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Necropolis of Palazzone in Perugia: integrated geomatic techniques for a geomorphological analysis

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Abstract—**In the geomorphological research field there has been an increasing diffusion of Geomatics in recent times: the introduction of new tools and methodologies has made possible to characterize and reconstruct Earth's surface in 3 dimensions at high resolution, allowing a much better description of the geometries. Geomatics is an applied science that deals with acquiring, modeling, analyzing, processing, archiving and providing geographic and spatial data information with an integrated approach. In particular, among the geomatic techniques that can be profitably utilized in Geomorphometry, there are LiDAR and photogrammetry. These technologies allow to generate high-resolution point clouds representing the soil surface geometry in greater detail than the classic survey techniques, allowing detailed analysis at a few centimeter scale. In this paper we present an application of geomatic methodologies to the case of the Necropolis of Palazzone, an Etruscan funeral site near Perugia, in central Italy: an excellent example of a site combining archaeological and geological interests, being a so called "*archeogeosite*". The geomatic models represent the basis for a sedimentary and geomorphological study of the cavities, a 3D analysis of the lithostratigraphic units aiming to a paleogeographic reconstruction of the Perugia hill. To measure and georeference the cavities and the ground surface of the site, the project has seen a synergistic use of different methodologies in order to obtain a 3D model on which carry out investigations both on the geomorphological and archaeological aspects.**

I. INTRODUCTION

Geomatics has progressively affirmed in the geomorphological field thanks to the development of new technologies. This survey science makes it possible to obtain accurate information regarding the environment, creating three-dimensional models that allow geomorphologists to study the shaping processes of the Earth's surface with resolutions not possible in the past [2,5,6]. An example of correct integration between the two sciences is the so-called "archeogeosite", an archaeological site where geological and geomorphological evolutionary conditions are determinant for the knowledge and correct interpretation of the site itself [8].

The Necropolis of Palazzone represents one of the most significant funerary sites of the Etruscan era in central Italy, with almost two hundred tombs excavated in the ground, dating from the fifth century B.C. to the Hellenistic age. Located on the south-east area of the Perugia hill of Perugia, the Necropolis is characterized by a sloping area of about 4 hectares [4]. Despite the obvious archeological importance, the site is penalized from a touristic point of view, being located in a peripheral area of Perugia town where there are no cultural itineraries and penalized by the presence of the above freeway and the adjacent railway. The project "*SILENE: a Lidar System for the Exploration of the NEcropolis of Palazzone - Remote Sensing and Geology for the enhancement of archaeological sites*" fits into this context, with the aim to increase the scientific value and tourist attraction of the site, applying geomatic techniques and using geological data. This project, promoted by the Geology and Engineering Departments of Perugia University, wants to produce an original geomorphological study of the cavities, defining their geometry and position (relative and absolute) creating a unique three-dimensional model in order to geologically correlate the cavities by placing them in the overall paleogeographic reconstruction of the Perugia hill [1].

II. GEOMATIC SURVEY

Due to the underground nature of the tombs (with narrow entrances and poor lighting), located on a slope with altimetric irregularities and partially covered by vegetation (olive trees, shrubs, bushes), the 3D survey of the Necropolis was performed with the integrated and synergistic use of a series of the most advanced and effective methodologies of Geomatics [3,7,9]. The geomatic survey workflow has included the following steps:

1. Creation of a 3D network by means of GNSS and Total Station, to georeference the subsequent surveys in a well-defined global datum (ETRF2000);
2. Generation of 3D point clouds of the cavities by Terrestrial Laser Scanning (TLS or T-LiDAR);
3. Total station survey of TLS targets from network points;

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4. Terrestrial digital photogrammetry as additional/alternative technique for the main cavity (Volumni's Hypogeum);
5. UAV digital photogrammetry for creating a DSM of the external ground surface;
6. GNSS NRTK survey for georeferencing the photo targets of the DSM and checking its accuracy;
7. Data post-processing and creation of the final products.

In total, 19 tombs of the Necropolis were surveyed, with a precision and a detail level that could not be reached with conventional survey methods.

