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3D metric Survey of the Mezzagnone Arab bath. From point clouds to 2D drawings and parametric model

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***Abstract* – The presented work reports the results of a multiscale and multi-sensors 3D metric survey achieved on the Arab Bath of Mezzagnone, an archaeological site in Sicily (Italy). Aerial and terrestrial techniques were combined to obtain detailed documentation of the selected asset and to explore the latest advancements in the archaeological heritage documentation domain.**
Specifically, the integration of Uncrewed Aerial Vehicles (UAV) photogrammetry using both nadir and oblique acquisitions, along with Terrestrial Laser Scanning (TLS) technology, was used for detailed documentation of the whole site.
The aim of the research consists in obtaining a foundation for documentation, study, restoration projects, and public promotion through the creation of a 3D model of the site, traditional 2D drawings, digital orthoimages, and a parametric model of the studied object. In the work, the adopted pipeline, from data acquisition to the final results, will be described with the evaluation and validation of the achieved accuracies.

INTRODUCTION

Innovative strategies derived from 3D multi-sensor metric survey approaches demonstrate that the documentation process can achieve commendable levels of sustainability, without losing the quality of information and level of detail, considering also time and cost. Moreover, when implementing these techniques in archaeological contexts, it is crucial to consider the spatial and temporal complexities involved while designing and achieving the 3D metric survey. The design of the survey project is a crucial phase of the overall documentation process, and just like the case study presented in this paper, it needs to be tailored to different purposes and be beneficial to experts from various fields of knowledge.
Furthermore, it is well recognized that the choice of specific approaches and techniques involving dedicated sensors yields corresponding outcomes in terms of the desired level of detail, accuracy, informative content, and involved resources.

Figure 1: picture of the site to better visualize the context, shot during a UAV mission

Finally, georeferencing spatial data plays a vital role in enabling the interoperability of datasets collected in a multi-temporal perspective, serving as an integral part of the overall process of monitoring and preserving cultural heritage and its study from experts of different branches of knowledge [1].
This study presents the integration of 3D metric survey techniques within a complex and distinctive test site: the so-called Arab Bath of Mezzagnone, near Santa Croce Camerina, Sicily. The Mezzagnone building, also known as the ‘Bagno di Mare,’ is a small thermal construction located in the territory of the municipality of Santa Croce Camerina (Province of Ragusa, southeastern Sicily). It is situated west of the urban center and near a spring called Fonte Paradiso. Over the past two centuries, this archaeological site and the neighbouring twin building of ‘Vigna di Mare,’ which unfortunately is now lost, have been the subject of extensive historiographical debate. The debate was focused on both their chronological attribution and their original purpose. The controversy regarding the identity of these two buildings has implications that go beyond the strictly regional context, instead extending to the broader question of the origins of Visigothic architecture and the transmission of Byzantine

stylistic and formal repertoire from the eastern Mediterranean regions to the Iberian Peninsula. These examples of provincial construction witness the circulation of models and floor plan schemes in the Mediterranean area and demonstrate the transmission of technical knowledge between the East and the West during the Early Middle Ages.

The main body of the complex consists of a building measuring 14.60 meters (northeast/southwest) x 9.90 meters (southeast/northwest). The architectural structure is characterized by massive masonry made of large square limestone blocks, which imparts grandeur and solidity to the ensemble. The main feature of the composition is primarily suggested by the dome that identifies and enhances the main compartment, as well as the barrel vault in the intermediate room. Although the complex remains largely unexplored - having not yet been the subject of extensive surveys until recent times - there are evident sections of masonry belonging to structures adjacent to the main body. The roofing system adheres to a specific hierarchical criterion in the sequence of spaces, derived from the functional requirements of each [2].

The survey of the Arab Bath was part of the SUNRISE summer school activities and was completed in September 2022 (https://poliflash.polito.it/studenti_polito/conclusa_la_prima_edizione_della_summer_school_sunrise_in_sicilia).

The 3D metric survey foresaw the deployment of different techniques and instruments and had as its primary goals the generation of several products, including aerial orthoimages and 3D surface models, to facilitate further analysis, restoration initiatives, and the promotion and valorization of the site. More specifically, the survey outputs have proven utterly valuable in order to perform traditional 2D CAD representations, which are fundamental for an archaeological approach: nonetheless, it should be considered that such outcomes could lead to a further step consisting in the realization of a parametric model of the architecture, to be helpful for historical reconstructions, restoration designing and managing much more information [1].

After the design of the survey project, several approaches and techniques were deployed in the field for data collection: terrestrial close-range photogrammetry, TLS acquisitions, and UAV photogrammetry to integrate the terrestrial data. All the acquisitions were georeferenced and metrically validated thanks to the setup and measurement of a topographic network and several Ground Control Points (GCPs) with traditional topographic techniques. An example of the generated 3D photogrammetric model is reported in Figure 2.

