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THE PAST BENEATH THE PRESENT: GPR AS A SCIENTIFIC INVESTIGATION FOR ARCHAEOLOGY AND CULTURAL HERITAGE PRESERVATION

Pier Matteo BARONE [1,*], Carlotta FERRARA [2]

[1] The American University of Rome, Via Pietro Roselli, 4 00153 Rome, Italy
[2] CREA – Research Centre of Forestry and Wood, Arezzo (Italy)

Abstract

The presence of modern structures and infrastructures is relevant if you want to plan an archaeological or cultural heritage project in a populated area (e.g., cities and countryside). Both natural and manmade objects "hidden" in the subsurface (like tree roots, electrical cables, pipelines, tunnels, etc.) can interfere in preservation of buried heritage. The main advantage of a conservation approach is the application of different non-destructive techniques (NDTs) to obtain the best result, in terms of both resolution and accuracy, without digging. One of these NDTs, i.e., the Ground Penetrating Radar (GPR) method, is used in this paper. The examples shown here demonstrate not only that the use of the GPR technique, as a scientific investigation, represents an effective and non-destructive methodology for discovering, recovering, and understanding archeological data but also it can be applied to better understand the evolution of the ancient Past through the development of the Present.

***Keywords**: GPR; NDT; Archaeology; Cultural Heritage; Management; Conservation*

Introduction

The presence of modern structures and infrastructures is relevant if you want to plan an archaeological or cultural heritage project in a populated area (e.g., cities and countryside). Both natural and manmade objects "hidden" in the subsurface (like tree roots, electrical cables, pipelines, tunnels, etc.) can interfere in preservation of buried heritage [1-12].

The main advantage of a conservation approach is the application of different non-destructive techniques (NDTs) to obtain the best result, in terms of both resolution and accuracy, without digging. One of these NDTs, i.e., the Ground Penetrating Radar (GPR) method, is used in this paper. Ground penetrating radar (GPR) has recently become the most important physical technique in cultural heritage preservation [13-18].

Radar (RAdio Detection And Ranging) systems were initially developed as a means of using microwaves to detect the presence of objects, typically aircraft and ships, and derive their range from the transmitter. Radar is based on the transmitting of radiation pulses and recording of the reflections. GPR technology has seen the development of systems capable of providing ground surface images from different systems probing the ground and mapping subsurface features [1, 19].

* Corresponding author: p.barone@aur.edu

Materials and methods

GPR operates at frequencies between a few MHz and 3GHz, and the depth of the penetration is sensitive to the electrical properties of the ground. For example, in the case of ground with a relatively high conductivity (i.e., saturated clay), the depth of penetration may be less than 0.5m.

The radar unit produces a pulsed electromagnetic wave that travels through the ground at a velocity controlled by the electrical properties of the ground. Differences in relative permittivity (dielectric constant) or electrical conductivity due to changes in soil/material type or water chemistry result in the waves being reflected. The transmitting antenna also receives the signals reflected from subsurface interfaces or buried objects. The receiving electronics amplify and digitize the reflected signals, which are stored on disk or tape for complete post-processing [1]. The radar record is similar to a seismic record in that it consists of a waveform in the time domain. Thus, once the antenna receives the return signal, the radar system provides an accurate time base for storing and displaying the radar record. Immediate on-site results may be viewed on a graphics display. By moving the radar antenna over the material surface, a continuous real-time section (so-called radargram) is built up by arranging each radar record next to the other. The horizontal axis of the section represents the distance (m), and the vertical axis represents the two-way travel times (TWT) of reflections in nanoseconds (ns). To transform this information into distance, the velocity must be known [20]. The lines shown on the radargram represent reflectors and are constructed of coalescing wiggle traces from individual radar records (Fig. 1).

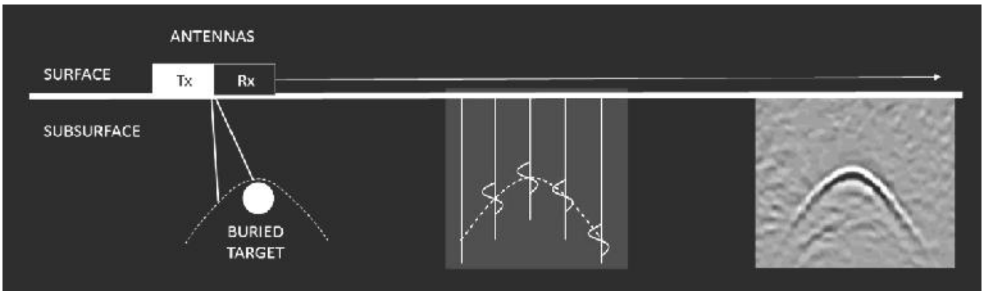

Fig. 1. The hyperbolic anomaly, shown here, is the resultant of the point-source reflectors. Note that only the peak of the hyperbola represents the true location of the source.

