# GPR and passive seismic investigations in the church of Santa Maria delle Grazie at Campi Salentina (Lecce, Italy)


Emanuele Colica
*Department of Geosciences*
*University of Malta*
Msida, Malta
emanuele.colica@um.edu.mt

Sebastiano D'Amico
*Department of Geosciences*
*University of Malta*
Msida, Malta
sebastiano.damico@um.edu.mt

Luciano Galone
*Department of Geosciences*
*University of Malta*
Msida, Malta
luciano.galone@um.edu.mt

Giovanni Leucci
*Institute of Science for the Cultural Heritage*
*ISPC-CNR*
Lecce, Italy
giovanni.leucci@cnr.it

Lara De Giorgi
*Institute of Science for the Cultural Heritage*
*ISPC-CNR*
Lecce, Italy
lara.degiorgi@cnr.it

Lucrezia Longhitano
*Department of Cultural Heritage*
*University of Catania*
Catania, Italy
lucrezia.longhitano@gmail.com

Giorgio Rizzo
*Cultural Heritage Direction*
*Diocesis of Lecce*
Lecce, Italy
beniculturalidiocesilecce@gmail.com

Raffaele Persico
line 2: *Department of Environmental Engineering DIAM*
*University of Calabria*
Calabria, Italy
raffaele.persico@unical.it



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***Abstract*— In the present contribution we propose the results of an integrated measurement campaign including ground penetrating radar and passive seismic data achieved in the church of Santa Maria delle Grazie at Campi Salentina, a town close to Lecce, in southern Italy. The passive seismic results corroborate the interpretation of the main (quite numerous at it will be shown) anomalies identified thanks to the GPR investigation.**



***Keywords—GPR, passive seismic, cultural heritage, non-invasive methods***


## I. Introduction

Geophysical investigation of historic buildings, and in particular of ancient churches, reveals in many cases hidden details regarding the history of the monument at hand that have been forgotten, in particular with regard to previous foundations, walled doors, (as well as walled windows or walled ciboria), stairs and rooms not any longer existing and in many cases tombs and crypts under the floor level [1-4]. Further relevant pieces of information can be achieved regarding the fracture state and consequently the stability of the building, which is particularly important because in most cases historical churches are not just "museums" but rather are also buildings fully exploited for their religious tasks and aims in the current days [1-2,5-6].

GPR is often the most suitable technique for investigating these kinds of features, because the depth and size of the anomalies looked for are in many cases well matched with the penetration and resolution capabilities of this instrument, even if many example of other techniques can be found too, as e.g. seismic [5,6] or geoelectric investigations [4].

In this paper we propose part of the results of an investigation performed in the church of Santa Maria delle Grazie, at Campi Salentina, Lecce, southern Italy, where it was of interest to identify the presence of possible buried hypogeal crypts under the floor. Indeed, the presence of part of the crypts was already known, in particular in the right hand aisle, because of past investigations. However, there were only hypotheses about the presence of crypts under the main nave. The combined investigations have been reasonably shown the presence of a crypt also under the main nave and of several hypogeal rooms under the aisles.

## II. The Monument

The church of Santa Maria delle Grazie is the most important monument of the town of Campi Salentina, in the outskirts of Lecce, Southern Italy.
This sacred building is a complex visible from any direction because it is surrounded by three streets and a square looking at the façade.
We know, thanks to the discovery of gothic remains, that the first building of this monument dates back about at the end of the 14$^{th}$ century. Then subsequent modifications, enrichments and expansions are reliably documented during the 16$^{th}$ century (the rose window), the 17$^{th}$ century, i.e. the century of the main baroque monuments (to this period date back the monumental entrance of the main nave, as well as the wooden gilded pulpit and the wooden chorus around the main altar, as well as many decorations of the lateral altars present in the aisles), and 18$^{th}$ centuries (to which date beack the inauguration of the portals for the direct access to the aisles as well as the construction of the Big Chapel of the Sacrament. However, the subsequent decorations have erased many of the original ones. In particular, in the inner of the church (Latin cross shaped), no 16$^{th}$ century feature is any longer perceivable. The building comprises also, on the left hand side, a further portal called "Porta della Tramontana" and a truncated bell tower. The truncated bell tower replaces a previous bell tower demolished after the severe damage suffered because of a strong earthquake in 1743. However, the second bell tower was never finished.
The church of Campi Salentina has always been one of the most important sites of cultural, artistical and religious interest in the area of the towns on the northern side of Lecce. This building indeed shields valuable works of art, because of the learned and refined customers (mainly the noble

