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Multiple GPR surveys in urban area. The case of S. Giovanni in Laterano and S. Croce in Gerusalemme, as part of ERC Rome Transformed Project.

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Abstract

The geophysical prospection is generally considered as the attempt to locate structures of archaeological interest buried in the natural subsoil, but in many cases, when applied in urban centers, this attempt could file due to the effect and disturbances caused by recent man-made structures in the subsoil, covering any signal related to possible archaeological structures. In the present paper the GPR surveys carried out in two urban archaeological sites in Roma, characterised by different targets and environmental conditions, are presented and discussed.
The Rome Transformed 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 [4]. An important aspect of the project strategy is the employment of different geophysical methods (GPR and ERT) suitable for deep stratigraphic urban investigations. In the present paper the surveys made with GPR method to investigate different sites in the area of S. Giovanni in Laterano and Santa Croce in Gerusalemme, as part of the ERC-funded Rome Transformed project (2019-2024) are presented and discussed.

I. INTRODUCTION

In the last decades, research and technical issues are related to the geophysical prospection in urban area to locate archaeological remains and/or subsurface cavities to produce hazard mapping. In many cases, cavities, voids and collapses represent disruptions to the geometry of an originally near-horizontal layered system.
Geophysical methods can be employed to identify the feature geometries by contrasts in the physical properties, but can be strongly influenced by cultural features that interfere with instrument measurements (utilities, structures, surficial debris).
The critical phase of the geophysical prospection in urban area is related to the processing and the interpretation of the collected data and the characterization of the degree of confidence in the interpretations.
Urban subsoil often consists of many layers which attest the history of a place, preserving in essence records of alternating phases of construction and destruction.
The shallow subsurface of modern cities contains reams of pipes, cellars, wells, cavities, tunnels, graves and foundation walls of former houses, churches and town fortifications.
As known, the most promising non-destructive geophysical prospection method for use in urban area is GPR (Ground Penetrating Radar). GPR measurements are less affected by the presence of metallic structures than magnetometry and they result in the largest amount of data of all commonly employed near-surface geophysical methods, providing detailed three-dimensional information about the subsurface, [1], [2] and [3].
While geophysical prospection is generally considered as the attempt to locate structures of archaeological interest, in many cases, when applied in urban centres, this attempt could fail due to the effect and disturbances caused by recent man-made structures in the subsoil, which veil any signal related to structures of archaeological interest.
Challenges for GPR prospection 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.
In the complex site considered in the Rome Transformed Project, a series of GPR surveys employing different frequencies were carried out.
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In the present paper the surveys made with GPR method to investigate different sites in the area of S. Giovanni in Laterano and Santa Croce in Gerusalemme, as part of the ERC-funded Rome Transformed project (2019-2024) are

presented and discussed, Fig. 1. 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.

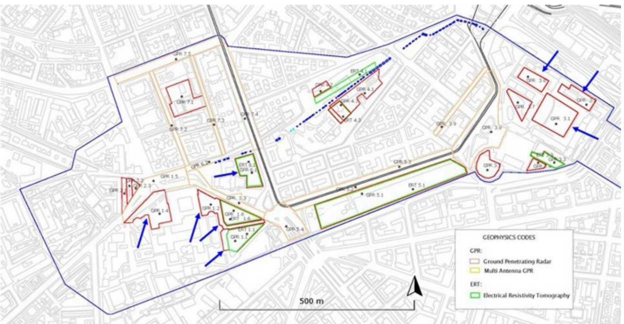

Fig.1 – Rome, the Eastern Caelian. Location of the area investigated with GPR methods.

II. METHOD

For the field measurements two different GPR SIR3000 and SIR4000 Systems (GSSI), the first equipped with a 400 MHz antenna with constant off-set and the 70 MHz monostatic antenna, the second equipped with digital dual frequency antenna with 300/800 MHz were used. The 400 MHz antenna was as a compromise between depth penetration to about 2 - 3 meter and resolution of features on the order of 0.15 – 0.20 m in order to define the archaeological features of interest. The 70 MHz antenna was employed to investigate at a depth penetration more than 2 - 3 m and with a resolution more than 0.30 m. The 300/800 MHz antenna was employed to investigate simultaneously two different depth ranges, 0-3 and 0-5 m, with different resolution.

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 [5]. With the aim of obtaining a planimetric vision of all possible anomalous bodies the time-slice representation technique was applied using all processed profiles, [5] and [6]. 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.

