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Study and 3D survey of the Roman baths in the archaeological site of *Lylibaeum* (Marsala, Italy)

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Abstract. Archaeological documentation is a fundamental step for research and conservation planning phases. Nowadays traditional recording is always supported by geomatics technologies which offer important support to the growth of archaeological study. The integration of sensors and methodologies seems to give the best results, in terms of time, costs and accuracy of products. In particular, the combination of Terrestrial Laser Scanner (TLS) and Unmanned Aerial Vehicle (UAV) can help the documentation of complex sites and the production of 3D and 2D products for different purposes. The paper focuses on the integration of TLS and UAV methodologies to record the thermal baths of the Roman *Domus* in the archaeological Park of *Lylibaeum* (Marsala, Italy). The combination of range and image data are useful to achieve a complete 3D model and a high-resolution orthophoto of the site, in order to provide accurate and complete documentation for archaeological research and conservative project.

1. Introduction

The integration of geomatics technologies satisfies expectations in many complex onsite surveys for archaeological documentation, with the challenge to choose, case-by-case, the most appropriate methodologies, depending on issues and features of the area. In particular, in the field of archaeological surveying, the combination of Terrestrial Laser Scanner (TLS) and Unmanned Aerial Vehicle (UAV) can help to optimize the documentation and to achieve accurate and realistic products [1]. TLS can be used to produce 3D point clouds with dense geometry information, UAV allows to acquire images for a photogrammetric survey of wide or inaccessible areas and provides information to derive geometry and texture for 3D modeling [2, 3].

The technologies integration has become increasingly used to record large and complex archaeological areas where complex surfaces have to be accurately measured and the level of detail is correlated with the geometric complexity of the object to be measured. Multi-sensor approach allows to fulfil all the surveying and archaeological needs and to highlight the intrinsic potentialities of each 3D modeling techniques [4]. The integration of different modelling techniques seems to be the ideal solution for a fast and low-cost survey [5].

In archaeological contexts, the integrated TLS and UAV approach is usually performed to define the relationship between the surrounding environment and the archaeological remains for different interpretations of archaeological sites [6-8].



Digital 3D models, obtained from integrated surveys, allow a possible integration of data with different levels of detail [9]; moreover, they are generally used to derive measurements (sections, plans, etc.) and to create new ways of representation and visualization in a 3D environment. High-resolution 3D models can be also useful to improve the analysis and interpretation of artefacts, to monitor alteration processes over time and to plan conservation projects.

The paper presents the result of a multi-sensor approach carried out for the accurate and detailed thermal baths 3D modelling of the so-called Roman *Domus* in the Archaeological Park of Lilibeo-Marsala (Italy). A combined TLS and very low-altitude UAV survey has been employed to obtain a very high-resolution 3D reconstruction of the archaeological structures and of mosaics *in situ*.

The survey and 3D modelling of the thermal baths are part of a larger project aimed at a complete documentation of the whole archaeological remains of the Park [10]. The Archaeological Park of Lilibeo-Marsala preserves the remains of the ancient city of *Lilybaeum*, the modern city of Marsala. The north-east area of the Park is entirely occupied by the ruins of *Insulae* I, II and III, which offer an important testimony of the urban organization of the city in the Roman time.

The *Insula* I holds ruins of a large and rich private residence, the so-called Roman *Domus* discovered in 1939; the *Domus* is one of the most significant remains of the ancient *Lilybaeum* [11]. The north-western sector of the *Domus* was completely converted in thermal baths during the end of the II century and the beginning of the III century A.D..

In order to protect this archaeological area, the Roman *Domus* was covered with a concrete roof; the space arrangement, the complex geometry of preserved structures and the presence of some modern barriers required adequate planning to identify the most appropriate technology and methodology to be used for the 3D data acquisition of this area.

The work was first carried out through a TLS survey of the whole Roman *Domus* area with a topographic approach. Additional scans were planned to record in detail only the thermal baths of the *Domus*. Then a very low-altitude flight with a multi-rotor UAV was performed to carry out a photogrammetric survey and to produce data for integrating the TLS information. The low-altitude UAV survey was mainly aimed to record the mosaics still *in situ* which decorate some thermal rooms.

A 3D model and a very detailed orthophoto of the thermal baths were realized. The integration of range and UAV techniques allows to overcome modern barriers of the site and to obtain complete and accurate documentation of structures and mosaics of the site.

