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GPR INVESTIGATIONS AT THE BASILICA OF COPERTINO (LECCE, SOUTHERN ITALY)

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Abstract

GPR survey was undertaken inside and outside the Basilica of Our Lady of the Snows in Copertino, a village located a few kilometres Southwest of Lecce (Italy). The church was built in 1088 CE by the will of the Norman Count Goffredo of Conversano and was originally entitled to the Virgin. In 1255 Manfredi, Prince of Taranto and Count of Copertino elevated it to basilica entitling it to the Virgin of the Snows. It is the mother church of Copertino, already directed basilica and in 2011 elevated to the rank of minor basilica. The purpose of the survey was to obtain information about the existence of ancient structures beneath and outside the church. No document or writing exists to confirm the presence of structures under the church. However, there are several oral testimonies handed down over the centuries that suggest the presence of these ancient structures. Survey was carried out using a IDS Hi Mod georadar system, incorporating the dual band 200-600MHz centre frequency antennae. The GPR time slices were constructed from closely spaced parallel profiles. The time slices, computed from averaging radar reflections over vertical time windows several nanoseconds thick, are used to map subsoil features associated with the structures, probably of anthropogenic origin. To facilitate the interpretation of the results, a three-dimensional image was constructed using closely spaced parallel profiles, which are linearly interpolated.

***Keywords**: GPR; Cultural Heritage; 3D visualization; Anomalies.*

Introduction

Ground-penetrating radar (GPR) is a fast and cost-effective electromagnetic (EM) method, which in favorable conditions, i.e. mainly resistive non-magnetic environments, can provide valuable information on the shallow subsurface. As it is based on the propagation and reflection of EM waves, it is sensitive to variations of the EM parameters in the subsoil, specially the dielectric constant and the electric conductivity [1]. Despite its relatively low penetration depth (specially with high-frequency antennae and in moderately conductive environments), the GPR resolution capability (also depending on frequency and soil properties) is far greater than that obtained by other geophysical methods. This makes the technique suitable for high-resolution shallow studies such as archaeological applications and shallow stratigraphy mapping. In this work paper the results of a GPR survey carried out inside and immediately outside the Basilica of Our Lady of the Snows, located in the centre of the medieval settlement of Copertino (Fig. 1), a small town sited at 13 km Southwest of Lecce

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(Apulia Region, Southern Italy), are reported. The research was carried out inside the Project DiCeT (*LivingLab Di Cultura e Tecnologia - PON 2007-2013, Ricerca & Competitività*). The purpose of the surveys was to obtain information about the existence of ancient structures under the church and immediately to the north of the building.

The Mother Church of Copertino (Fig. 2), dedicated to the cult of *Sancta Maria ad Nives*, was raised in 2011 by Benedict XVI to the rank of Pontifical Basilica Minore.

Fig. 1. Location of the Basilica of Our Lady of the Snows (red area) in Copertino (Lecce, Italy).

Fig. 2. The Basilica of Our Lady of the Snows in Copertino (Lecce, Italy).

The basilica was built in 1088 CE on the ancient church of San Nicola, Greek-Byzantine rite, it was rebuilt by Prince Manfredi of Swabia, Count of Copertino, who raised it to basilica entitling it to *Sancta Maria ad Nives*, the Virgin of the Snows. The structure has undergone expansions and renovations over the centuries, particularly concentrated in the '500 and '700, and then assumes its present form. The basilica is accessed through the main portal, embellished by an imposing bronze door created in 1985 by artists and Gianese Del Savio. The second entrance opens onto the façade of the right side, and is defined portal of lions for the presence of two Romanesque lions. The area of interest in the investigated sectors of the church and of the churchyard is not deeper than 5m, well within the range of GPR surveying techniques. A dual band 200-600 MHz centre frequency antennae was used in all profiles.

The dual band antennae has proved to be a good compromise between resolution and depth of penetration. The radar data are displayed in three-dimensional format. This is well documented, especially for mapping both archaeological and geological features [2-13].