A. GNSS and Total Station survey

The GNSS technique has been used for two purposes:

- to establish a reference network of the area, expressed in the global datum ETRF2000, for georeferencing the TLS and photogrammetric surveys;
- to check the accuracy of the DSM from UAV survey, through a large number of surface points measured directly.

The GNSS positioning was performed in real time (RTK base-rover and NRTK supported by the GPSUMBRIA permanent network), obtaining a <2 cm position accuracy. Two Topcon GR-5 GPS-GLONASS receivers were used. The overall scheme of the reference network is shown in Figure 1.

By means of a total station (Leica TS06), the reference network was completed connecting the GNSS points outside the tombs with 5 subnets (fig. 1), outside and inside the tombs. Finally, a large number of targets were measured with the total station from the network vertices. The targets, consisting of square plates with a black/white checkerboard pattern, are necessary for the point clouds georeferencing.

B. TLS survey

The detailed survey of the cavities was carried out using the TLS (Terrestrial LiDAR) technique. The laser scanning is one of the most powerful and productive geomatic survey systems, allowing to perform a real 3D scan of the object, thanks to its ability to measure a great number of points in short times (almost one million points per second in the present case). The result of TLS measures is a point cloud, in this case with superimposed RGB colors, deriving from an integrated camera.

A CAM2 FARO FOCUS 3D X130 instrument was used for scanning the 19 tombs, for a total of over 60 scans (900 million points) with an average resolution of about 12 mm at 10 meters distance and an acquisition time of 5-10 minutes for each scan. For describing the geometry of the cavities correctly, it is necessary to scan the object from multiple points of view in order to have overlapping areas. The clouds must be oriented to each other (relative orientation) through a 3D rototranslation maintaining a fixed reference cloud. This process requires common points between adjacent scans: a minimum of 4 targets (see above) and a set of 6 calibrated spheres, 3 of which have to be common to adjacent scans. This procedure was carried out with the Faro Scene software v. 6.2.

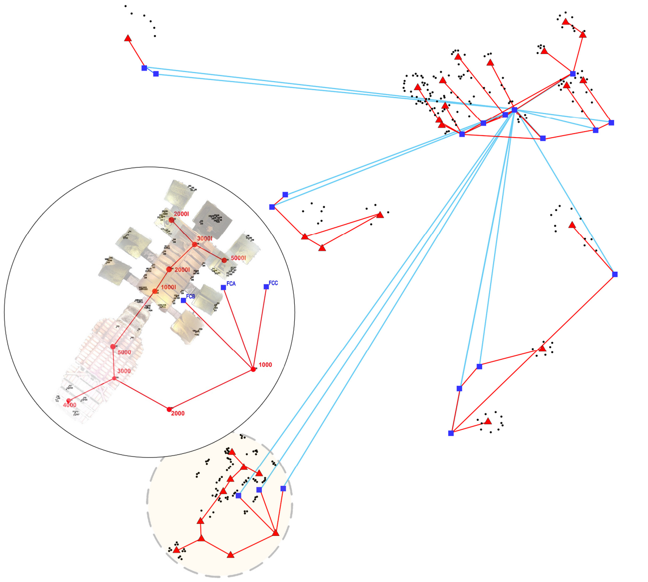

Figure 1. Reference network of Necropolis. On the left-hand side detail of Volumni's network.

The relative orientation generated a unique assembled 3D cloud (Fig. 2), where the density of the points is of the order of 1 cm from each other. The relative orientation was followed by an absolute orientation: an overall georeferencing in the ETRF2000 datum, carried out through the Leica Cyclone software v. 9.1.4. The algorithm is a spatial rototranslation on the 3D target coordinates in the assigned datum, determined by the reference network operations. The georeference residuals on targets are shown in table 1: the mean RMS value is about 5 mm.

C. Terrestrial digital photogrammetry

For the Volumni's Hypogeum (the major tomb) a 3D model was also created using high resolution digital terrestrial images. The shape and position of the object are reconstructed through photogrammetry identifying common points from multiple distinct images of the same object, through automated processes of SfM (Structure from Motion). The images, taken by a Nikon D800E camera (sensor size 24x36 mm and 36.3 megapixels resolution) were processed with the Agisoft Photoscan software v. 1.2. The result of the photogrammetric survey is also a point cloud, similar to the TLS one. It was then possible to obtain a continuous surface model by connecting the cloud points with a triangular mesh network (TIN). Both on the cloud and on the TIN surface it is possible to apply textures extracted from the digital photographs, creating a 3D photorealistic model.

