3D GPR model in the military district of San Giacomo (Palermo)

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Introduction

The aim of this work is to verify the presence of buried anthropogenic structures and the archaeological imprint inside the Bonsignore square (fig. 1), located inside the 12th Carabinieri Regiment Barrack within the city of Palermo. The study is moreover focused on the analysis of probable links between these buried structures and those, already studied (Capizzi et al., 2021), recognized inside the church of San Paolo D'Alga, present on one side of the square. The area was investigated using the Ground Penetrating Radar (GPR) technique.

The GPR is a geophysical method using radiated impulsive electromagnetic waves obtaining information on the subsoil. The relative permittivity of the different subsoil layers is the main property that influences waves velocity. Both magnetic permeability and electrical conductivity furthermore controls the amplitude and attenuation of a propagating wave (Baker et al., 2007). Indeed, wave propagation velocity depends on the dielectric constant and magnetic susceptibility of the media (Baker et al., 2007, Cozzolino et al., 2018). Depending on these different physical features, different for any subsoil layers, electromagnetic wave that travels underground is subjected todifferent phenomena during the passage from one medium to another. Using antennas with different features also realized prospections with more or less depth of investigation or resolution depending on the antennas shape and size of the and frequencies and wavelengths applied.

GPR is a non-destructive investigation methodology that is a great advantage to investigate monumental assets. Many studies on the architectural heritage in which GPR techniques were applied for different purposes are present, such as verifying structural elements stability of churches (Ranalli et al., 2004; Masini et al., 2010; Pérez-Gracia et al., 2013) or the damage degree of others historical buildings (Binda et al., 2005). Furthermore, many studies focused on preservation of mural paintings (Pieraccini et al., 2005; De Giorgi et al., 2020) and mosaic (Capizzi et al., 2012). Another use is related to the detection of previous architectural planimetries buried (Cozzolino et al., 2020; Capizzi et al., 2021) as well as other ancient structures like walls (Basile et

al., 2000), canals and tunnels (Chías et al., 2013) nowadays not visible on the surface within urban areas.