The most effective way to display three dimensional radar data is through 'time slice' (or depth slice) maps [13]. These horizontal slices may not be the most suitable visualization technique in the case of great subsurface complexity because, for example, false amplitude anomalies can occur when the slicing planes cross dipping or undulating reflectors. However, time slices still remain the easiest and most rapid means to provide a synthetic plan view of the anomaly pattern, specially for large areas. For small-size zones a more complete understanding of the subsurface can be achieved by means of various three-dimensional data presentations, including three-dimensional cubes, chair views and slices parallel to the axes or along arbitrary directions. In the present work, the three-dimensional image was constructed using closely spaced parallel radar profiles acquired in the basilica.

Materials and methods

The GPR survey was performed, with IDS Hi Mod georadar system, inside and outside the church along parallel profiles at 0.35m spacing using a dual band 200-600MHz centre frequency antennae. A map of GPR profiles is shown in Figure 3.

Fig. 3. The GPR profiles location.

The following acquisition parameters were selected: samples per scan, 512; recording time window, 80 ns for 600MHz antenna and 160 ns for 200MHz antenna; gain function, manual. The quality of the raw data did not require advanced processing techniques. However, an easier interpretation using the GPR-Slice software [14]. The following data processing has been performed: (i) amplitude normalization, consisting of the declipping of saturated (and thus clipped) traces by means of a polynomial interpolation procedure; (ii) background removal, whereby the filter is a simple arithmetic process that sums all the amplitudes of reflections that were recorded at the same time along a profile and divides by the number of traces summed the resulting composite digital wave, which is an average of all background noise, is then subtracted from the data set; (iii) Kirchhoff two-dimensional velocity migration [15], which is a time migration of a two-dimensional profile on the basis of a two-dimensional velocity distribution is performed. The goal of the migration is to trace back the reflection and diffraction energy to their 'source'. A profile acquired inside the church is shown in Figure 3. A close examination of the data showed the presence of the numerous reflection hyperbolae from a point source. This allows us to estimate the EM wave velocity propagation [13, 15] of 0.084 m/ns in the surveyed area. Most of the anomalies observed are confined from about 8 ns to about 25 ns; this is also the case in all the other profiles acquired in the area. The uppermost reflection event, slightly undulating (from about 4 ns to about 5 ns), labelled D in Figure 4, denotes a strong electromagnetic contrast. This event has been interpreted to result from a more compact layer associated probably with the bottom of the filling for the base of the church flooring. Of course this almost horizontal reflection has been weakened by the processing applied. In the radar sections a reflection event (labelled T in Figure 4) is clearly identifiable at the time ranging from about 8 ns to about 20 ns (from 0.34m to 0.84m in depth).

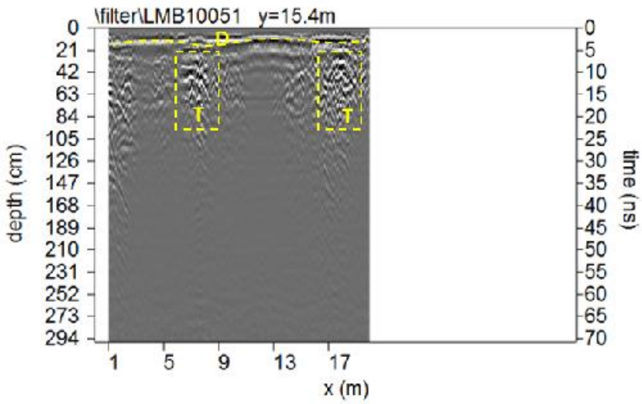

Fig. 4. GPR processed profile acquired inside the church.