The work allowed to study in detail the system of the Roman baths and to fulfil archaeological documentation and conservation needs.

2. The Roman thermal baths

The *thermae* or Roman baths are the best-preserved Roman remains in the world and their remains are present in many archaeological sites. Constructed as a grand bathing and socializing complex, the Roman bath buildings' functions were not limited to purely hygienic purposes but they also facilitated relaxation and social activities and were fixtures in Roman life.

Roman baths are not only splendid examples of Roman luxury and architecture but also of technique and resource management, functioning as a complex identity in an even more complex urban and rural unit [12]. The archaeological remains of the bath complexes are source of information about the Roman knowledge in the field of the fluid-dynamics and heat transfer [13].

In addition to public *thermae*, private baths are well documented in domestic Roman *villae* or *domus* and were considered most interesting in the study of the mutual influences and interaction between public and private baths on a functional level [12]. The presence of thermal rooms in private residences was a luxury reserved for the upper classes and shows the inclinations of wealthy owners. Compared to public complexes, private bathing facilities show more flexible ground plans depending on the available space and the owner's personal wealth and preferences [14]. Even if domestic baths are dubbed as "private" they were habitually designed to accommodate more than one bather and they usually used for such social purposes [15].

The Roman baths were generally supplied with water coming from an adjacent natural river or stream, or from an aqueduct. The water management, in connection with the urban water distribution system and the implications of this for the location of baths, offers an interesting example of how the water disposal of bath houses was integrated into a city's water management [16, 17].

Roman baths were organized according to a path in a clear sequence of rooms, which generally started with a cold room (*frigidarium*), crossed an intermediate one (*tepidarium*) and ended in the hottest room (*caldarium*) (figure 1). Depending on the size and luxury of the establishment, all of these rooms could have pools, heated to the appropriate degree [18].

Usually, the first room was the *apodyterium* or changing room allowing people a place to change their clothing in relative privacy. The first of the pools used was the *frigidarium* which was completely unheated. The second pool was the *tepidarium* which possessed some heating capabilities and was the separation between cold and hot baths. Often, vents connected this room with the next one, the *caldarium*, in order to pipe hot air from this room.



Figure 1. The sequence of western thermal rooms in the Roman *Domus*.

The heating system was very sophisticated and it was based on the underfloor heating technique called *hypocaustum*. The ceiling of the hypocaust was raised above the ground by bricks pillars (*suspensurae*). In this way, the hot air generated by the underground wood-fired furnace (*praefurnium*), located near the rooms to be heated, could circulate through this enclosed area by heating the floors and walls of the rooms above. The hot air also passed under the surface of hollow walls thanks to ceramic pipes (*tubuli*) placed between walls and plaster and allowed for an even distribution of temperature throughout the room. The smoke came out through the roof (figure 2).

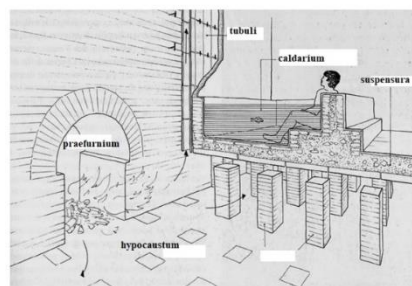


Figure 2. Heating system of Roman baths, from [19].

The *Insula I* holds ruins of a large and rich private residence, the so-called Roman *Domus* (figure 3). Probably the area of the *Insula I* was originally occupied by two houses. Between the end of the II and the beginning of the III century A.D., the area was totally modified and the two housing units were joined into a single large *Domus*. The *Domus* became a luxurious housing complex and it was divided into three separate parts: a public area, a private area and a thermal sector. The *Domus* shows an articulated structure, with many rooms and thermal baths, most of them decorated with polychrome mosaics, marbles and paintings.

The entrance to the thermal rooms was characterized by a small space decorated with a mosaic scene of ‘*cave canem*’ (watch out for dog). The entrance gave admission into the *apodyterium*, a room for undressing in which visitors met before entering the baths proper. The Roman *Domus* baths show a large central cold bathroom (*frigidarium*), decorated with a floor mosaic that divided two areas: the eastern area used as pools, and the western with rooms used as *laconicum* (a dry hot room), *tepidarium* (warm bath) and *caldarium* (hot bath).



