress, located on the western highest point of the hill of Epipolae, is an important element of the 27 km long fortifications, built by the tyrant Dyonisius between 5th and 4th century b.C. Siracusa was vulnerable to attacks from Athens, that's why Dyonisius rapidly decided, as Diodorus Siculus narrates, to build the fortification made up of a defensive system of walls surrounding the entire Epipolae as far as the sea. «Certainly, the main attraction of this enormous defensive system is represented by the fortress known as “Euryalus Castle” [...] for its particular pointed shape as its name suggests, in Greek ΕΥΡΥΗΛΟΣ Euryelos means nailhead, which refers to the whole fortress» [7]. The fortified site is mentioned by Thucydides, Diodorus Siculus, Plutarch, Livius, Cicero, Virgil, Pomponius Mela and Strabo. From these descriptions Vincenzo Mirabella etched his famous plate, reported by 18th century travellers, which represents the walls and Epipolae, though in a fantastic way. The morphological complexity of the ruins, “scientifically” attributed to Euryalus Castle during the second half of the 19th century, emerged during a difficult campaign «of excavations aimed at the planimetric reconstruction of the huge defensive fortification» [8].

During the 19th century the area was deeply studied and excavated by F. S. Cavallari and Holm, at the beginning of the 20th century by P. Orsi and Generals Rocchi and Schramm and then by Mauzeri in 1928 and G. V. Gentili from 1959 to 1961.

2.2. Methodology

Digital processing plays a fundamental role within the wider issues of sustainable development and strategies connected with the protection of archaeological heritage (museums or sites). Actually, the establishment of a methodological protocol for the virtual rendering is a priority and is strictly linked with the requirements of the modern process of digitalised representation. Even if different technologies and survey instruments for the monitoring and documentation of cultural heritage are available today, the main difficulty is to find out the most appropriate methods for the solutions of each single case study. Taking this into consideration, the survey campaign of Euryalus Castle had the main purpose of experimenting with integrated methodologies of data collection, useful to do simulation tests in similar areas. In general, land surveying with remotely piloted aircraft systems is the ordinary way of monitoring outdoor areas in the field of geographical and topographical information systems. For survey investigations of archaeological sites, it is better use methodologies connected with the specific geo-morphology of the site. It is possible then to find out different conditions. For example, when it is possible to establish a continuum (meaning that the remains of architectural structures are considered as a unicum with the territory, without any particular emerging or inaccessible elements) between the environment and the archaeological remains, both aerial photogrammetric survey and TLS survey can be used. In particular, if the specific object to investigate is an archaeological artefact and not the environment it is encased in, the exclusive application of laser scanning survey gives very good results. Conversely, laser scanning survey is fundamental when we undertake the study of archaeological sites where the remains left have a tri-dimensional consistency comparable with the architectural scale and stand in areas where it is necessary to plan a survey from



Figure 2. Point cloud from TLS: Altar of Hieron, Temple of Apollo, Euryalus Castle.

the ground [9]. It can also be considered sufficient in relation to the dimension and position of the structure. (Figure 2)

Last, in our specific case study on Euryalus Castle, considering its majesty and complexity, an articulated operative approach was adopted: traditional TLS surveying systems were supported by UAV aerial photogrammetry. In Italy UAV activities are regulated by ENAC (Italian Civil Aviation Authority) the first European authority which published in 2013 the first edition of Regulation of Unmanned Vehicles. Later, in 2019, the European Commission published the Implementing Regulation (EU) 2019/947 which defines for pilots and operators the rules for the operations of UAV, depending on the different flight zones. In the same year, ENAC made it mandatory for drones the identification plate and identified the D-Flight platform, the technological infrastructure which provides all services related to registration, identification, publication of information about geographical areas applicable to UAV. In our specific case, it was necessary to have ENAC authorization and the permission of the Sigonella Airport Command Centre in order to survey the archaeological site of Euryalus Castle using UAV photogrammetry, because the site is located in a restricted airspace. Moreover, being the context characterised by deep moats with cavities and corridors dug in the rock, aerial photogrammetric survey was integrated with a terrestrial laser scanning survey with active sensors which can appropriately manage data referring to structures under the form of geometrically complex ruins. The conducted study provides a scientifically and intellectual rigorous digital model which can be used as a visual document, fundamental for the interpretation of archaeological remains and for cultural dissemination.

