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Integrated geomatic methodologies to reconstruct the ancient topography of Rome

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I. INTRODUCTION

The current urban centre of Rome is built upon up to ten metres of anthropic layers formed between the Early Bronze Age, when the Capitolium was first occupied, and the present days. These layers represent an inestimable record of the events (buildings, demolitions, collapses, fires, floods, etc.) that shaped the appearance of the eternal city. However, most of time the investigations take place near or under contemporary historical or modern structures, which made the excavations very complex from a technical point of view. One of the most complex issue become to precisely place in a common tridimensional framework the structures gradually unearthed, to compare them with the already known (and placed) ancient features (Bitelli et al., 2017; Radicioni et al., 2017). Along this line of research, starting from 2008, the Superintendence of Rome is gradually building up a webgis called SITAR (Sistema Informativo Territoriale Archeologico di Roma) (De Tommasi et al., 2012) to bring together all the archaeological features of Rome, based on the datum Roma40. The aim of this paper is to present a possible effective workflow to precisely place the ancient buildings and features using geomatic methodologies. A recent excavation in the centre of Rome will be used as a case study.

The correct reconstruction of the structures unearthed during an archaeological excavation in an urban environment must integrate geometric information from various sources and certainly:

a) Contemporary large scale cartographies of the urban fabric georeferenced to absolute reference systems (EPSG, 2020).
b) Topographic surveys with terrestrial instruments of the current excavation area that provide the coordinates of remarkable points of the area itself; the absolute positioning of the survey is often made more complex by the reduced visibility of the sky and consequently of the GPS/Gnss constellations (Alessandri et al., 2019; Baiocchi et al., 2016; Eyre et al., 2016).
c) Laser scanning surveys that provide three-dimensional point clouds and corrected images that must be oriented with respect to the points of terrestrial surveys (Angelini et al., 2017).
d) Photogrammetric acquisitions that, through classic or SFM models, can render the details of the excavation or the entire clouds of three-dimensional points (Alicandro, 2018; Chikatsu and Takahashi, 2009; Fritsch and Syll, 2015; Guarnieri et al. 2011; Lo Brutto, 2017; Mandelli et al., 2017; Nocerino et al., 2014; Perfetti et al., 2017; Stocchi et al., 2017; Troisi et al., 2017).
e) Chronicles, map drawings, diagrams, reports and photos of previous investigations in the same area, often carried out during the construction of the modern buildings; this information is generally referred to local reference systems.
f) Cartographies showing three-dimensional characteristics of the area in periods prior to urbanization, usually georeferenced in reference systems that are no longer used and difficult to reconstruct (Lelo, 2020).
g) Ancient cartographies, georeferenced in reference systems no longer known (e.g. the *Forma Urbis Romae*, fig. 1) (Cozza, 1968; Gatti, 1959).

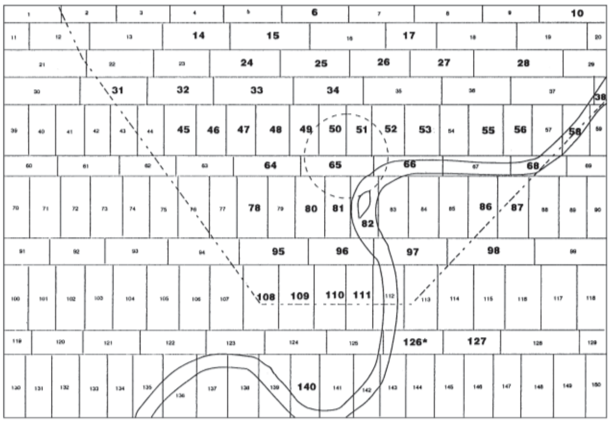

Figure 1 – Map of the slabs of the Forma Urbis Romae: the Severan Marble Plan of Rome carved in the beginning of the 3rd cent. CE (from Rodríguez Almeida, 2002)

h) Georeferenced databases of underground technological networks in use or decommissioned including: electricity grid, gas grid, sewerage system, subways and underground car parks.
i) Results of geophysical underground surveys: geoelectric, seismic and georadar. The results must also be georeferenced with respect to known points, generally obtained by topographic surveys.
j) Evidence of cognitive and/or geognostic perforations that provide detailed information on the vertical sequence of the various layers in specific remarkable points, to be positioned with classic topographic surveys.