Figure 3. The Roman *Domus* archaeological area.

3. Data acquisition

The presence of modern barriers among various zones, as a wooden walkway, that crosses the entire site, and large pillars, that support a modern concrete roof realized to protect archaeological remains of the *Domus*, was a challenge for the surveying.

In order to have the same reference system for all data, before TLS and UAV acquisitions, a topographic survey with a total station was carried out to measure a topographic network inside the archaeological Park [10]. Some control points were also measured on the surface of the *Domus* archaeological structures and on mosaics *tesserae* to georeference the photogrammetric survey in the same reference system of the TLS point cloud.

3.1. TLS survey

A TLS survey of the Roman *Domus* was carried out to document the whole archaeological area and was aimed to record the complex site morphology characterized by many rooms [10].

To overcome the logistical difficulties of the survey, a first TLS acquisition of the *Domus* was carried out with a Topcon GLS-2000 laser scanner. This device allows using a topographic approach for scans registration, which is useful in cases where standard approaches (scans with high percentages of overlap) are difficult to use [20]. Scan points can be planned along a traverse path by setting the point from which to perform the scan and from which to measure the previous scan 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.

The GLS-2000 survey was planned to have an overall point cloud of the whole *Domus*. A total of 9 scans (P1-P9) were carried out along a traverse path to record first the whole *Domus* area and to generate a reference point cloud of the site. To take advantage of the GLS-2000 topographic approach, the first scan point was arranged on a topographic point, previously measured with a Leica TPS 1105 total station [10]. In this way, it was possible to generate a georeferenced point cloud.

In order to acquire in detail the thermal area of the *Domus*, additional scans were planned. The complexity of the preserved thermal structures, with different heights and shapes, caused many shaded areas that forced to complete this survey with other TLS surveys. Therefore a second scan survey was carried out with the GLS-2000; finally, a third scan survey with a Faro Focus 3D was realized. All these scans were performed as single scans with high overlap with the reference point cloud [11].

All GLS-2000 scans were acquired with a full-dome field of view (360° in the horizontal direction and 270° in the vertical direction) with an average sampling step of 12.5 mm at 10 m. Instead, the Faro

scans were arranged by setting 360° horizontal and 180° vertical field of views, with a resolution of 6 mm at 10 m (figure 4).



Figure 4. GLS-200 scans position along the traverse path (red circles) in the whole area of the Roman *Domus* (blue shape). Additional GLS-2000 (violet triangles) and Faro (black triangles) scan positions of the thermal rooms (yellow area with red outline). Internal (green) and external (grey) wooden walkway.

3.2. UAV survey

Although the GLS-2000 and the Faro Focus 3D have both an integrated camera to capture images of the scene, images quality was not satisfying to document the archaeological preserved structures, especially for the onsite mosaics recording. Therefore, to integrate the TLS point cloud of the *Domus* thermal rooms, a low-altitude UAV survey of the whole area was planned to acquire also high-resolution images to generate a detailed photo-realistic 3D model and a high-resolution orthophoto, with particular attention to record mosaics of the thermal rooms. Despite a classical terrestrial photogrammetric acquisition, the low-altitude UAV survey allowed to acquire images in a very fast way. The survey was carried out with a multirotor quadcopter Phantom 4 equipped with an onboard camera stabilized with 3-axis gimbal, with a 1/2.3" CMOS sensor, a resolution of 12.4 MP (4000 pixels x 3000 pixels) and a focal length of 3.6 mm. Due to the complexity of the area to be overflown (with the presence of large pillars that support the modern concrete roof) and the difficulty of maintaining GPS signal under the roof it was decided to fly in manual mode. Nadiral images were acquired at an approximate altitude of 3 m (figure 5). A total of 1590 images were collected with a Ground Sample Distance (GSD) of about 0.8 millimetres.



Figure 5. UAV acquisition.

3.3 Data processing and data integration

In the first data processing phase, the TLS and photogrammetric data are separately processed and two 3D models are achieved.

GLS-2000 scans acquired with the traverse approach were imported in Topcon Positioning Magnet Collage software. Thanks to the topographic approach, all scans were automatically registered. The accuracy of the registration was verified on the scans points coordinates RMSE. Values are of about a few millimetres for east and north coordinates and of about 1 centimetre for height. A reference point

cloud of about 8 million points was achieved. Single GLS-2000 scans were also imported in Magnet Collage and registered with a cloud-to-cloud approach with the reference point cloud. RMSE between the reference point cloud and every single scan was in the order of 4÷5 millimetres. A final point cloud of about 14 million points was generated.

