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Original article

High-resolution geomatic and geophysical techniques integrated with chemical analyses for the characterization of a Roman wall

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ABSTRACT

The aim of this work is the characterization of an ancient Roman wall through high-resolution geomatic and geophysical methods. Chemical analyses were performed in order to better identify the constitutive material. The archaeological wall of pre-Trajan age, discovered in 2011, is decorated with mosaics and located in a subterranean gallery below the Trajan's Baths on the Oppian hill (Rome historical centre). The dataset was collected using a 3D high-resolution laser scanner for the reconstruction and analysis of the skin wall, a Ground Penetrating Radar (GPR) to investigate the inner core of the wall and chemical analyses to characterize the composition of plaster and mosaics. The joint interpretation of data collected with different methodologies demonstrates the capability of the proposed method to characterize the wall in terms of constructive materials and to detect fractures and discontinuities between materials. A classification of the intensity parameter was performed starting with a visual analysis of the textured model built from laser scanner data before comparing it with the georadar results and the chemical analyses of the constitutive elements of the wall. Fractures and discontinuities partially visible on the surface of the structure and present in the inner part were mapped combining laser scanner and georadar data. The obtained results show that the integrated interpretation of the proposed techniques can provide important information about composition, geometry of the wall, correlation between physical and mechanical parameters and an extensive mapping of fractures and anomalies embedded within the wall.

1. Research aims

The aim of the research presented hereafter is the application of different investigation techniques to cultural heritage in order to explore the potential of an integrated survey approach. The combination of the analyses, preformed with different techniques, allows obtaining a better description of the current conditions of the structure investigated. This information can help archeologists to plan restoration and/or safety projects.

2. Introduction

The characterization of ancient structures through non-invasive methods has been gradually affirmed when archeological campaigns are planned. Nevertheless, few studies concerning the application of a multi-method non-destructive testing have been applied in previous years for monitoring cultural heritage sites, in particular using high-resolution techniques.

Some interesting applications, involving mainly geophysical methods, include Ground Penetrating Radar (GPR) and seismic tomography [1,2], GPR and Electrical Resistivity Tomography [3] or geomatics and geotechnical methodologies [4].

In the following paragraphs, the joint application of high-resolution geomatics (laser scanner), geophysical (GPR) techniques and chemical analysis is proposed to characterize an archaeological wall of pre-Trajan age [5].

The Terrestrial Laser Scanner (TLS) has been widely used to reconstruct the shape and the volumes of complex objects and

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structures, within projects aimed at the implementation of different survey techniques (e.g. 3D laser scanner, ground base radar interferometry) adopted to monitor the conservation conditions of historic sites [6–8].

Laser scanners are a well-known geomatic methodology that allows the acquisition of the 3D spatial coordinates of a dense point cloud that describes the shape of an object with a very high level of accuracy (ranging from a few millimeters to some centimeters) [9]. An intensity parameter can be associated at each point, which is a function of the distance to the object, the angle of incidence of the laser beam and the object's reflectance properties [10]. The intensity parameter was used to differentiate materials.

When a calibrated camera is coupled with the TLS, a digital representation of the surveyed object can be obtained as a function, for each point, of a radiometric value (RGB parameter).

Ground penetrating radar (GPR) has had widespread use for archaeological prospection during the last few decades to detect and characterize ancient structures [11–14] and to locate Roman buildings [15–17]. Studies using GPR confirmed the capability of the GPR method for investigation of structures, to define the constructive materials and to locate and detect voids and hidden objects inside ancient structures.

The study was completed with the chemical characterization of the materials constituting the mosaic and plaster, in order to determine the construction techniques and the quality of execution. Chemical exams where carried out by integrating optical and electron microscopy, spectroscopy and thermo-gravimetric analyses.

All these elements are useful to assess the current state of the structure and to provide indications to the archaeologists.

The proposed study involves the sequential application of TLS, GPR and chemical analysis for the characterization of a Roman wall that cannot be investigated with intrusive methods because covered by a precious mosaic. The integrated interpretation of the proposed techniques can provide important information about composition, geometry of the wall, correlation between physical and mechanical parameters and an extensive mapping of fractures and anomalies embedded within the wall.

TLS and GPR data were referenced in a common reference system having the xy plane coinciding with the plane of the mosaic wall and the z-axis directed inward.

