New results from the GPR surveys at the area surrounding the Basilica at S. Croce in Gerusalemme, (Roma, Italy)

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Abstract

The ERC Rome Transformed Project, launched for the study of the Eastern Caelin in Rome, aimed to detect and map the archaeological structures under this portion of the town without performing excavations. In the present paper the new results from the surveys made with GPR method to investigate different sites in the surrounding area of the Basilica at Santa Croce in Gerusalemme, as part of the ERC-funded Rome Transformed project (2019-2025) are presented and discussed. In particular the results obtained in the area of the *Castrense* amphitheatre and the *carceres* near *Circus Varianus* are presented and analysed.

I. INTRODUCTION

Recent research issues have been developed to the investigations in urban area with the aim to locate subsurface targets, as cavities and/or archaeological remains, and to produce hazard mapping. For these kind of applications the geophysical methods can be employed to identify feature geometries by observing contrasts in physical properties, but the presence of utilities, structures and surficial debris can interfere with instrument measurements. In this context, the most useful non-destructive geophysical prospection method for urban surveys is GPR (ground penetrating radar), [1], [2], [3].

Modern underground structures (as bars and slabs of reinforced concrete, metallic pipes, cables and associated trenches and building debris) occurring at shallow depth often display a stronger contrast in physical properties relative to the surrounding subsoil than less well expressed archaeological structures, which often are buried at greater depth, [2], [3], [4].

Challenges for GPR survey in city centres lie in the large number of obstacles present in the urban environments. Traffic islands, metallic gully covers, lamp posts, buildings, trees and parked vehicles cause irregular survey geometries, holes in the surveyed area and disturbing anomalies in the GPR measurements.

The Rome Transformed Project, developed for the study of the Eastern Caelin in Rome, aimed to detect and map the archaeological structures under this portion of the city without performing excavations. The project aims to enhance the knowledge of Rome place in cultural change across the Mediterranean world by mapping political, military and religious changes to the Eastern Caelian from the first to eighth centuries AD, [5], [7], [8].

This project has made it possible to design and develope a new methodology for the study of ancient topographical and archaeological remains buried in urban contexts that until now have been little studied because of their complexity. This complexity is linked to several well-known constraints that we have to cope with: high footprint over the ground of urban furniture, cars, but also tourists; high impact in the subsoil of utilities but also complexity of archaeological multi-phased deposits and finally a disturbed electromagnetic spectrum, [6].

The Rome Transformed Project is developed between: the New Castle University (UK), PI Prof. I. Haynes; the Florence University (Italy), Prof. P. Liverani and Prof. M. Azzari; the British School at Rome (Italy), Dott. S. Kay and the Institute of Heritage Sciences (ISPC-CNR, Roma), Dott. S. Piro.

Studying an urban centre needs to minimize the above mentioned constraints. The constraints situated over the ground surface can be minimized thanks to a rigorous prior management. The subsoil constraints assume that the plan and depth of the known servitudes, possibly georeferenced, are available in advance, as well as the location of the visible sewer drains on the surface.

In the present paper the new results from the surveys made with GPR method to investigate different sites in the surrounding area of Santa Croce in Gerusalemme (areas 3.1, 3.2, 3.6 and 3.8), as part of the ERC-funded Rome Transformed project (2019-2025) are presented and discussed, Fig.1. The interpretations of the obtained GPR results were developed through the collaboration of Thea Ravasi and Gianluca Foschi of the Rome Transformed research team.

The area SA3.1 corresponds to the *Castrense* amphitheatre constructed entirely in *opus testaceum* during Severian period; the building served as a venue for spectacles [9]. It was later incorporated into the Aurelian Wall. Today only part of the first architectural order and a

small portion of the second can be seen on the building's exterior. Another aim of the archaeological studies, in this area, was specifically to locate the *carceres* connecting the right and left wing of the *Circus Varianus*.
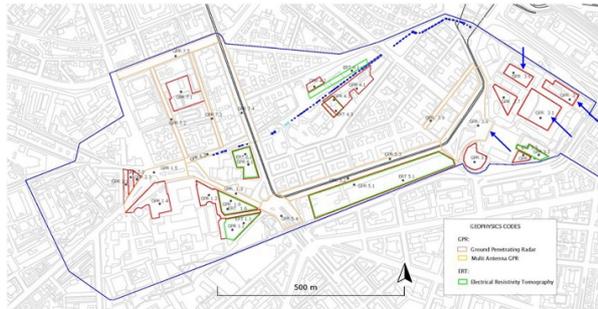