Figure 2:Photogrammetric 3D model and relative acquisition scheme

DESCRIPTION OF THE WORKFLOW

A comprehensive 3D survey was conducted on-site to collect data from multiple sensors and achieve complete site documentation. The data collection was carried out in several stages, following consolidated approaches:

1. Materialization of a topographic network of 9 vertices measured using static GPS/GNSS receivers and total station.

2. Setting up and measurement of markers with a total station. Those points were employed as Ground Control Points (GCPs) and CPs (Check Points) for the photogrammetric process, for registering the LiDAR scans, and for the accuracy evaluation.

3. LiDAR data acquisition (19 scans were captured to cover the whole area).

4. UAV photogrammetric flights to capture nadiral and oblique images.

5. Terrestrial Close-Range image acquisition.

As usual, the topographic network is the fieldwork's starting point. Static GPS/GNSS receivers were used to measure the different vertices, and data were then post-processed using an ad hoc software solution.

The adjustment was performed using three permanent stations of the Hexagon SmartNet network adopting the UTM 33N /WGS84 reference system.

In the second phase of fieldwork, several points were measured on the surface of the masonries using coded paper targets that served as GCPs or CPs in the scan registration and the photogrammetric process. Each target was measured on the field using traditional topographic techniques by means of a total station. A FARO Focus Premium by CAM2 was employed for the terrestrial laser scanning.

Furthermore, terrestrial surveys were performed using mobile mapping systems. Different instruments were used: GEOSlam ZEB HORIZON and Leica BLKtoGo. This dataset will not be considered in the final discussion, though.

Moreover, a terrestrial close-range photogrammetric acquisition was completed with a Sony Alpha7R camera equipped with a 24 mm lens. The acquisitions design was planned considering the shape of the building, beginning with the basin of the Arab bath up to the dome and realizing very large overlapping (> 80%) and convergent shoots. The terrestrial photogrammetry has played a main role in obtaining an accurate 3D dataset to generate the architectural drawings.

The last part of the activities on the field was related to the photogrammetric flights performed on the area, which had the aim of completing the documentation of the Arab Bath and its surroundings. The integration of both nadir and oblique acquisitions allowed the production of a detailed 3D model of the area and the building, with a high-detail, especially in the documentation of the vertical surfaces. Regarding the UAV photogrammetry, two drones were used for this purpose: DJI Mavic Mini and DJI Matrice 300 equipped with the Zenmuse L1 payload (only the RGB component was used and described in this paper).

The TLS scans were registered with the well known Faro Scene software, as displayed in Figure 3; the UAV and terrestrial images were used for the photogrammetric process to obtain dense point clouds, 3D models, Digital Surface Models (DSM) and Orthoimages. During the processing steps, all the data were georeferenced and scaled thanks to the topographic measurements and through the use of GCPs and CPs for evaluating the final metric accuracy. Mean RMS on the CPs have been taken in account for all the process of the elaborations, and the results are exposed in Table 1.

Geomatics multi-sensor approaches enable the collection of three-dimensional (3D) data at various scales in a reduced amount of time. When it comes to architectural and archaeological documentation, highly detailed data is typically obtained using TLS (active sensor) and Close Range Photogrammetry - CRP (passive sensor).

Range-based and image-based techniques have each their pros and cons, however, the integration of these two approaches is generally the best solution to obtain a complete model that allows to integrate both metric and non-metric information. Not only those models allow the reconstruction of the object's geometry but also the assessment of superficial and structural pathologies affecting the considered asset. Additionally, these integrated methods offer several benefits, such as the ccreation of orthoimages, Digital Elevation Models (DEM), as well as standard survey products in both two-dimensional (2D) and three-dimensional (3D) representations.

Over the past few years, Uncrewed Aerial Vehicle (UAV) platforms have emerged as widely used systems for addressing mapping and 3D modelling challenges. One of the key benefits these platforms offer to the field of archaeological documentation is the availability of cost-effective alternatives to traditional manned aerial photogrammetry techniques. Both multi-rotor and fixed-wing UAVs are now capable of autonomously and semi-