Once the geophysical data have been collected, they must be processed for interpretation and presentation. Good on-field acquisition will minimize many of the known data acquisition artifacts, and particular care should be taken to maintain good antenna coupling with the ground surface [1, 21]. Graphical representation of the GPR data is an essential step in visualizing, understanding and interpreting the results. The survey report should present appropriate data plots to support specialist and non-specialist readers in interpreting the data. For most survey reports, grayscale plots of the radargrams (i.e., GPR sections or B-scans) are the primary presentation format, and several improvements have been introduced to create a more solid appearance. If one has collected multi-profile grids, one can develop maps (i.e., time/depth slices or C-scans) representing various depths by using the average envelope amplitude and by interpolating among all the radargrams. Finally, if the quality of the data allows, it is possible to produce a 3D representation of a feature based on the GPR measurements. This interpretation is the result of a false-perspective cut-away model or an isosurface (i.e., a pseudo-3D reconstruction), in which a threshold value is chosen based on the average envelope amplitude. Isosurface plots are of significant help in interpreting the spatial relationships between anomalies [1, 19, 21] (Fig. 2).

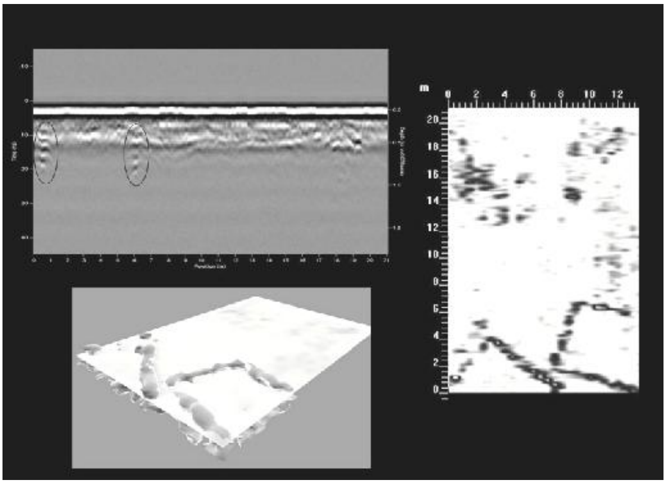

Fig. 2. Three typical graphic presentations of GPR data: a radargram (i.e., GPR section or B-scan, upper left), a map (i.e., time/depth slices or C-scan, right), and an isosurface plot (i.e., pseudo-3D reconstruction, lower left).

The first example will illustrate the possible damages caused by the tree-root architecture in a historical site. Starting from the 17th century until nowadays, the root growth of tall trees in the middle of a historical cemetery without monitoring has created the need to understand the possible injuries to the buried graves (Fig. 3a). The GPR allowed clarifying non-invasively the potential threat of these root architecture beneath the soil.

Fig. 3. The *Parte Antica* of the Non-Catholic cemetery of Rome with the cohabitation of trees and burials (a); the rectangle highlights the survey area close to the Roman Caracalla Baths and, partially, in the area of a modern athletic stadium (b) and the entrance of the Renaissance Villa Maruffi (c).

The second example will show how a modern structure has unconsciously sealed an archaeological building. It is the case of a professional athletics track built recently few meters above a Roman palace (Fig. 3c). The GPR detected not only the shape of the archaeological remains, but also its location and depth, helping to reconstruct the ancient past of the area.

If the two above examples are related to an urban context, the next one is due to a countryside environment. The presence of a Renaissance abode in the so-called *Campagna Romana* (Countryside of Rome) is a very good example of preservation of human landscape (Fig. 3b). The geophysical approach using the GPR helped to plan more accurately a cultural heritage management and recovery of the historical and precious building.