3. Data acquisition: aerial and terrestrial approaches

3.1. Terrestrial Laser Scanning technology

The selection of the implemented technical methodology was based not only on the geomorphological characteristics of the site, also on the architectural features of the artefacts themselves. In particular, the implementation of indirect and non-invasive techniques is the ideal solution especially when operating in large and/or inaccessible archaeological areas. That's why, in some cases, it was necessary to implement an integrated survey which included the use of active and passive sensors. The digital surveying of the investigated archaeological sites has been mainly carried out with terrestrial laser scanner Leica Scanstation C10. The all-in-one platform, capable of full-dome interior scanning at the speed of 50K pts/sec and with a long-range scanning (300m), is perfect for 3D mapping of complex articulated and oversized sites. Establishing the positions of reference points within the area to be surveyed is an essential requirement to achieve automation in the combination of the all-available scans during the digital data post-processing phase. Tall and easily recognisable architectural elements present in the Temple of Apollo and in the Altar of Hieron sites suggest that the conducted methodological approach is appropriate to generate a dense point cloud. Conversely, in the present case study, the survey campaign has been carried out in two different moments and with two different methods. The first one has been conducted using almost exclusively active sensors and concentrating survey activities along the northern side of the building for the analysis of the remains of the defensive walls. On this occasion, six scans were delivered and various target points were positioned. Resolution parameters were set to guarantee the survey of each reference point every 6mm

at a distance of 10m. It was necessary to scan the area nearby the moats placing the instrument to mark the previously set up tripod targets. (Figure 3)

It was necessary then considering the uneven ground of the site in comparison with the other examined cases (steep ground, moats, rubbles) to have an aerial view of the area using UAV technology. (Figure 4)



Figure 3. The survey campaign with TLS.



Figure 4. The survey campaign with UAV.

Euryalus Castle is totally integrated into its surrounding area and is actually considered a ruin rather than an architectural structure. Thick vegetation and land degradation are obstacles to TLS surveying. Moreover, land morphology and the absence of any defined architectural structure worsen the detection of reference points useful for precise 3D modelling. However, laser scanning technology providing a big amount of data and accuracy of measurements can be confirmed as the most appropriate approach for the study and documentation of the research team.

The present case study made it necessary to implement any other integrated methodology in order to gather any missing information and obtain a complete final product.

3.2. UAV photogrammetry

Nowadays, it is fully demonstrated how the results obtained from Image Based Modelling (IMB) are as accurate as those obtained from traditional LIDAR systems. Advances in technology have determined the development of the modern UAV photogrammetry. This technology refers to a class of aerial vehicles that can fly without human control and are able to record manual or programmed videos. It also presents two advantages, high speed of survey activities and access to remote or inhospitable areas. The UAV photogrammetric survey of the present research has been conducted with a SKYROBOTIC SR-SF6 hexacopter and two ultralight DJI SPARK quadcopters. The hexacopter has a max. takeoff weight of 5.5 kilos (payload included) and is equipped with a camera Sony QX 100, 20.2 MP. This drone has been used to shoot nadir images acquired during predefined automatic flight programmed with an integrated GPS system. The first step of the survey campaign developed in the laboratory set six different flight schedules of about 5-10 min. each. The SkyDirector software managed the flight schedule which connected the drone to the ground control station with the definition of specific waypoints: take off, photomosaic, landing. In order to obtain good image overlaying, percentage of 65% overlap/sidelap and an altitude of 30 were preset. (Figure 5)

Harmless drones have been mainly used to acquire, without any preset shooting time, nadir images closer to the ground, to shoot videos and to map emerged and submerged areas of the moats of the military fortress.