All these sources of information must be inserted in a single three-dimensional reference system that allows to reconstruct the relative spatial relationships with at least centimeter accuracy (Barbarella, 2014; Brigante, 2014). The reconstruction of unknown local and/or historical reference systems is a complex issue that has been tackled for quite some time already (Baiocchi and Lelo, 2014; Baiocchi et al. 2013). As far as the planimetric part is concerned, a simple rototranslation is often not sufficient due to the different forms of the reference networks and the different cartographic projections used. The knowledge of some unchanged points at known coordinates can in some cases allow a reverse engineering process allowing the recovery of the original geometric information (Baiocchi and Lelo, 2010). Only in the case of surveys or maps with little extension and in local reference systems the use of simple rototranslations without major deformations can be used.

Reconstructing the altimetric reference systems (datum) is often more complex, also considering that in the city of Rome different altimetric reference systems were officially used with differences up to several tens of centimetres, during the twentieth century (Alimonti et al., 2018). This makes often difficult to establish stratigraphic correlations between surveys carried out in different periods.

II. MATERIALS AND METHODS

The current experimentation took place in the basement of a modern building in the centre of Rome (Fig. 2). The investigations were initially carried out only to verify the feasibility of some modifications to the structure of the building. Geophysical, geoelectric, seismic tests and geognostic perforation to a depth of about 25 metres were carried from the current surface. Not surprisingly, they immediately revealed archaeological features few centimetres below the pavement of the basement up to a depth of about 9 metres below surface. Following these data, an archaeological excavation was carried out to check the consistency of these findings. Soon the correct positioning of the findings become crucial, to place them in the already known ancient topography. Before starting the work, some sources listed in the previous list were already available:

a) The 1:2000 scale vector cartography of the urban area, georeferenced in Gauss Boaga coordinates (EPSG: 3004) of 2005 and the the vector cartography scale 1:5000 of the Lazio Region, georeferenced in Gauss Boaga coordinates (EPSG: 3004) of 2003

e) Report of previous excavations in the area with reliefs in local coordinates, archived at the Superintendence of Rome;

f) Historical maps available on the web in the same area such as "Carta del censo" 1:4000 of 1866 and "Nolli" 1:2910 of 1748 in planoaltimetric reference systems (Lelo, 2002).

g) The fragment 035dd (Rodríguez Almeida, 1981) from the slab 95 of the *Forma Urbis Romae* (Fig. 1), the 3rd cent. CE Marble Plan, of the area (Cozza, 1968; Gatti, 1959).

The first aim of this work was to correctly locate the data that could be obtained from the geognostic survey both planimetrically and altimetrically. The geognostic perforation was carried out starting from the ground floor of the building. This choice was dictated by logistical issues since the boring machine could not reach the basement. The heights have been referred to the ground floor which is in any case the level of the pavement on the road. Starting from a depth of 3.5m and up to a deep of 9m, anthropic materials were found and particularly the presence of stone materials of considerable thickness was observed. Unfortunately, the presence of gaps (without considering the obvious initial gap between the ground and the basement floors), probably due to the presence of cavities or different consolidation of the materials once extracted, did not allow the exact reconstruction of the heights of the different layers. This information was necessary, with as much accuracy as possible, to assess the feasibility and correctly plan further excavations to investigate the buried structures suggested by the findings of stone materials.

Figure 2 – The location of the geognostic perforation on a reconstruction of the morphologies in Roman times. (after Leonardi et al., 2010)

In order to correctly position the geognostic survey, it was not possible to directly use GPS/GNNS positioning because the drilling had been carried out indoors. Moreover, even outside the building, the height of the other surrounding buildings did not allow an easy visibility of the GPS/GNSS constellation and it was therefore necessary to design and survey a topographical network to connect some GPS stations detected nearby with the axis of the geognostic drill. The network was also used to position some photogrammetric markers that were placed in the basement room to georeference the photogrammetric surveys. The points were acquired in redundant numbers to allow the subsequent separate assessment of the accuracy and precision of the survey (Fig. 3).