Note that in all these GPR surveys the FINDAR system (Sensors & Software, Inc.) is used, equipped with a bistatic 500MHz antennas, collecting both radargrams and depth-slices.

Results and Discussion

Non-Catholic Cemetery, Rome

A Ground-Penetrating Radar (GPR) survey is conducted in the Non-Catholic Cemetery in Rome (Italy). This cemetery, a unique spot within the walls of Rome, has attracted tourists from all over the world for the past three centuries. The sacredness of the site and the troubled sequence of events during its history increase the difficulty of performing archaeological excavations to obtain a precise record of the burials. Moreover, the presence of several trees in the so-called *Parte Antica* (ancient part of the cemetery) can create a lot of problem to the integrity of the precious and historical burials beneath [22] (Fig. 3a).

In particular, for detecting the tree roots architecture in the subsoil, the GPR survey plays an important role to non-destructively investigate the subsurface of the cemetery. This is the first time in which it is possible to perform such a geophysical survey at this site. Furthermore, this study based on the radar data interpretation suggests that caution should be used if the surveyed area will be subjected to a conservation management process.

Many tree roots were discovered throughout the plot, stretching out from a nearby tree. As it is possible to see in the GPR map (Fig. 4a), approximately at 0.3m depth, these trees have created a complex root architecture beneath the soil, easily to detect using the GPR. Comparing also the radargram (Fig. 4b), these confirmed the presence of the typical hyperbolic events related to the tree roots between 0.05m and 0.4m deep. This result together with the information gained about the depth of the burial [23] shows the real possibility of these roots to damage seriously some of the burials.

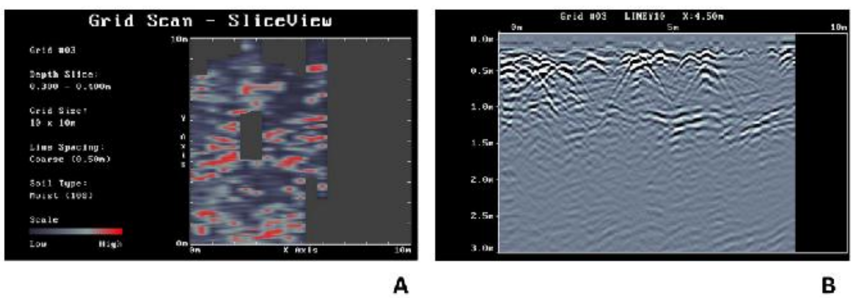

Fig. 4. The depth-slice at 0.3m illustrates the presence of the typical "star-shape" root architecture around and beneath the tree (a) and the several hyperbolic events due to the buried roots at a depth between 0.05m and 0.4m (b).

Domus septem Parthorum, Rome

The presence of the modern "Nando Martellini" athletic stadium, very close to the Carcalla Baths, in the center of Rome, is just one of the several cases in which GPR investigations can help the urban archaeology of the so-called Eternal City.

The *Domus septem Parthorum* (the House of the seven Parthians) is a monumental ancient complex, not completely excavated, which has changed functions from public to private, and, maybe, to religious purpose during the centuries [24] (Fig. 3b).

The first research was to understand the archaeological evidences beneath the soil, partially discovered by the 1986-1997 excavations [25]. In particular, the GPR (Ground Penetrating Radar) research is focused to better define the buried ancient structure with a high both vertical and horizontal resolution in order to highlight the shallow top of the buried standing walls. An ERT (Electric Resistivity Tomography) confirmed the GPR results and, moreover, detect the pavement of this ancient building at a depth of about 6m [26]. However, this research detected two corners of the buried building collecting data on a grass area, but a third corner was hypothesized beneath the athletic track. For this reason, the GPR was fundamental in this research due to its non-destructive ability to map the subsurface.

Figure 5a illustrates the research area above the athletic track in which the GPR technique is involved. In the radargram of figure 5b, at about 1m depth, a strong anomaly is well visible and well defined due to the presence of a strong reflector. This reflector, as easily recognizable in the depth-slice in figure 5c, is the wall related to both the visible apse, partially excavated, and the other two corners. The anomalies are due to a Late Antiquity building with a rectangular geometry according to the visible apse [27].