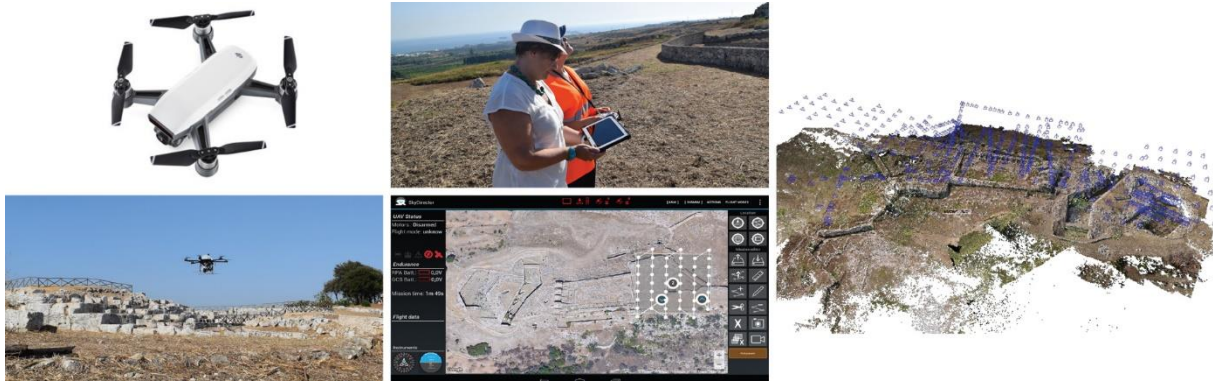


Figure 5. The two different UAV's systems used. Flight plan of the area of interest.

3.3. Data processing

Output data acquired from laser scanning were processed through Cyclone software in order to create a dense point cloud. Data acquired from UAV photogrammetry were processed through 3DF Zephyr which is based on the principles of SfM (Structure from Motion). Starting from a set of digital images it is possible to create a 3D model in four subsequent steps: sparse point cloud; dense point cloud; mesh; textured model. (Figure 6, 7, 8, 9)

The software processed 466 images of the total amount of 590. It was necessary to do a lot of tests in order to detect the appropriate parameters to process the majority of photograms. Fixing the category “UrbanEnvironment” and taking into account nadir shots it was possible to generate a starting sparse point cloud. As recent researches have demonstrated the application of integrated survey techniques provide better results as far as precision and optimisation of the final product is concerned. That's why the starting model has been integrated with the point cloud generated through TLS survey and with the point cloud generated with Zephyr with the oblique shots taken by the mini drones for the mapping of the castle towers and the moats. All the scans were aligned along the point cloud acquired from laser scanning survey and which was considered the reference point while the other two-point clouds acquired from UAV photogrammetry were considered moving objects. In order to obtain a correct alignment, it was necessary to move and manually scale the point clouds (raw alignment) and, then, to detect and define the reference points. After registering the point clouds with their reference points, an ICP (Iterative Closest Point) registration was executed. ICP is an algorithm, employed to minimise the difference between point clouds. The three-point clouds so created were merged to generate a discontinuous model suitable for the meshing procedure for the extraction of surfaces.



Figure 6. Sparse point cloud.

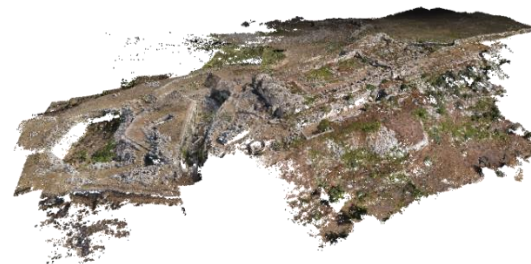


Figure 7. Dense point cloud.



Figure 8. Mesh model.

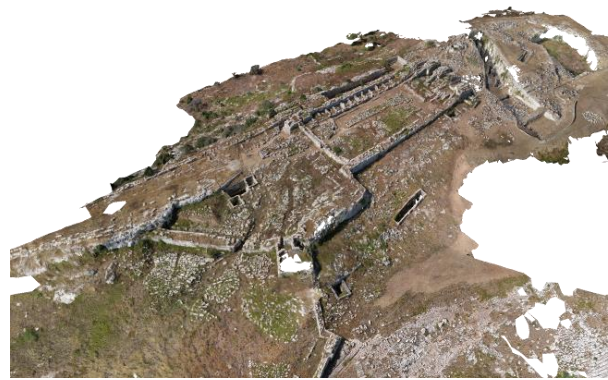


Figure 9. 3D textured model.

Such procedure involved a great amount of computation so the model was sampled in different blocks which were treated one by one. Finally, a 3D photorealistic model was obtained from the previous continuous model through textured meshing. (Figure 10)



Figure 10. Orthophoto from TLS and UAS technology.