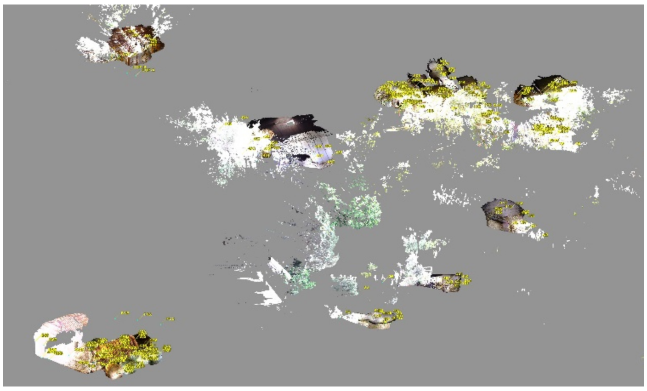

Figure 2. Final point cloud of the underground cavities resulting from the assembly of the single scans.

Target	Weight	RMS (m)	(E,N,H) residuals (m)
226	1	0.005	(0.003,0.003,-0.002)
254	1	0.003	(-0.003,0.000,-0.001)
224	1	0.005	(0.002,-0.004,0.001)
223	1	0.004	(-0.004,-0.001,0.001)
221	1	0.008	(0.001,-0.008,0.000)
225	1	0.009	(0.001,-0.009,0.001)
245	1	0.003	(-0.003,0.000,0.000)
201	1	0.004	(0.001,0.004,0.001)
203	1	0.005	(0.000,0.005,0.000)
246	1	0.003	(-0.003,0.000,0.001)
222	1	0.006	(0.003,0.005,-0.002)
200	1	0.005	(0.002,0.004,0.001)

Table 1. Resulting errors for 3D point cloud georeferencing.

D. UAV survey

A photogrammetric survey was performed with digital photographs acquired by drone (UAV) to define the geometry of the ground surface in the Necropolis area and connect it to the 3D model of the underground spaces. In order to obtain accurate results from a metric point of view, consolidated photogrammetric criteria were applied for all phases of the process (e.g. the guidelines described in [10]).

A SeeFly EBee fixed-wing drone with internal camera Canon S110 (12 MP) and GNSS receiver was used. The flight was designed to obtain a GSD (Ground Sampling Distance) of 4 cm: considering the focal length (5.4 mm), the sensor size (1/1.7″) and resolution (4000x3000 pixel) a height above ground of about 110 meters is necessary. In total, 140 frames were acquired. A set of 25 targets with checkerboard pattern (A3 size) were placed on the ground before the flight as GCP (Ground Control Points), and determined in ETRF2000 by GNSS, to georeference the survey. From the photogrammetric processing through bundle adjustment (Pix4D software), 3D digital models of the ground surface (DSM and DTM) and a digital color orthophoto of the Necropolis area were obtained. The point cloud obtained from the drone flight was then assembled to the TLS cloud, obtaining a unique 3D model of the area and the underground cavities (Fig. 3).

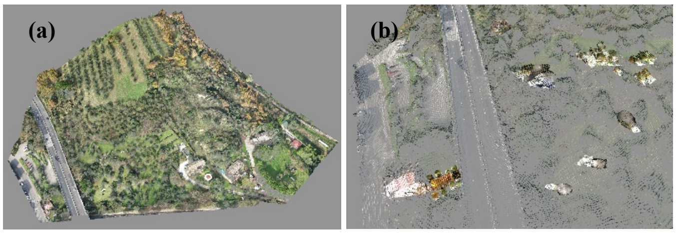

Figure 3. DSM generated by UAV survey (a) and assembled 3D model including outside and underground (b).