Fig.1 – Rome, the Eastern Caelian. Location of the area SA3.1, 3.2, 3.6, 3.8, investigated with GPR methods,

The Basilica of Santa Croce in Gerusalemme (area SA3.8) presents a complex and layered structural history, intrinsically linked to its origins as part of the *Sessorian Palace* in Rome. The structural analysis made by Rome Transformed team (Ravasi and Foschi) of the surviving evidence has identified few main structural phases, one of this, that is not archaeologically documented, has been suggested by GPR survey carried out inside the Basilica by CNR ISPC team. The aim of the GPR surveys was to locate, into the ground, possible remains of these archaeological structures at different depths.

II. METHOD

In this complex urban area a series of geophysical surveys employing GPR (Ground Penetrating Radar) with different systems equipped with different antennas (frequencies) were carried out. For the field measurements a GSSI SIR3000 equipped with a 70 MHz monostatic antenna and a GSSI SIR4000 system equipped with digital bistatic dual frequency antenna with 300/800 MHz were employed. The horizontal spacing between parallel profiles at the site was 0.50 *m*, employing these antennas. Radar reflections along the transepts were recorded continuously, with different length and horizontal stacking set to 3 scans.

Acquisition was made using a high-resolution approach in which parallel profiles were recorded very closely across the site. Signal processing, image processing, and visualization techniques have been used in conjunction with data modelling, elaboration, and interpretation of the recorded subsurface amplitudes, [10].

The surveys at the surrounding areas of the Basilica of Santa Croce in Gerusalemme (SA3.1 – 3.2 – 3.6 – 3.8) were undertaken in early July 2020, early October 2020 and mid January 2021 by a team from CNR ISPC, [3].

In the area SA3.1 – 3.2 – 3.6, a total of 455 adjacent

profiles across the site were collected alternatively in forward and reverse directions employing the GSSI cart system equipped with odometer. All radar reflections within the 140 ns (twt) time window for 70 MHz antenna and a depth range of 2-4 m with 300/800 MHz antenna were recorded digitally in the field as 16 and 32 bit data, respectively, and 512 samples per radar scan.

III. PROCESSING AND RESULTS

During the elaboration of the single ground penetrating radar profiles, the following electromagnetic signal analysis procedure was applied: (a) analysis of the radargram and application of a suitable gain function; (b) removal of DC drift (antenna/ground coupling effect); (c) resampling of radar traces along each single profile; (d) application of the bandpass filter on each single profile; (e) application of the background removal filter on each individual profile; (f) migration.

With the aim of obtaining a planimetric vision of all possible anomalous bodies the time-slice (2D planimetric image) representation technique was applied using all processed profiles, [10], [11]. Time-slices are calculated by creating 2-D horizontal contour maps of the averaged absolute value of the wave amplitude from a specified time value across parallel profiles.

Reflection amplitude maps (time slice data sets) were generated by spatially averaging the squared wave amplitudes of radar reflections in the horizontal as well as the vertical. The squared amplitudes were averaged horizontally every 0.25 *m* along the reflection profiles and 3 *ns* (for 300 *MHz* antenna) and 6 *ns* (for 70 *MHz* antenna) time windows (with a 10% overlapping of each slice) vertically. The resampled amplitudes were gridded using the inverse distance algorithm with a search radius of 1.00 *m*. All the GPR profiles were processed with GPR-SLICE v7.0 Ground Penetrating Radar Imaging Software.

Figure 2 shows the anomalies located at the estimated depth of 0.80 m, individuated in the area SA 3.1, 3.2 and 3.6. At this depth, the area is characterized by many reflections due to portion of possible structures.
Area A1-2 (area SA3.1) – A1: two circular anomalies with size 1.3 m and diameter 6.0 m; A2: linear anomaly with dimension 1.2 m x 41.0 m. A3: anomaly with dimension 1.4 x 48.5 m; A4: anomaly with dimension 3.1 x 23.4 m; A5: anomaly with dimension 1.4 x 5.0 m (3 segments of perpendicular utilities ?).
Area B (area SA3.2) - this area is characterized by the presence of many linear and perpendicular anomalies with the following dimensions: B1: 1.2 x 78 m, and 1.2 x 19.8 m (the shorter); B2: 3.7 x 6.4 m and B3: 3.2 x 2.2 m.