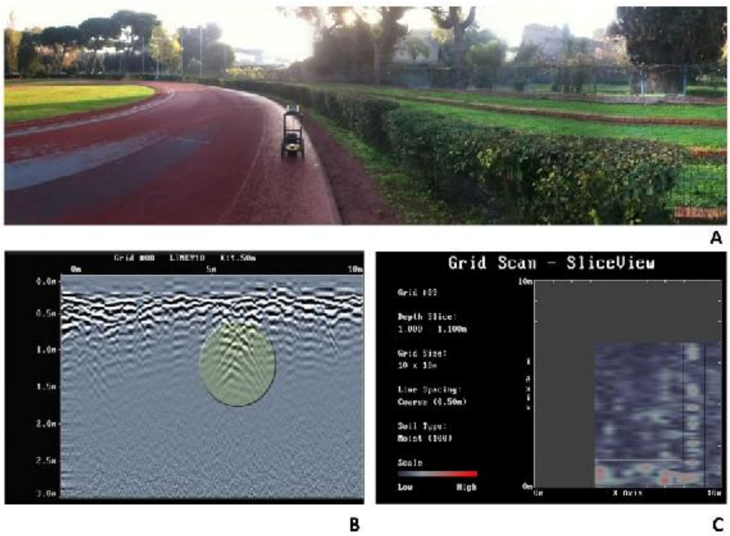

Fig. 5. The GPR area beneath the athletic track (a); the circle highlights a strong hyperbolic event in the radargram at about 1m depth due to the corner of the buried building (b) and the map at 1m depth shows the typical 90-degree shape of the building corner detected by the GPR (c).

Villa Maruffi, Ciampino (RM)

The aim of this research is to highlight the capability of the geophysical prospection, such as the GPR, studying, saving, and valuating a precious site like the Villa Maruffi (Ciampino) in the countryside of Rome (Fig. 3c). This is a Renaissance villa built by the Maruffi family related to the very famous and rich Roman family Colonna. Villa Maruffi represents a very good example of conservation in the manmade landscape in the so-called *Campagna Romana* (Roman Countryside) [28].

The GPR survey can help to understand not only the real evolution of this precious building, but also the possible conservation plans to lead restorations and a correct valorization [29].

In the figure 6 it is possible to notice how the GPR depth-slices, at a depth of 0.7m, show relevant anomalies in red around both the southern and western sides. Some elongated anomalies close to the main entrance are related to possible walls, as well as the strong rectangular anomaly on the southern side.

Fig. 6. The relevant red GPR anomalies at about 0.7m depth around Villa Maruffi due to possible buried structures.

Conclusions

The territory has a lot of stratifications resulting from complex dynamics produced by what is generally understood as a cultural process. This leads to think about the importance of the approach to its management. The aim of this paper is to broaden the 'archaeological views' and throw light on the solving capacity of modern technologies.

Detecting possible threats for buried and unknown cultural heritage thanks to a GPR survey is of a paramount importance to lead a future management like in the case of the Non-Catholic cemetery of Rome.

In an intricate urban context like Rome, taking into consideration the several reuses of the area during the centuries, included the recent construction of a modern athletic stadium, the non-destructive acquisition of important GPR information is essential not only to obtain a coherent answer to a historical interpretative problem, but also to have a coherent idea of the urban evolution during the past.

Moreover, also the countryside development of Rome is far from a simple interpretation. The third example here pinpoints the level of criticality due to the preservation of a cultural heritage like a Renaissance building and its previous environment, allowing to plan carefully restoration and reassessment, based on the knowledge of the subsurface potential.

When it is used in the protection of archaeological and cultural heritage, the GPR surveys provide basic information not only to increase the knowledge of the Past, but also to facilitate and properly plan any excavations and/or valorization. The GPR results can be interpreted and represented in order to allow an accurate reconstruction of the evolution of a historic site and answering crucial questions for archaeological research and cultural heritage management.

Thanks to its rapidity during the data acquisition, to its high sensitivity to buried anomalies, and to a nowadays relatively contained costs, the GPR is one of the best remote and non-destructive sensor for investigating heritage sites both known and not yet brought to light, enabling the development of displaying multidisciplinary intervention protocol for the protection, restoration and enhancement of places of cultural significance.

In conclusion, these three examples demonstrate not only that the use of the GPR technique, as a scientific investigation, represents an effective and non-destructive methodology for discovering, recovering, understanding, and preserving archeological data but also it can be applied to better understand the evolution of the ancient Past through the development of the Present.

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