This event is probably related to the presence of tombs. The arrangement of the profiles in a grid has allowed us to correlate, spatially, the important reflections within two-dimensional reflection profiles (standard radar sections). A way to obtain visually useful maps for understanding the plan distribution of reflection amplitudes within specific time intervals is the creation of horizontal time slices. Time slices examine only reflection amplitude changes (or energy changes if the square value is used instead of the absolute value) within specific time intervals, and thus within consecutive soil layers of nearly constant thickness. Each time slice is, therefore, roughly comparable to a standard archaeological excavation level [13]. Areas of low reflection amplitude (or energy) indicate uniform matrix materials or quite homogeneous soils, whereas those of high amplitude denote zones of high die-electrical subsurface properties contrast, such as buried archaeological features, voids or important stratigraphical changes. In the present work the time slice technique has been used to display the energy variations within the 5 ns time window. The time slices acquired by 200 and 600MHz antennas were georeferenced in the map of the church and managed in a GIS platform (Figs. 5-10).

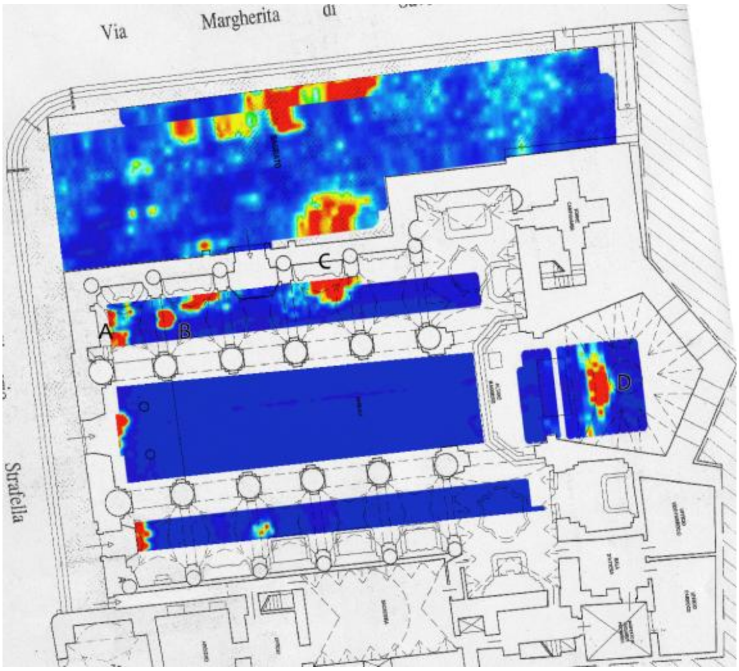

Fig. 5. GPR time slice (45-66 cm depth; 600MHz antenna) georeferenced in the map (north oriented) of the church.

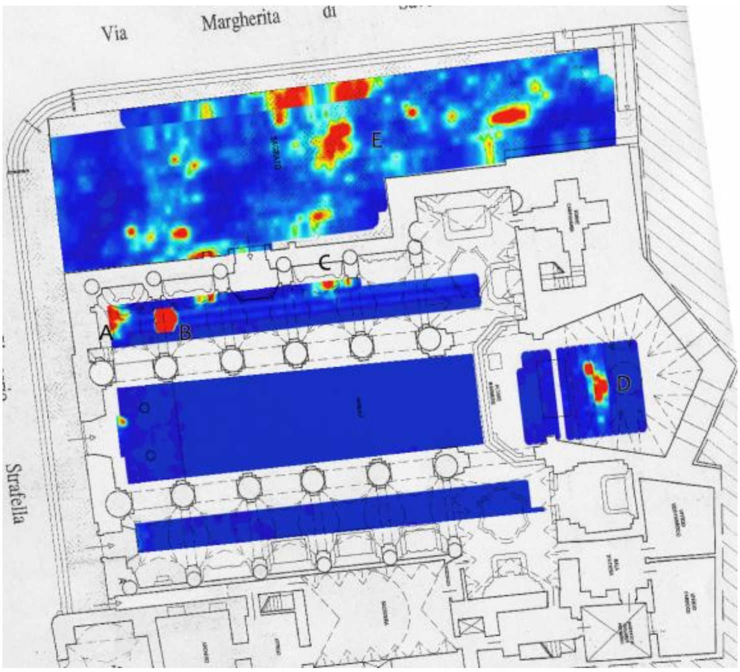

Fig. 6. GPR time slices (134-155 cm depth; 600MHz antenna) georeferenced in the map (north oriented) of the church.