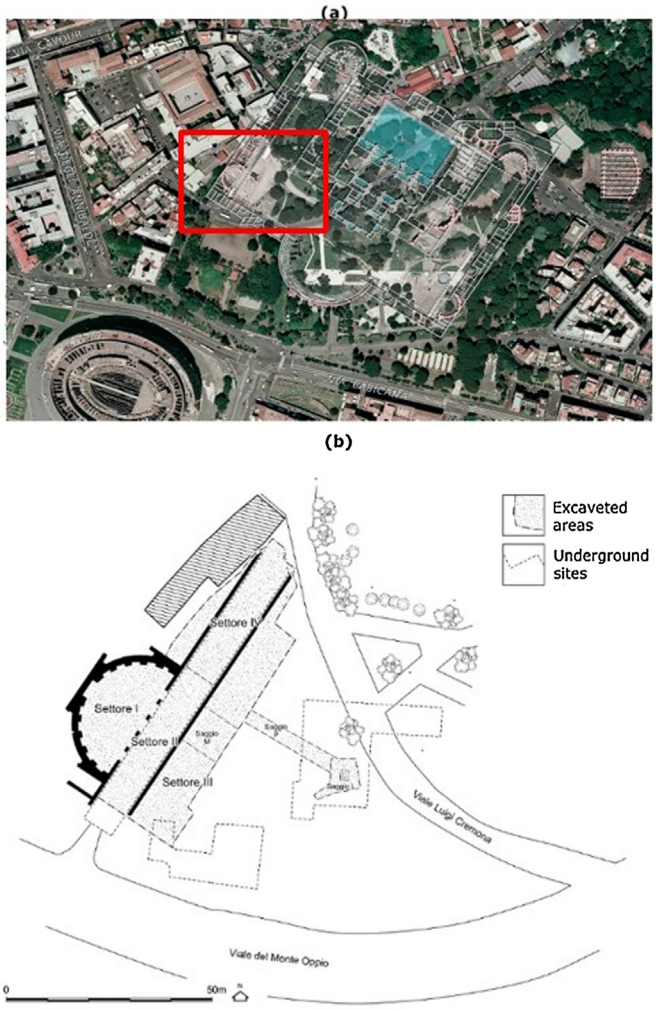

Fig. 1. (a) Archeological plan of the excavated area. (b) Enlarged view of the area within the black square.

3. Archaeological site description

In 1998, the archaeological excavations carried out by the Sovrintendenza Capitolina ai Beni Culturali (Authority of Cultural Heritage of Rome) in the southwest corner of the Trajan's Baths on the Oppian hill in Rome (Fig. 1) (near the Domus Aurea) brought to light an extraordinary large painted fresco with the representation of an ancient city.

The fresco, named "The Painted City", pertained to a building preserved inside a subterranean gallery below the Baths and the painting itself was older than the baths.

Subsequent archeological excavations inside the gallery itself revealed other evidence of a whole district of ancient Rome: these buildings dated after 64 AD, the year of the famous Nero's fire that destroyed this part of the City, and earlier than the Trajan's Baths, opened on June 22, 109 AD.

The gallery was in fact built to support the Bath's porticus above (15/16 meters higher) and was based upon the earlier buildings that are well preserved below the baths themselves. Since the Trajanic construction is oriented differently from the earlier buildings, they arise diagonally with respect to the gallery.

The building with the fresco of the "Painted City" was located on the bottom of the gallery, whereas another building was found in the middle of the gallery itself, with a large room of about 10×16 meters, which preserves wide areas of wall mosaic. This room, connected with a nymphaeum, was probably part of a larger *domus*, most of which hasn't been excavated.

The larger wall of this room extends for 15 m long and 0.9 m wide (Fig. 2), while its height, hitherto not entirely discovered (originally maybe 10–11 m), is currently ranging from 3 to 5 meters. It is partially decorated with mosaics with at least two orders of representation: in the upper part stands the God Apollo with the Muses, and in the lower part is a columned portico, with people standing both in front of and inside it.

The earlier phase of this wall is partially exposed in the lower part, formed by large travertine blocks, which suggest the existence of three entrances; in the later phase a brick masonry was superimposed upon the wall and placed inside the doors, which were then closed; the mosaics, upon a thick layer of plaster, were placed all over the wall.

Since this wall consists of different materials (travertine and bricks), which are largely covered by plaster and mosaics, it was essential to assess the material types and the integrity of the wall, in order to avoid any possible collapse during the further excavations. In light of this, it was crucial to achieve an accurate mapping of them, using data acquired by means of geophysical investigations and laser scanning and to retrieve information about composition and quality of plaster and mosaic through chemical analysis.