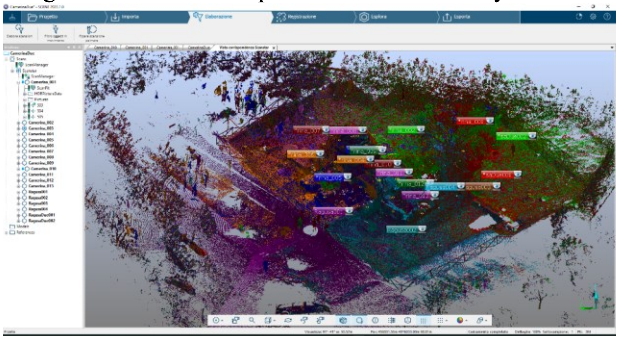

Figure 3: registration of FARO laser scanning

automatically capturing photogrammetric data using high-resolution digital cameras. Thereafter, the photogrammetric process with Structure from Motion (SfM) approaches enables the rapid generation of point clouds, DSM/DTM (Digital Terrain Models), orthophotos, textured 3D models, and allows the creation of 2D drawings with controlled and known accuracy, facilitating precise documentation of the considered asset. Typically, when acquiring data for architectural and archaeological documentation for creating orthophotos, the camera is positioned to capture nadir-oriented images (lens axis pointing downward). Aerial photogrammetry has recently seen a growing focus on utilizing oblique images, and research in the geomatics field has been directed in the past years toward optimizing algorithms for incorporating these "non-conventional" perspectives into the photogrammetric process and maximizing their contribute [3].

Specifically, the integration of oblique images enables favourable outcomes when dealing with objects characterized by significant vertical extent, radial symmetry, and multiple primary facades; qualities that are present in the Mezzagnone Arab Bath archaeological site, and in general when dealing with well-preserved archaeological and architectural contexts.

In the domain of Building Archaeology, these capabilities find their greatest potential, serving purposes such as stratigraphical analysis, building technique identification, material and virtual restoration and digital communication (e.g., augmented/virtual reality). Furthermore, the generated 3D models can provide a valuable contribution to the activities of monitoring the state of conservation. Among the different available solutions, one of the most promising tools for managing 3D reality-based information stored in a digital, updatable, and editable database appears to be 3D Geographic Information Systems (GIS) and Historic Building Information Modelling (HBIM).As last step, a 3D parametric modeller was used. Inside such tool, all generated objects are defined by their geometries and shapes, which are determined by their inherent properties or relationships with other interconnected objects.

A relational database also serves as a fundamental tool for gathering and retrieving both geometric and alphanumeric data. This data get utterly useful for tasks such as planning and managing future projects, documenting the current state of objects, or reconstructing past object configurations.

To achieve these objectives, custom relational query processes can be employed, particularly when analyzing the stratigraphy of historical architecture or archaeological sites in relation to IFC surfaces. This might involve interactive tables, such as "IFC Building" and "stratigraphic lecture," to delve into the historical evolution while addressing specific research requirements.
Within a BIM server, one can seamlessly investigate IFC models through simple queries. However, for a comprehensive analysis of cultural heritage contexts, it's essential to integrate extracted data from IFC entities with other types of data linked to the object.
Designing a customized workbench tailored for historical buildings or archaeological sites, such as our case, presents significant challenges. For instance, one could consider the incorporation of a tool like "stratigraphic units." This tool would be designed to analyze and interpret stratigraphic evidences, transforming it into parametric surfaces linked to the IFC model. Furthermore, such a tool could facilitate the classification of these units, much like the categorization of archaeological findings, distinguishing between positive units (representing accumulation activities) and negative units (indicating erosion or removal activities) [4] [5] .

RESULTS AND APPLICABILITY

As stated in the previous sections, the aim of the presented activities was to obtain complete and detailed documentation of the Arab Bath and to evaluate the contribution of different geomatics techniques in the generation of 3D metric products. The first output considered was related to the generation of 2D drawings at different representational scales (examples are reported in Figure 4 and 5). The first products generated were the plans: one to cover a wider area of the site, for which a scale of 1:200 was chosen; one to represent the architecture in close detail, and the last to represent the inner volumes, for which a traditional scale of 1:50 was chosen. By doing so, it was necessary to integrate the terrestrial LiDAR data and the orthoimages from the aerial ones to represent all the main elements of the asset. The laser point cloud has been extremely useful in documenting all the masonry features at a high-detail scale: despite giving generally good and wide coverage, the higher parts of the building lacked details. Otherwise, the orthoimages from the UAV, as well as the point cloud could be integrated into the terrestrial point cloud deficiencies to generate a complete 3d model of the site. As a matter of fact, with the aim of obtaining the different architectural plans, in the drawing phase, the different datasets were merged. By doing so, it was possible to

UAV Photogrammetry	0.015 m
Terrestrial Photogrammetry	0.008 m
Terrestrial Laser Scanning	0.011 m

Table 1: Mean RMS on the CPs[5]

obtain complete architectural drawings: four main facades from NE, NW, SE and SE, and two sections.