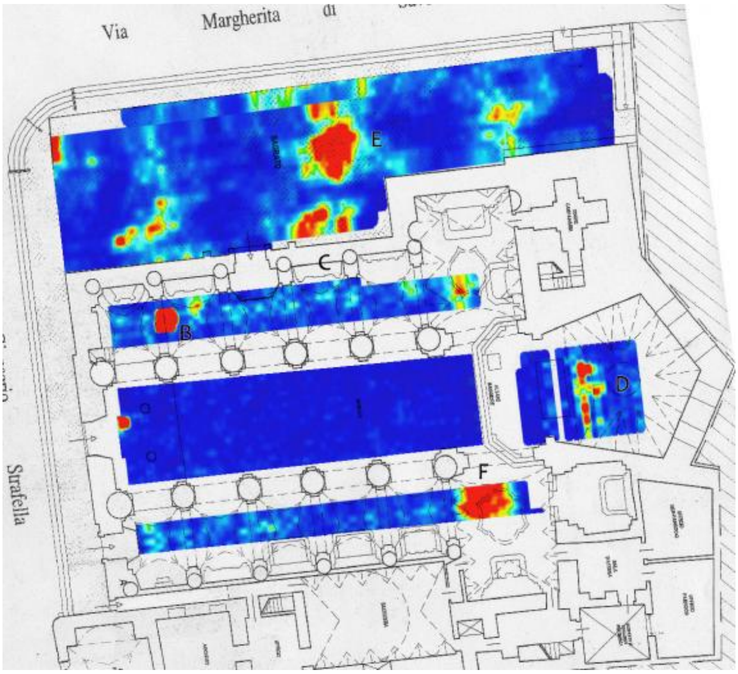

Fig 7. GPR time slices (268-289 cm depth; 600MHz antenna) georeferenced in the map (north oriented) of the church.

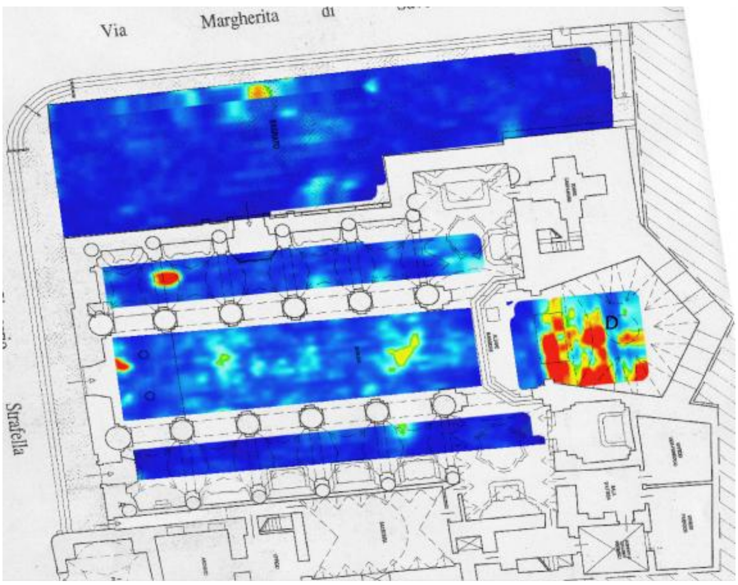

Fig. 8. GPR time slices (463-504 cm depth; 200MHz antenna) georeferenced in the map (north oriented) of the church.