families that were the feudal owners ("baroni") of Campi Salentina from 14th to 18th century. These feudatories assigned the works to the best available artists available at their time, many of which exponents of the Neapolitan school. The set of these works has composed a well-assembled and harmonious result inherited by the successive local inhabitants up to the modern ones, that in most cases are fully aware of the value and the beauty of such an heritage.

Fig. 1: Location (left hand side) and façade (right hand side) of the church of Santa Maria delle Grazie at Campi Salentina

## III. GPR INVESTIGATION AND RESULTS

In Fig. 2 the map of the measurement lines is shown. Indeed the meaningful weight of the pews and the available time hindered us from recording data along an orthogonal grid and, above all, we were looking for large anomalies, which made less severe the necessity of a rectangular grid. However, we adopted a transect between the observation lines of 25 cm, which is a quite narrow step. The exploited GPR system was a pulsed RIS Hi-mode GPR manufactured by IDSGeoradar with a dual ground coupled antenna at nominal central frequency 200 and 600 MHz, respectively. In this contribution we will focus on the data at 600 MHz.

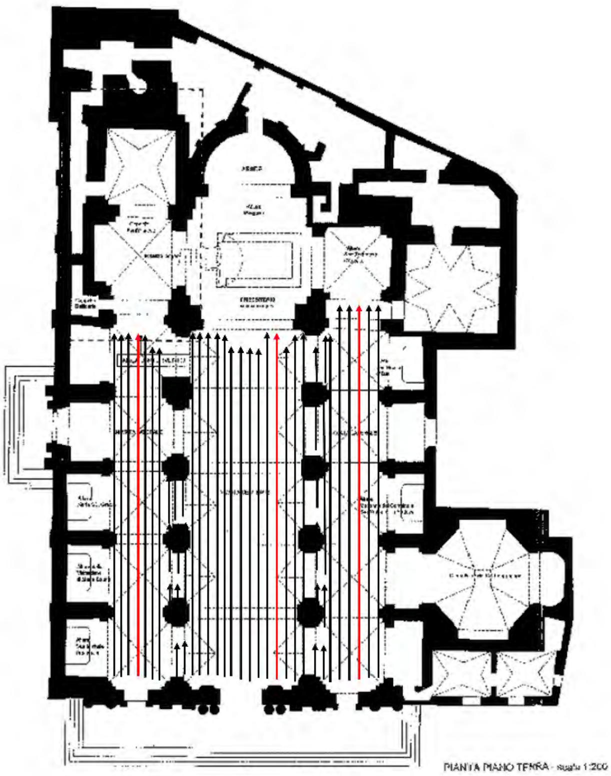


Fig. 2: Schematic of the observation lines run through with the GPR. The three red arrows are the position of the Bscans represented in Fig. 3.