CONCLUSIONS

In situations involving complex architectures or sites, integrating data from multiple sensors can be considered the optimal solution for achieving a comprehensive 3D documentation at several scales. Indeed, when evaluating the three approaches followed in the case study, it becomes clear that they offer different pros and cons and contribute in different ways to the documentation process. Each of the aforementioned products has its own advantages and disadvantages, encompassing factors such as image quality, information richness, and time and resources (human, software, and hardware) invested in obtaining the desired outcomes.
To begin with, it was observed that the LiDAR instruments are preferable not to be influenced by atmospheric conditions and lighting compared to photogrammetric methods. Therefore, the choice of the technique largely hinges on the specific characteristics of the sites under consideration and the available timeframe for conducting fieldwork. Nonetheless, a high-quality texture outcome for the model is reachable by the combination of Terrestrial Laser Scanning (TLS) with camera acquisition. Furthermore, it should be taken into account the increasingly automated algorithms within digital photogrammetry, which demonstrates extremely competitive in saving time for processing and in the level of human involvement, in contrast to managing laser point clouds.
The geometrical definition obtained through UAV photogrammetry differs significantly in terms of point cloud density; however, this technique achieves a satisfactory definition of Digital Surface Models (DSMs) by leveraging a combination of nadir and oblique cameras, which are already become utterly prevalent in research applications. In the case of Arab Bath of Mezzagnone, the integration of oblique images proved highly beneficial in augmenting the quantity and quality of information derived from the point cloud.
A complete 3D reconstruction of the complex ancient architecture and surrounding area was achieved thanks to the integration of information coming from the different sensors: the aerial photogrammetry, combining nadir and oblique images, allowed to reach the parts that were not taken by the terrestrial acquisitions.

A very high detail level of the texture for the 3D model was satisfactorily achieved: this was a fundamental goal in order to go ahead with the traditional archaeological documentation of the site, realizing good quality 2D CAD drawings. Nevertheless there is room for further enhancement in terms of textures. The presence of lens flare and significant shadows had a substantial impact on the images, needing additional radiometric corrections to improve the texture quality.

Finally, the precision of the achieved point clouds has the potential to generate a parametric model of the architecture as well. Surely at present times, this feature represents a new horizon for building archaeology research purposes, to be paralleled along with and integrated with the traditional drawing tools and study approaches. Some last considerations may be pointed out as far as regards the historiographical debate mentioned in the introduction. As a matter of fact, as we deal with archaeological or historical buildings, a digital survey and the following elaborations surely represent a mandatory step in order to carry out any type of study about the architecture itself. Naturally our case doesn't make any exception. The operation of the survey resulted in an utterly reliable 3D model on a metrical and texture plan:
this could be used and studied in any period following the field mission. Thanks to these results, the 2D architectural drawings permitted to go deeper into the understanding of the material state and the building techniques of the building itself. This permitted to gain a broader general perspective on the possible events that operated and modified the architecture throughout its history. Furthermore, as it has already be mentioned, the possibility of a parametric model was explored in order to evaluate the potential of managing the complexity of such archaeological/architectural object. In fact, it could
demonstrate extremely helpful in dealing with different levels of information, 3D representations and goals: scientific reconstruction of the architecture's geometry, monitoring of the assessment of superficial and structural pathologies affecting the considered object, basis for designing structural needed interventions and much more [6]. In this sense, a suggestion about further researches and studies about historiographical topics might go in the direction of archaeology of architecture and masonry
drawings. NW prospect and General plan
stratigraphy approaches. These might shed more light about the understanding of the building as an historical and material source, helping other fields such as restoration, conservation and scientific visual reconstruction of the different phases [7]. In any case, the final conclusions as far as it regards historiographical matters are up to the local Superintendency of the Ministry of Culture, which will be given the final results and products of this study.

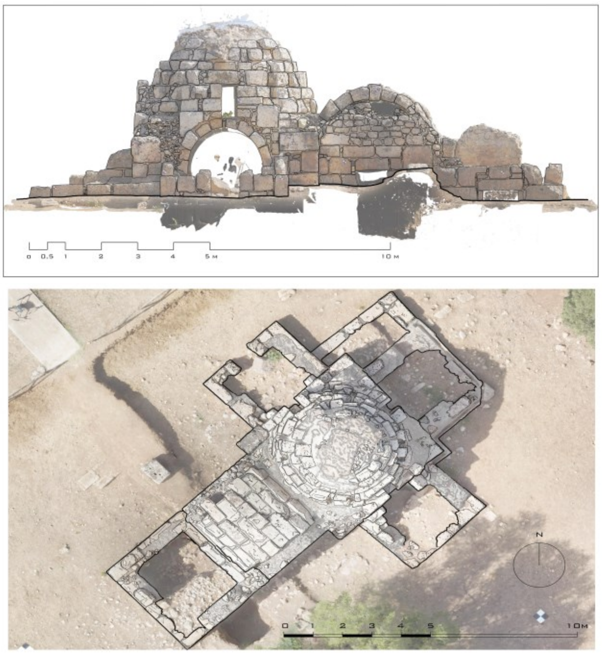

Figure 4 and 5: samples for the two dimensional CAD

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