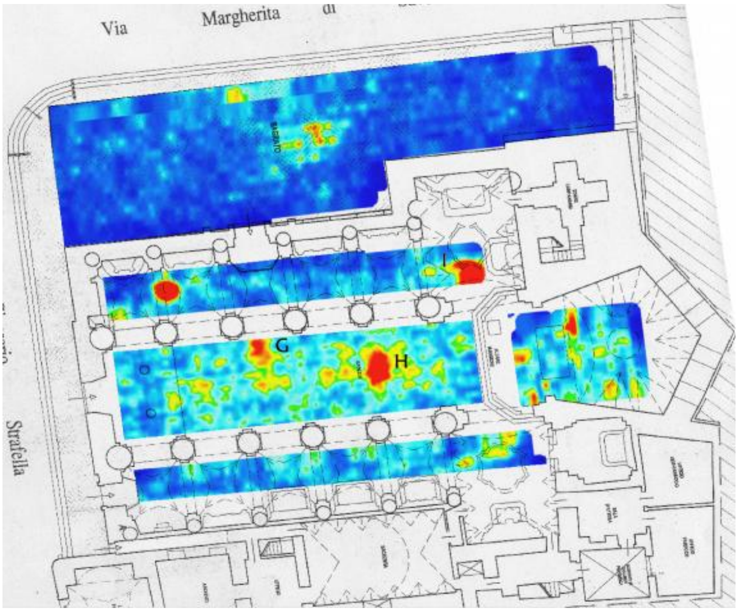

Fig. 9. GPR time slices (549-577 cm depth; 200MHz antenna) georeferenced in the map (north oriented) of the church.

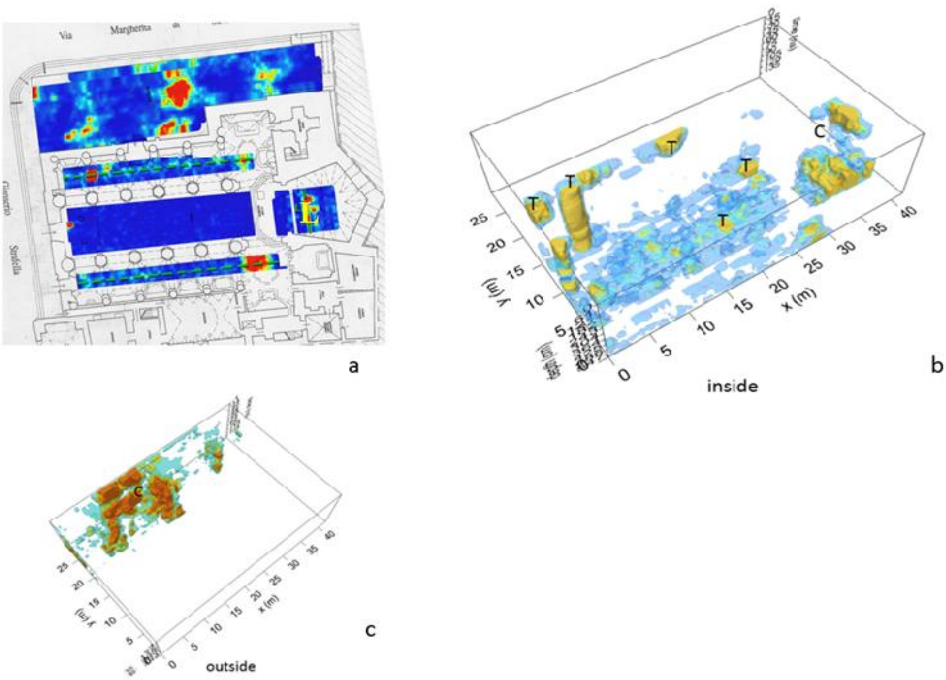

Fig. 10. a) GPR time slices (268-289cm depth; 600MHz antenna) georeferenced in the map (north oriented) of the church: in green a few anomalies that could be related to the buried walls of a building oldest to the current one, restored in the 18th century; b) the iso-surface 3D visualization of the area inside the church; c) the iso-surface 3D visualization of the area outside the church.