The data have been processed with the commercial code GPR-Slices (https://www.gpr-survey.com/) and the processing flow-chart consisted of the following steps: (i) header editing for inserting the geometrical information; (ii) frequency filtering; (iii) manual gain, to adjust the acquisition gain function and enhance the visibility of deeper anomalies; (iv) customized background removal to attenuate the horizontal banding in the deeper part of the sections (ringing); (v) estimation of the average electromagnetic wave velocity by hyperbola fitting; (vi) Kirchhoff migration [7]. The propagation velocity of the wave, essential for the migration procedure, have been worked out from the diffraction hyperbolas . After migration, time slices have been calculated so to achieve a pseudo-three-dimensional reconstruction of the buried scenario [8-9]. The slices have been retrieved with a time step of 3.8 ns, about corresponding to 20 cm. As usual, the time slices are averaged along the depth, whereas the range of levels considered and imaged is 310 cm. In Fig. 3, three processed Bscans are shown, respectively in the left-hand aisle, the central nave and the right-hand aisle looking toward the altar. The positions of these Bscans correspond to the three red arrows depicted in Fig. 2. From Fig. 3, we appreciate several anomalies, some more superficial at the beginning of the Bscan, namely on the side of the entrance, and some other at deeper levels corresponding to buried crypts.

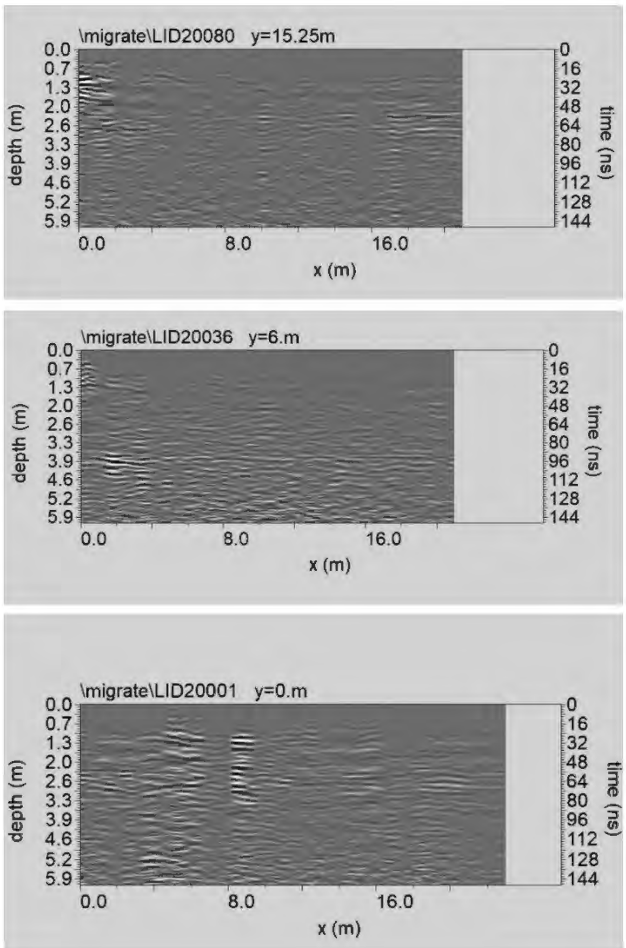

Fig. 3: Three Bscans gathered in the left-hand aisle (upper panel), central nave (central panel) and right-hand aisle (lower panel) respectively (data at 200 MHz).

However, the representation in slices makes the alleged crypt much clearer, as can be appreciated from fig. 4, where one of the most meaningful time slices is shown, relative to the time-depth of 43 ns (corresponding to about 190 cm).

As it can be appreciated, there is an understandable correspondence between the Bscans of Fig. 3 and the time slice of Fig. 4, because the anomalies of interest are quite large. They correspond probably to buried crypts. Indeed, previous works performed in the church and information available from historical documents had already indicated the presence of several crypts under the aisles, whereas the situation under the central nave was less known. In particular, the presence of at least one crypt was alleged but it position was not known. The GPR results suggest clearly the presence of this alleged crypt and, of course, clearly suggests its position and size.