4. Results and Conclusions

The final product, generated combining TLS and UAS technologies, is represented by a 3D model made up of 14000000 points and 7000000 polygons with a point density of about 200 pts/m². 3DLaser scanning survey provides accurate and precise point clouds with a margin of error of ± 4 mm.

However, UAV methodology significantly reduces data acquisition time in the field and makes survey operations easier. Moreover, high resolution UAV imagery (0.74 cm/pixel) provides detailed colour information and allows photorealistic rendering. Therefore, the combination of the proposed methodologies offers documentation of the archaeological Euryalus site, 3D precision processing and

high resolution of the area. Also, orthophoto processing makes site understanding and investigation easier providing georeferencing. In conclusion, the research shows how effective the multisensor approach is to optimise the results of the final model and also for the protection and dissemination of archaeological heritage. The model can purposefully support further investigation gathering additional information through the production of sections, orthophotos, etc.

References

- [1] Bilis T, Kouimtzoğlu T, Magnisali M, Tokmakidis P 2017. *The use of 3D scanning and photogrammetry techniques in the case study of the Roman Theatre of Nikopolis. Surveying, virtual reconstruction and restoration study*. In: ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W3, pp. 97-103 <https://doi.org/10.5194/isprs-archives-XLII-2-W3-97-2017>
- [2] Campi M, di Luggo A, Palomba D, Palomba R 2019. *Digital surveys and 3D reconstructions for augmented accessibility of archaeological heritage*. In: ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W9, pp. 205-212. <https://doi.org/10.5194/isprs-archives-XLII-2-W9-205-2019>
- [3] Bagnolo V, Paba N 2019. *UAV-based photogrammetry for archaeological heritage site survey and 3D modeling of the sardus pater temple (Italy)*. In: ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W17, pp. 45-51. <https://doi.org/10.5194/isprs-archives-XLII-2-W17-45-2019>
- [4] Jo Y H, Kim J Y 2017. *Three-dimensional digital documentation of heritage sites using terrestrial laser scanning and unmanned aerial vehicle photogrammetry*. In: ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W5, pp. 395-398. <https://doi.org/10.5194/isprs-archives-XLII-2-W5-395-2017>
- [5] Del Pozo S, Rodríguez-González P, Hernández-López D, Onrubia-Pintado J, González-Aguilera D 2019. *Sensor fusion for 3D archaeological documentation and reconstruction: case study of “Cueva Pintada” in Galdar, Gran Canaria*. In: ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W15, pp. 373-379. <https://doi.org/10.5194/isprs-archives-XLII-2-W15-373-2019>
- [6] Mateus L, Fernández J, Ferreira V, Oliveira C, Aguiar J, Gago A S, Pacheco P, Pernão J 2019. *TLS models generation assisted by UAV survey*. In: ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W15, pp. 767-773. <https://doi.org/10.5194/isprs-archives-XLII-2-W15-767-2019>
- [7] Voza C 1994. *Guida di Siracusa*. ERRE Produzioni Siracusa.
- [8] Zirone D 2011. *Storia della ricerca archeologica*. In Ampolo C. (a cura di). Siracusa. Immagine e storia di una città. Edizioni della Normale Pisa.
- [9] Taibi G, Valenti R, Aliano C, Paternò E 2016. *The Acme of a Complex Cultural Interiority: How to Resurrect and Redesign an Ancient Town*. In UNISCAPE En-Route - a. I - n. 4, pp.107-114. More references

Acknowledgments

Authors would like to thank Lieutenant Colonel A.A.r.a.n. M. Fanciulli and Inspector R. Cosentino for their authorization to fly over the concerned area; the Parco Archeologico of Neapolis in Siracusa represented by Director Architect C. Rizzuto and Dr. R. Lanteri for their authorization. Translation by Dr. M. Grancagnolo. The study conducted within the research program named “Visibile e Invisibile: percorsi interdisciplinari per una fruibilità diffusa dei beni Museali. Ricerca-Azione per una didattica inclusiva” (University research PIA.CE.RI 2020-2022) is the result of the collaboration between the two authors. In particular, R. Valenti wrote the following paragraphs 1.1, 2.1, 2.2; E. Paternò wrote the paragraphs 1.2, 3.1, 3.2, 3.3.