Area C (area SA3.1) - at this depth we observe a big high reflected surface with dimension of 109 square meters.

Fig. 2 – Areas SA3.1, 3.2 and 3.6. GPR time-slices at the estimated depth of 0.80 m.

Figure 3 shows the anomalies located at the estimated depth of 1.30 m, individuated in the area SA 3.1, 3.2 and 3.6. At this depth there are few short anomalies with high reflections along the limit of the investigated area.
Area A1-2 (SA3.1) – it is visible the A7 anomaly, due to an utility, with dimension 1.0 x 21.20 m (visible part). It is visible also the A8 anomaly with dimension 2.4 x 11.0 m (visible part). The other indicated anomalies are confirmed with the same dimensions observed at the minor depth.
Area B (SA3.2) – together with the previous anomalies that are confirmed, there is also the B4 anomaly with dimension 2.2 x 5.5 m.
Area C (SA3.1) – it is still present the C1 anomaly with larger dimension.

Fig. 3 – Areas SA3.1, 3.2 and 3.6. GPR time-slices at the estimated depth of 1.30 m.

Figure 4 shows the anomalies located at the estimated depth of 1.90 m, individuated in the area SA 3.1, 3.2 and 3.6. Area A1-2 (SA3.1) – the A7 anomaly, due to an utility, it is not visible. It is visible the A8 anomaly with dimension 2.4 x 11.0 m (visible part), but this anomaly is characterized by an extension of three linear segments with average dimension of (12.4 x 2.5 m) northern portion, (1.8 x 28.7 m) eastern portion and (10.8 x 2.1 m) southern portion. It is still present the A9 anomaly characterized by

two symmetrical portions with dimension 2.5 x 8.2 m at a distance of 17.8 m (as a portion of rectangular room). The other indicated anomalies are confirmed with the same dimensions observed at the minor depth.
Area B (SA3.2) – together with the previous anomalies that are confirmed, there is also the B4 anomaly with dimension 2.2 x 5.5 m.
Area C (SA3.1) – it is still present the C1 anomaly characterized by two semicircular portion with dimension 3.0 x 18.0 (western portion) and 3.0 x 8.7 m (eastern portion).

Fig. 4 – Areas SA3.1, 3.2 and 3.6. GPR time-slices at the estimated depth of 1.90 m.

Figure 5 shows the anomalies located at the estimated depth of 1.30 m, individuated in the area SA 3.8, square in front of Basilica at S. Croce in Gerusalemme. At this depth the area is characterized by the following anomalies. P1: main anomaly due to a utility (probably a channel hosting underground services), with dimension 2.4 x 46.8 m (visible part); P2: an utility with dimension 0.8 x 39.7 m; P3: a diffused anomaly, with the main with dimension 3.9 x 7.0 m. P4: anomaly with dimension 1.0 x 4.8 m (visible part).
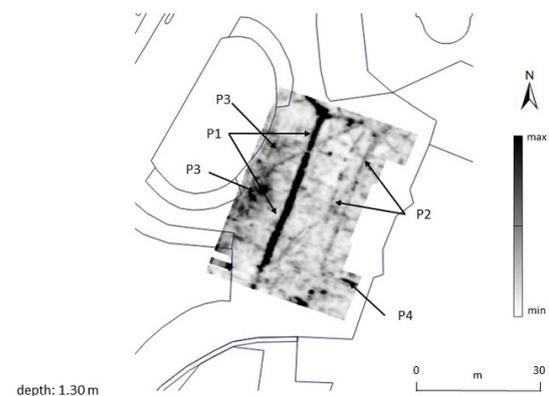

Fig. 5 – Areas SA3.8. GPR time-slices at the estimated depth of 1.30 m.

Figure 6 shows the anomalies located at the estimated depth of 2.10 m, individuated in the area SA3.8. At this depth the P1 anomaly is still visible with the same size and length. Inside the P5 position it is visible an anomaly with dimension 3.0 x 6.0 m. In the P4 position is visible a portion of the observed anomaly with dimension 0.7 x 3.4 m.
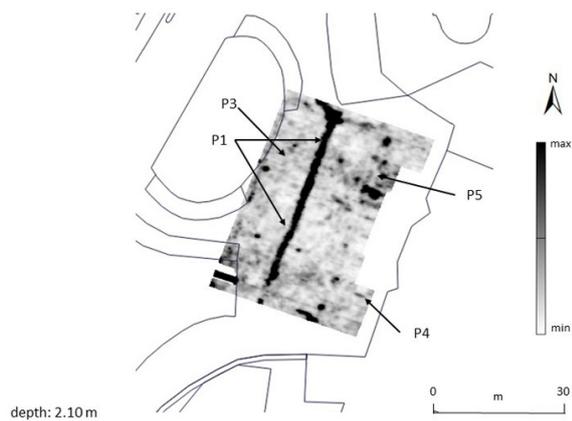

Fig. 6 – Areas SA3.8. GPR time-slices at the estimated depth of 2.10 m.