All the GPR profiles were processed with GPR-SLICE v7.0 Ground Penetrating Radar Imaging Software (Goodman, 2020).

III. PROCESSING AND RESULTS

All the GPR profiles collected with this standard equipment were processed with GPR-slice v7.0 Ground Penetrating Radar imaging software [6]. For each profile, a vertical ground penetrating radar section was obtained in which, by means of a suitable chromatic scale, the values of the amplitudes of the reflected waves are reported, according to the chosen time (or depth) scale.

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 was calculated using all processed profiles [6].

The results obtained in the current elaboration and interpretation phase are related to different levels of depth (surfaces) for an investigated subsoil thickness (depth) equal to 4.0 – 6.0 m.

San Giovanni in Laterano

A part of the area around S. Giovanni in Laterano Basilica was previously investigated (2012) by team members of Rome Trasformed Project employing GPR equipped with 400 and 70 MHz antenna. Many traces of possible archaeological structures were found, in particular recorded in the north-western area of the Piazza S. Giovanni in Laterano, [6].

The aim of the new GPR surveys is on the one hand to verify what has already been identified with the previous GPR surveys to locate Roman and high-medieval age remains and on the other to extend the area to be investigated towards the south of the square. The survey at San Giovanni in Laterano square was undertaken between in early March 2020 and a comprised a team from CNR ISPC.

For the measurements a GPR SIR3000 (GSSI), equipped with a 400 *MHz* (GSSI) bistatic antenna with constant offset, a 70 *MHz* (Subecho Radar) monostatic antenna and a SIR4000 (GSSI) system equipped with dual frequency antenna with 300/800 MHz were employed.

The horizontal spacing between parallel profiles at the site was 0.50 *m*, employing the four antennas. Radar reflections along the transepts were recorded continuously, with different length, and horizontal stacking was set to 3 scans.

In the area outside and around the Basilica (Piazza S. Giovanni in Laterano e Piazza Giovanni Paolo II) a total of 876 adjacent profiles across the site were collected alternatively in forward and reverse directions employing the GSSI cart systems equipped with odometer. All radar reflections within the 90*ns* for 400 *MHz* antenna, 125-140 and 230 *ns* for 70 *MHz* antenna (two-way-travel) time windows 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 and 512 samples per radar scan.

A nominal microwave velocity of about 0.12 *m/ns* was determined from fitting hyperbolas to the raw field data. This was used in estimating a penetration depth from the GPR survey.

With the aim of obtaining a planimetric vision of all possible anomalous bodies, the time-slice representation technique was applied using all processed profiles showing anomalous sources up to a depth of about 2.5 m, [5].

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 3 *ns* (for 400 *MHz* antenna) and 6 *ns* (for 70 *MHz* antenna) time windows (with a 10% overlapping of each slice). The resampled amplitudes were gridded using the inverse distance algorithm with a search radius of 0.75 *m*.

Figure 2 shows the time slices corresponding to the estimated depth of 0.8 m obtained with the 400 MHz antenna in the San Giovanni in Laterano square. The size of the anomalies indicated in the figure are approximate. A1: this anomaly is due to the presence of utility and it is characterized by low intensity; A4: anomaly with small dimension; A6: area with few anomalies without any defined geometrical shape, the surface is about 9.0 x 2.7 m; A7: area with anomalies; A8: anomaly with dimension 4.8 x 2.1 m; A9: anomaly with angular shape and dimension 14.1 x 8.6 m; A10: anomaly due to probable utility with dimension 43.5 x 0.7 m; A11: semicircular anomaly with dimension 21.2 x 1.1 m.

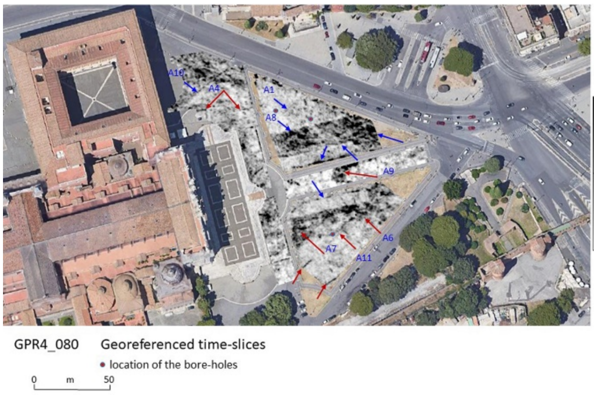

Fig.2 – S. Giovanni in Laterano square. GPR time-slices at the estimated depth of 0.80 m.