In this way it was possible to position the survey axis with centimetre accuracy by taking the height of the ground floor level as a reference for all the heights within the survey. As already said, the survey had some gaps that did not allow the exact altimetric reconstruction of the succession of the layers, with particular reference to the stone materials found in the first meters. In order to overcome this inconvenience, it was decided to use the photogrammetric sockets and SFM techniques to reconstruct the inside of the survey itself.

It was necessary to remove the water present in the hole, probably due to the presence of an aquifer under pressure already known in literature (Ventriglia, 1971). Subsequently, the possibility of photogrammetric acquisition of the inside of the borehole for the three-dimensional reconstruction of its walls was verified.

Since it was not possible to have photogrammetric markers inside the hole, we decided to lay a metric webbing inside the hole itself which made it possible both to strengthen the rigidity of the model in altimetry and to orient it in the external reference system.

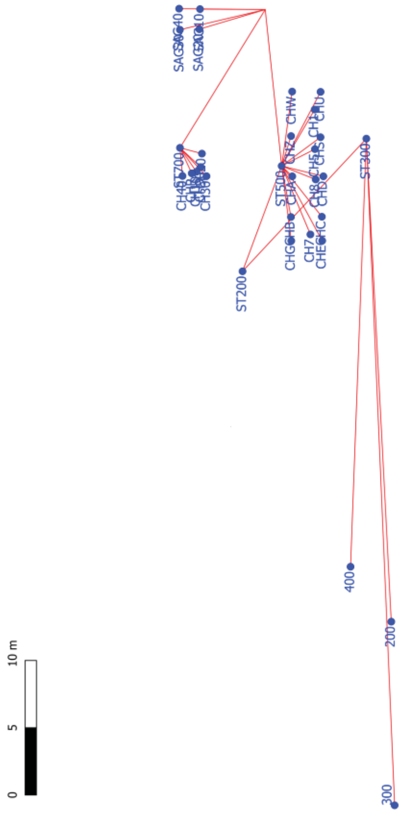

Figure 3 – Schematic view of the survey network

Several tests with different devices have been performed to verify which could be the best technical solution to correctly acquire the inside of the hole, in particular they have been tested:

1) A wireless commercial endoscope for holes, brand

Pancellent equipped with a 2.0 Megapixel camera and a coaxial illumination to the lens

2) Xiaomi Mi note 10 terminal in Macro mode

3) GoPro camera model Hero 3+ Macro mode

The main problem with such a shooting is the very small distances (10 cm. in diameter) inside the hole that make it difficult to focus the images. The endoscope had a "fish-eye" type lens that is oriented downwards with coaxial led lighting. However, it has been observed that the endoscope, mounted on a rigid flexible cable, has a tendency to easily touch the edges of the hole, making it dirty and consequently limiting the visibility and illumination of the images. The Xiaomi terminal, on the other hand, despite having good lighting and macro optics characteristics, is too bulky in size and is therefore difficult to handle correctly. The best results were obtained by mounting the GoPro camera on a rigid rod that allows to keep it with the back constantly in contact with the wall of the hole allowing the lens to acquire the opposite wall. The measurements were made in two ways. First the acquisition is made without rotating the chamber itself and always keeping the metric tape framed (Fig. 4). In this way the correlation between the various images was strengthened but only half of the hole was acquired. Then, a "swipe" was also made by rotating the camera as it went upwards, thus imposing a helicoidal motion. The two surveys were thus carried out obtaining the georeferenced three-dimensional model of the inside of the survey, allowing to verify the real thickness and depth of the stone materials crossed. This made it possible to correlate them with known or hypothesized ancient structures immediately adjacent to the building and helped to assess the opportunity and feasibility of subsequent test activities.

Figure 4 – A still frame from the GoPro video, showing a travertine block

III. CONCLUSIONS AND FURTHER DEVELOPMENTS

The experimentation constitutes the first phase of a longer work that involves the three-dimensional documentation of the various phases and probably the three-dimensional reconstruction of all the findings. It has shown the importance of correctly reporting with geomatic precision techniques all the information that can contribute to the reconstruction of the structures found or hypothesized. This approach allows a correct and safe exploration of the subsoil even in densely built-up areas.

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