Fig. 7 – Areas SA3.1. GPR time-slices at the estimated depth of 2.10 m.

IV.   CONCLUSIONS

Anomalies from the GPR surveys, obtained in the area SA3.1, that can be interpreted as evidence of *carceres* have been identified at a level of 0.8 m below ground to 4.0 m in depth (corresponding to the lower limit of the investigation). In the 70 MHz antenna survey, what seems to correspond to the line of the *carceres* becomes visible at 2.8 m below ground, an altitude that matches the level of the second-phase lane in the northern excavations of the *Circus Varianus*, Fig.7.

Currently, the best evidence for positioning the *carceres* in the GPR survey conducted as part of the Rome Transformed project, anchored to GPS points accurate within a few centimetres. The key to positioning the *carceres* has been identifying the foundation grid of the north wing of the Caserma Umberto I in the georeferenced GPR survey, Fig.8. The foundations appear in the GPR slices at a depth of 0.8 m below the current ground level and can be readily anchored to their outline in the original excavation plans of the *carceres*.

It was in the spaces between these foundations that archaeologists excavated the connection between the *carceres* and the north wing of the *Circus Varianus* in the early 1960s. Consequently these foundations provide a grid close enough to the *carceres* structures to allow for more accurate positioning than was previously possible.
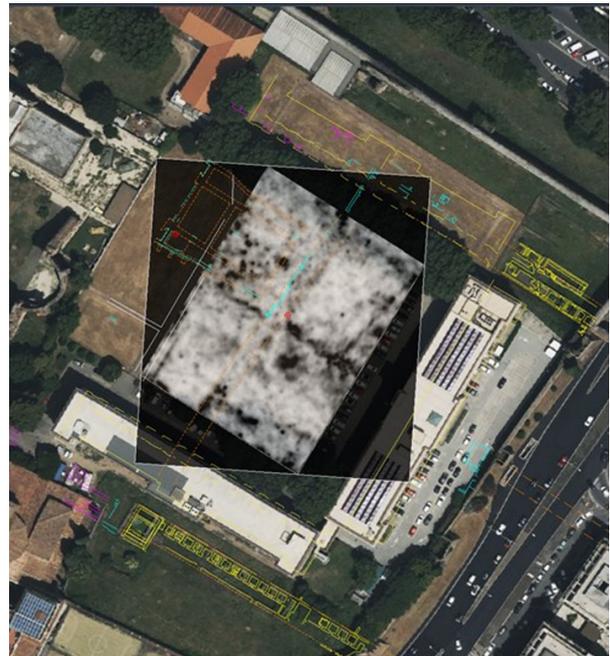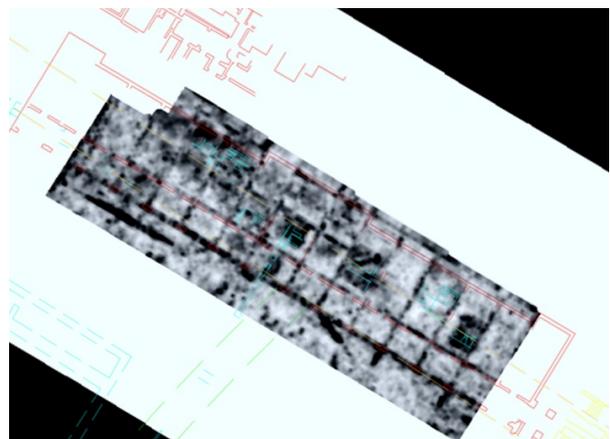

Fig. 8 – Areas SA3.2. GPR time-slices at the estimated depth of 0.80 m.

Employing Ground Penetrating Radar method to investigate unexcavated areas around the Basilica at S. Croce in Gerusalemme site allowed us to recognize features which are compatible with the information given by the archeologists in terms of architecture and structure type. The detailed analysis of the results obtained employing GPR surveys, allowed us to recognize the organization of this sectors of the town.

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