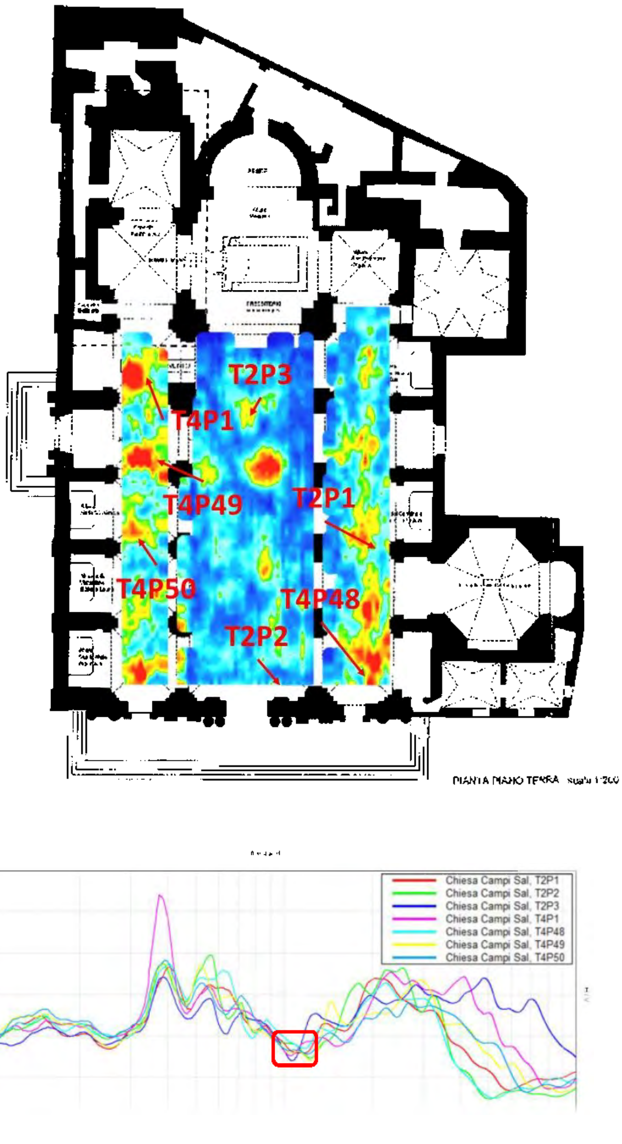


Fig. 4: Top: Time slices at 54 ns (about 225 cm). Bottom: H/V of a seismic measurement taken in correspondence of the GPR anomaly

## IV. Passive Seismic Investigation and Results

In this paper, we have also applied the HVSR (Horizontal to Vertical Spectral Ratio) method in order to investigate, in a non-invasive manner, the subsoil structures underneath the test site.

This method requires the recording of at least 20-30 minutes of three-component ambient noise vibrations for each recording site [10]. During the processing, the time domain is converted to the frequency domain by the use of a Fourier Transform on every component. The horizontal spectra are averaged and finally the horizontal to vertical spectral ratio is computed. The peaks can be related to underground features such as geology structures, voids etc.

Fig. 4 shows the location of the measuring points as well as the preliminary results obtained at each recording site. Our measurements results show a clear peak between 3 and 4 Hz which is most probably linked to the geological stratigraphy underneath the church or some features related to the building which needs to be investigated further. However, the HVSR measurements taken at the specific locations within the church show a dip below one at about 10 Hz that can be attributed to the free vibrations of the floor overlaying potential voids. Since Fig. 4 reports also the GPR results, it is possible to notice that most H/V locations correspond with GPR anomalies. This enforces the interpretation that mosgt of them correspond to voids.

## V. Conclusions

In this contribution, we have reported part of the results achieved in the framework of a measurement campaign performed in the church of Santa Maria delle Grazie in Campi Salentina (Lecce, Italy). Specifically, we have shown GPR and passive seismic data taken in several points. In particular, we gathered passive seismic data both in points were the GPR data showed presence of strong anomalies and in points with no meaningful GPR anomaly was evident. The comparison of the data showed a good correspondence between the natural the seismic vibrations and the presence of strong buried anomalies, so enforcing the interpretation of the results

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