The accuracy of the DSM was verified performing a metric comparison between the DSM heights and those directly measured on the ground by GNSS; the Leica Cyclone software was used for this purpose. The measured GNSS points do not coincide with the DSM square grid (approximately 20 x 20 cm). For each GNSS point, the 4 surrounding points of the DSM grid were interpolated with an inverse distance algorithm, verifying the absence of significant altitude differences (> 5 cm).

A first statistical analysis of the differences shows a mean value of -0,07 m and a median of -0,06 m. Figure 5 shows the difference distribution. The few centimeters systematism is included in the altimetric accuracy of the UAV photogrammetric survey (estimated at ± 10 cm). The maximum positive and negative deviations are limited to a very low percentage of the points and are attributable to the DSM distortions caused by the presence of vegetation.

E. Geological and Geomatic data integration

As well as defining the relative and absolute geometry of the Necropolis, the geomatic survey products (3D point cloud and DSM/DTM) has allowed to reconstruct the landform units that characterize the area for a better understanding of the paleogeographic environment in which the sediments had formed. The tombs are located at different levels within the deposits belonging to Perugia hill structure, so their bare earth walls can be considered as parts of 3D geological sections, allowing to observe and describe the hill sediments from various angles (because they are oriented differently). The cavities point clouds integrated by the digital images made the “geological reading” and the paleoenvironmental interpretation easier than by simply observing surface outcrops, often hidden by vegetation or debris coverings.

The analyzed area spans from an altitude of about 210 m (Hypogeum of Volumni) to 238 m a.s.l. The analysis carried out highlighted that two lithostratigraphic units can be individuated: the Volumni Unit (Vol) and the Palazzone Unit (Plz); in both depositional units there is evidence of a fluvial-type (braided) depositional paleo-environment [8]. The geological and geomorphological structure of the area will be discussed more in detail in the full version of the paper.

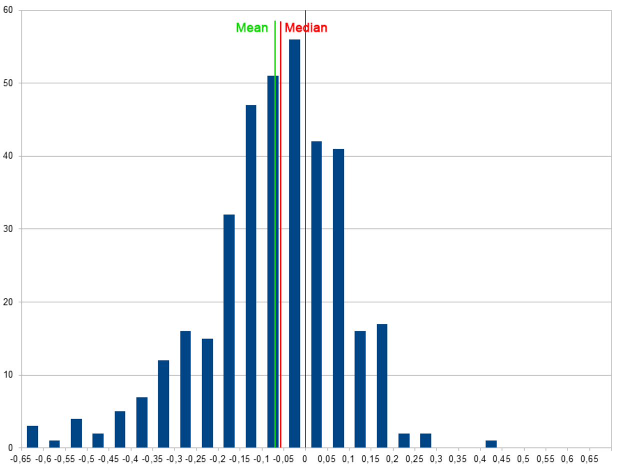

Figure 5. Statistical distribution of the differences between GNSS measures and photogrammetric DTM. Absolute frequency vs. differences in meters.

III. Final results and products

For all the surveyed tombs, a series of detailed CAD drawings were also obtained (plans, sections, internal elevations) from the 3D models, available for technical or archaeological studies. For some cavities, 3D continuous surface models with triangular meshes (TIN), created with a specific 3D modeling software (3DReshaper), allow for a more realistic and homogeneous details visualization. These models were used to create virtual tours, uploaded in the project website http://www.silenepg.it, contributing to increase the site museum visit experience.

IV. Conclusions

Geomatics plays a leading role in many applied sciences such as Geomorphometry, thanks to the ability to acquire spatial information. The integrated use of different geomatic techniques makes it possible to perform an accurate 3D survey of the outside and the underground spaces, with an accuracy of a few centimeters order. The geomatic techniques are typically non-invasive and preserve the historical and archaeological sites. They allow to obtain a very detailed documentation, both from the archaeological and the geological points of view, producing traditional drawings beside innovative digital media (3D mesh, virtual tours) increasing the tourist attraction of the site. All these data, complementary to each other, form the basis for a digital archive available at any time.

Using the geomatic techniques, it was possible to obtain a detailed geomorphological analysis allowing to recognize the lithostratigraphic units and to put them in relation with the Perugia hill structure.

This work demonstrates how the integration of different methodologies is necessary to obtain a complete model on which accurate investigations at multiple levels can be carried out.

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