Figure 3 shows the time slices corresponding to the estimated depth of 1.5 m obtained with the 400 MHz antenna, in the area GPR 1.1, 1.2 and 1.6. At this depth the area are characterized by many reflections due to the presence of portion of structures. The size of the anomalies, indicated below, are approximate. A4: traces of linear anomalies (possible walls); A12: utility with the dimension 106.5 x 1.4 m; A13: circular anomaly with diameter 7.30 m and size 1.1 m; A14: anomaly with L shape and dimension (7.8 x 1.4 m) + (5,1 x 2.2 m).

Fig. 3 – S. Giovanni in Laterano square. GPR time-slices at the estimated depth of 1.50 m.

Santa Croce in Gerusalemme

The surveys at Santa Croce in Gerusalemme were undertaken in early July 2020, early October 2020 and mid January 2021 by a team from CNR ISPC (Roma).

For the measurements a GSSI SIR3000 equipped with a 70 MHz monostatic antenna and a SIR4000 system equipped with digital dual frequency antenna with 300/800 MHz were employed. The horizontal spacing between parallel profiles at the site was 0.50 *m*, employing this dual frequency antenna. Radar reflections along the transepts were recorded continuously, with different length and horizontal stacking set to 3 scans.

In this area 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 and 512 samples per radar scan. Time slice data sets were generated by spatially averaging the squared wave amplitudes of radar reflections in the horizontal as well as the vertical.

Figure 4 shows the time slices corresponding to the estimated depth of 1.3 *m* obtained with the 300 MHz digital antenna. The GPR images are characterized by the presence of many anomalies with different dimension and shapes with a regular geometrical location. At this depth the area (A) is characterized by many reflections due to portion of possible structures. A1: two circular anomalies with size 1.3 m and diameter 6.0 m; A2: linear anomaly

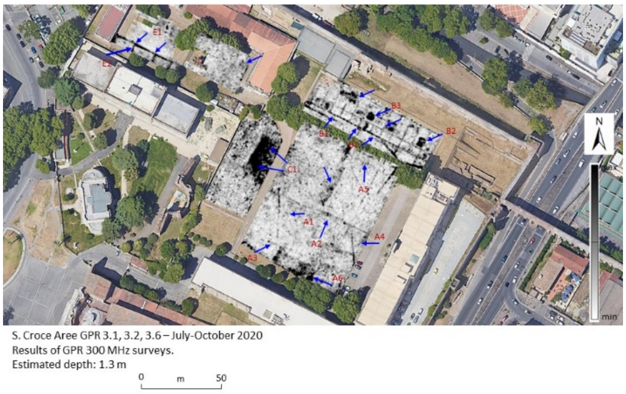

Fig. 4 – S. Croce in Gerusalemme. GPR time-slices at the estimated depth of 1.30 m.

with dimension 1.2 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 (three segments of perpendicular utilities). In the sector (B) the area is characterized by the presence of many linear an perpendicular anomalies with the following dimensions, B1: 1.2 x 78 m and 1.2 x 19.8 m (the shorter); B2: anomaly with dimension 3.7 x 6.4 m and B3: with dimension 3.2 x 2.2 m. In the sector (C) we observe a big high reflected surface with dimension of 109 square meters. In the sector (D) we do not observe any clear anomalies, but a different small reflections. In sector € we observe two kinds of linear and perpendicular anomalies with dimensions, E1: 0.9 x 12.0 m and E2: 0.7 x 4.3 m.
Figure 5 shows the anomalies located at the estimated depth of 1.9 m, individuated in the area GPR 3.1. In the sector (A) there are few short anomalies with high reflections along the limit of the investigated area. In the sector (B) we observe an enhancement of the dimensions for B4: 2.3 x 5.9 m and B5: 5.0 x 2.0 m. In the sector (C) it is possible to observe two semicircular anomalies with dimension, size 1.8 m at a distance, each other, of 3.4 m. In the sectors D and E we observe only few linear anomalies.
Figure 6 shows the anomalies located at the estimated depth of 1.9 m, individuated in the area GPR 3.8. In the square area we observe the following anomalies. P1: main anomaly due to an utility (probably a channel hosting underground services), with dimension 2.4 x 46.8 m (visible part). 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). P5: in this position we observe few highest reflections with not regular shape and average dimension of 1.6 x 2.0 m, contained inside an anomalous area with a surface of 42.4 square meters.