Results and discussions

Many high-amplitude anomalies are visible inside the church (central, northern and southern naves, and altar area) and outside the building, in the churchyard area located immediately to the north. The 600MHz time slices well document the first 3m of depth, while the 200MHz time slices confirm the 600MHz data between 1 and 3m and add very interesting data between 3 and 6m of depth. The anomalies highlighted by GPR survey are probably related to the presence of one crypt, several tombs and buried structures at variables depths (0.4-5.8m). In particular, between the depth of 0.4 and 2m, an interesting anomaly probably related to a tomb located under the pavement of the church is visible at the western end of the northern nave (labelled A in Figures 5-6). It is significantly located at the base of the funerary monument of Tristan de Clermont (born around 1380 – died in 1432), who became Count of Copertino marrying Caterina Orsini Del Balzo, young daughter of Maria d'Enghien and Raimondo Del Balzo Orsini, Prince of Taranto.

Other interesting anomalies are visible in the northern nave, both in the western sector (where buried structures are visible: labelled B in Figures 5-7) and in the central sector, immediately to the east of the northern access of the church (labelled C in Figures 5-7). The last anomaly, which is less strong below 1 m deep, could be related to a large tomb or structures that lie between the northern nave and the churchyard immediately to the north. The anomalies visible in the altar area from 0.4 m of depth (labelled D in Figures 5-8) are probably related to a crypt. They are evident until a depth of 5m. Starting from 2m of depth and until about 5m, other interesting anomalies are visible in the churchyard (labelled E in Figures 5-7). They could be related to structures, tombs and silos. Between 2 and 3m of depth, a large anomaly is visible in the eastern end of the southern nave of the church. It could be related to an underground structure or a large tomb or a silos. In the central nave of the church no significant anomalies are visible until 5.5m of depth, where three main anomalies could be related to graves or silos excavated in the rocky bank. No anomalies could be securely related to the previous structures of the church, which was built in the second half of XIth century and re-built in the second half of XIIIth century, while the present building is the result of some transformations occurred between XVIth and XVIIIth century. In particular, from 1563 the lateral naves were added and in 1580 the pentagonal apses was built; moreover, another important restoration occurred at the beginning of 1700s, when the Romanesque columns with figurate capitals that divided the naves were incorporated by quadrangular pilasters. The only few anomalies that could be related to a church oldest the current building, which was restored in the XVIIIth century, as we said, are visible in the time slice regarding the depth of 2.7-2.9m (GPR data acquired by the 600MHz antenna); it is only a suggestion, which need a verify through an archaeological investigation. These anomalies, which could be related to buried walls, are very few in the northern and southern naves (Figure 10a), while are more evident in the altar area (labelled L in Figure 10a), where can be previous the current pentagonal apses built in 1580. Lastly, the data, acquired on a grid with parallel profiles at 0.35m spaced, allow us also to build a three-dimensional file using a linear interpolation. The three-dimensional file has been used to plot the data acquired inside and outside the church in three dimensions. Figure 10b and c show plots of the iso-surface amplitude. It is possible to see the structures better, labelled C (crypt) and T (tombs or silos) in Figure 10b and labelled C (underground structure or tomb) in Figure 10c. This type of visualization confirms the archaeological interpretation using the two-dimensional standard radar sections.

Conclusions

The principal difficulties encountered in undertaking this survey were the non-existence of written documents (such as maps) that describe the evolution of the church and particularly the presence or otherwise of buried structures (such as crypts or graves). Nevertheless oral testimonies about the existence, inside the church, of buried structures were numerous. As a result of this study the testimonies about the existence of buried structures seems to be confirmed. The survey carried out inside and outside the church suggests clearly the presence of tombs, walls, silos and at least a crypt in correspondence of the altar area. In fact, time-slice maps, used mainly to enhance the horizontal relationships between amplitude anomalies found in the standard two dimensional radar sections, point to several anomalies that can be interpreted as buried structures of probable anthropogenic origin. The three-dimensional visualization proposed, as a three-dimensional plot of reflected electromagnetic wave amplitude, has facilitated the archaeological interpretation of the data.

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