The GLS-2000 point cloud was imported in Autodesk Recap in order to carry out an automatic registration with the Faro scans. At the end of the registering process a quantitative assessment was done by evaluating the percentage of three Recap parameters: *overlap* (>70%), *balance* (>50%) and *points <6 mm* (99%). A final point cloud (GLS-2000 and Faro scans) of the Roman *Domus* of about 60 million points was achieved (figure 6).



Figure 6. TLS 3D model of the thermal rooms.

While TLS data was used to produce an accurate product with geometry information, UAV acquisition is aimed to create a photorealistic textured model and a high-resolution orthophoto. The most significant difficulty during all field recording operations was determined by light conditions of the site. Even though all images were modified before the post-processing step, light differences are still visible in the final product.

The photogrammetric dataset was processed with the Agisoft Metashape software. During the orientation step, the coordinates of topographic points were used as Ground Control Point (GCP) and as Check Point (CP) to evaluate images orientation accuracy by considering the Root Mean Square Error (RMSE) of GCP and CP. The RMSE of the 5 GCP and 4 CP was of few millimetres for north and east coordinates and of 1 centimetre for height. From the photogrammetric point cloud the surface model of the thermal rooms was generated and textured to provide a photorealistic representation of the archaeological area. An orthophoto with a resolution of 2 mm was last generated (figure 7).

Both the TLS 3D model and the orthophoto of the thermal baths are used for the production of a 2D plan. In particular, a complete plan of the thermal structures was realized for research and conservation purposes (figure 8); the TLS 3D model became useful to complete the drawing of archaeological structures under the wooden walkway not visible in the orthophoto (figure 9).



Figure 7. Orthophoto of the thermal rooms generated from the UAV survey.

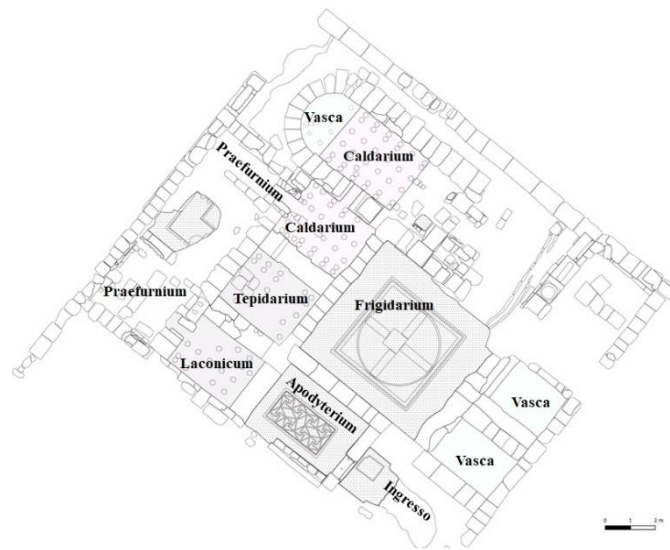


Figure 8. Plan of the thermal baths.

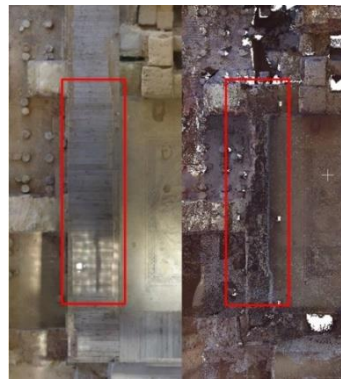


Figure 9. Orthophoto with the walkway (left) and TLS 3D model without (right).

4. Conclusions

The paper describes an integrated TLS and low-altitude UAV survey of the thermal baths of the Roman *Domus* in the Archaeological Park of Lilibeo-Marsala. The work took advantage of the multi-source approach to describe, with a very high resolution, the remains of the archaeological site and its mosaics still in situ.

The integrated survey has allowed achieving a detailed and accurate 3D model and a high-resolution orthophoto of the archaeological area in order to document onsite structures, with particular attention to mosaics documentation, and to create an updated 3D and 2D documentation for future conservation and valorization projects.

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