IV. CONCLUSIONS

Ground Peetrating Radar (GPR) surveys at the selected areas produced significant and fruitful results which demonstrate that when appropriately targeted and analysed GPR can be successfully undertaken for archaeological purposes in complex urban environments.
This project is still in progress with the integrated interpretation of all results obtained with the geophysical methods together with the indications and hypothesis proposed by the archaeologists.

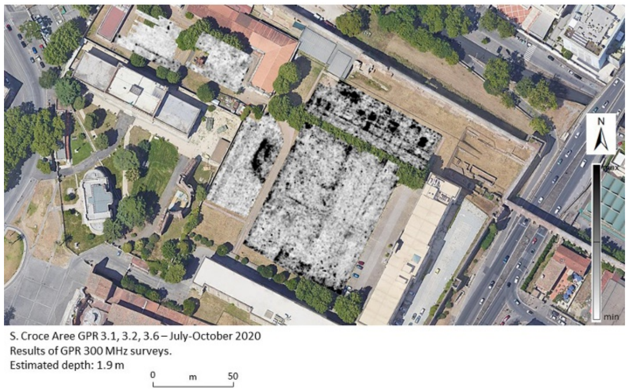

Fig. 5 – S. Croce in Gerusalemme. GPR time-slices at the estimated depth of 1.90 m.

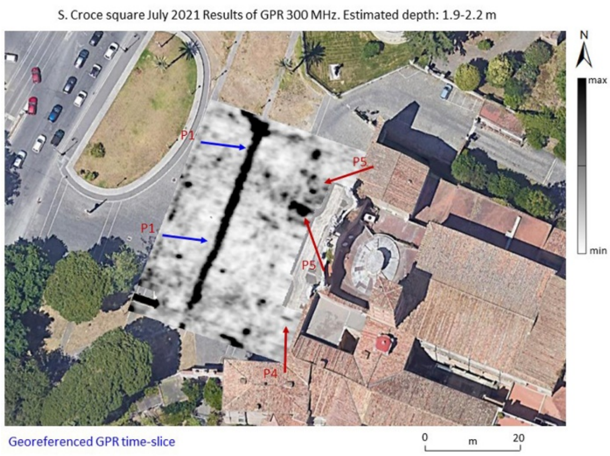

Fig. 6 – S. Croce in Gerusalemme square. GPR time-slices at the estimated depth of 1.90-2.20 m.

REFERENCES

[1] Trinks I., P. Karlsson, A. Biwall and A. Hinterlaitner, 2009. Mapping the urban subsoil using ground penetrating radar – challenges and potentials for archaeological prospection, ArchaeoScience, revue d'archeometrié, suppl. 33, pp. 237-240.

[2] Piro S. and D. Goodman, 2008. Integrated GPR data processing for archaeological surveys in urban area. The case of Forum (Roma, Italy), 12th International Conference on Ground Penetrating Radar, June 16-19, 2008, Birmingham, UK. Proceedings Extanded Abstract Volume.

[3] Piro S., Zamuner D., 2016. Investigating the urban archaeological sites using Ground Penetrating Radar. The cases of Palatino Hill and St John Lateran Basilica (Roma, Italy). Acta IMEKO, Vol. 5, issue 2, pp 80-85. ISSN: 2221-870X. DOI: 10.21014/acta imeko/v5i2.234 .

[4] Haynes, I.P., Liverani, P., Kay, S., Piro, S., Ravasi, T. and Carboni, F. 2020. Rome Transformed: Researching the Eastern Caelian C1-C8 CE (Rome), in *Papers of the British School at Rome* 88, pp. 354-357.

[5] Goodman D., Piro S., 2013. GPR Remote sensing in Archaeology, Springer: Berlin.

[6] Piro S., Haynes I., Liverani P., Zamuner D., 2020. Ground Penetrating Radar Survey in the Saint John Lateran Basilica. In "The Basilica of Saint John Lateran to 1600", Ed.s Bosman L., Haynes I.P., Liverani P. Cambridge University Press (London, UK), pp. 52-70, ISBN: 978-1-108-83976-1; DOI: 10.1017/9781108885096.

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