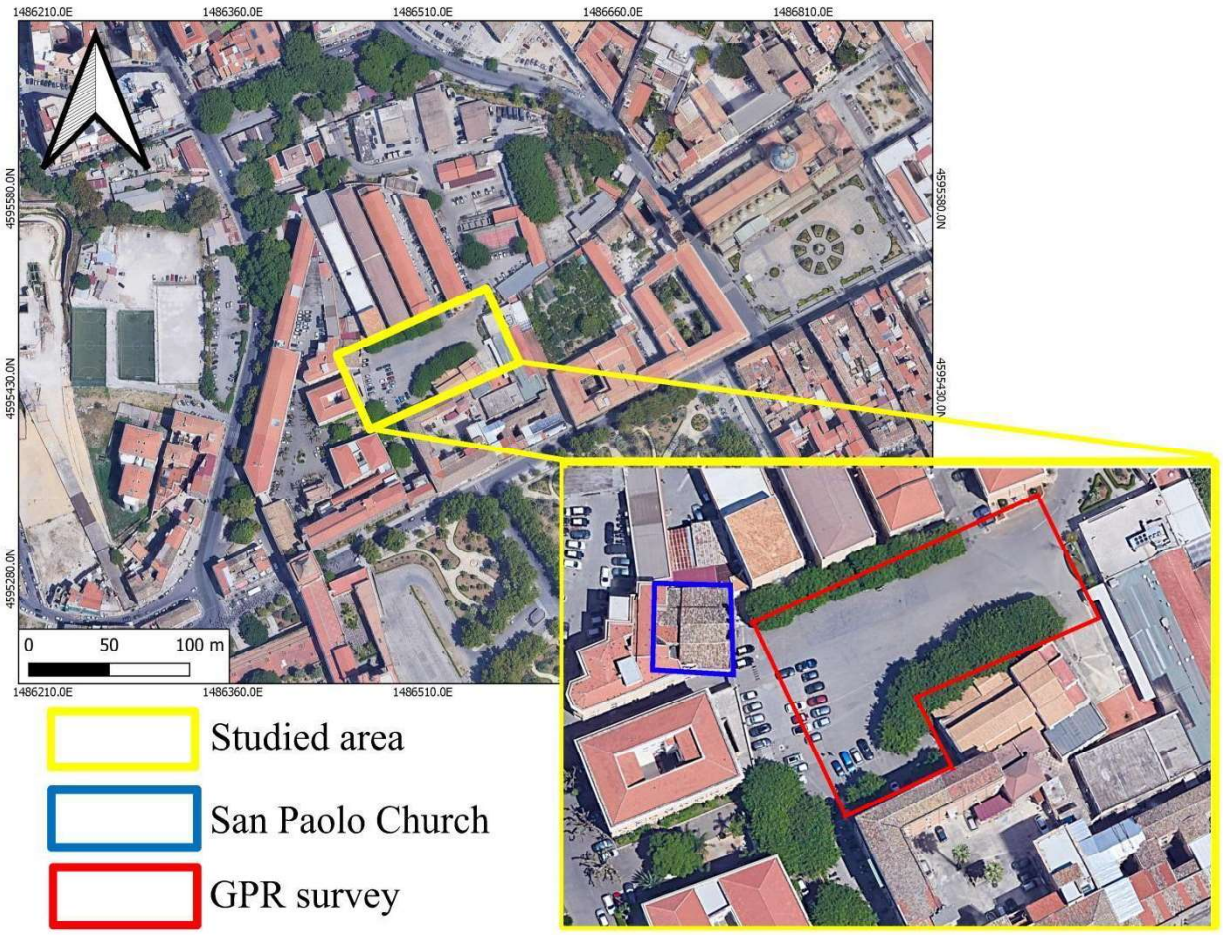

Figure 1. Barracks of Carabinieri of Palermo. Location of GPR acquisition (red polygon).

Investigated area and previous studies

The monumental ensemble of the military district of San Giacomo (Palermo, 1816) is located in the historic center of Palermo, in the western ancient, fortified area of the city, mentioned by historians with the name Galka or Alga (from the Arabic "al-Halqah", or "the enclosure"). In this area the Kasr of the Arabs rose dominant, and later it became the residence of Norman princes and kings and transformed over the centuries until it took on the shape of today's Royal Palace.

In the Galka district from the XVII century a vast military complex was set up; today the area hosting the headquarter of the Command of the Sicily Carabinieri Legion, contains several historic buildings of high artistic interest.

When the military quarter and the San Giacomo hospital were built in 1622, many churches, such as San Giacomo dei Militari, Saint Mary Magdalen and San Paolo d 'Alga, were enclosed within this military complex, together with other religious buildings.

After the unification of Italy in 1860, many historical buildings of this district risked being demolished by the military to expand the barracks. In 2019 the complex was included in the UNESCO "Arab-Norman Palermo and the Cathedral Churches of Cefalú and Monreale" itinerary.

The San Paolo D'Alga Church, used until few years ago as a gym for the barracks cadets, was investigated using ground penetrating radar surveys (Capizzi et al., 2021). Thanks to these geophysical analyses, old perimeter walls, different from the current ones, were partially recognized and an archaeological campaign began.

GPR surveys

At the square of the Carabinieri were acquired 158 georadar profiles, parallel to each other, with aninterdistance of 50 cm. A total of about 4250 linear meter of GPR profile were acquired.

Geophysical surveys were carried out using a multichannel georadar system (RIS MF HI-MOD system of IDS (Ingegneria dei Sistemi s.p.a.) which is equipped with a 200-600 MHz multi-frequency antenna, which allows high performance in detecting anomalies in the subsoil. This system can generate, capture, amplify, filter, and storing signals and enable to view the data acquired in real-time. Test profiles were performed to choose the acquisition parameters and to optimize the signal during the scan phase. All profiles were acquired with both antennas to have a good surface detail (600 MHz) and an adequate depth of investigation (200 MHz).

The data were initially processed with ReflexW software (Sandmeier, 2016). The acquired data are usually noising and this makes subsequent interpretation difficult. For these reasons, some pre-processing steps results necessary. The data processing operations flow is completely arbitrary choice, mainly depending on the raw data quality. Parameters elaboration criteria chosen should not excessively affect data originality to avoid an over-processing that could lead to unrealistic representations. In this way, each GPR profile has been analyzed to eliminate the consistent and inconsistent noise present in the original data. In particular, the following pre-processing operations were applied:

a) Static correction: this operation facilitates a correction for each trace in time direction and is applied to eliminate time delays related to trigger errors.

b) The Butterworth type frequency filter: is a filter that eliminates electromagnetic noise characterized by frequencies other than those of the transmitted signal. For data captured with the 600 MHz antenna, a 100-1200 MHz band pass filter was used, and for data captured with the 200 MHz antenna, a 35 -600 MHz band pass filter was used.

c) Energy decay: a tool useful for highlighting low ranges of amplitudes acquired signal against the highest ones. A gain curve is applied in time domain on the complete profile.

d) Background removal: this 2D filter allows to eliminate temporally consistent noise and moreover is useful to make some signal portions, previously covered by noise, more visible.

e) Time cut: this filter offers the possibility to limit or to extend each recorded trace in time. This operation is truly worthwhile to eliminate the deeper part of acquired profile in which signals are hard to analyze.

f) Kirchoff migration: this is a pre-processing phase realized in the time domain; velocities weighted summation, computed for each point of the profile basing on hyperboles of reflection present inside a preset bandwidth, is performed (Tillard et al., 1995). The migration is one of the most important filters that is performed if strong diffractions are present. The velocity for the Kirchoff migration was set to m/ns.

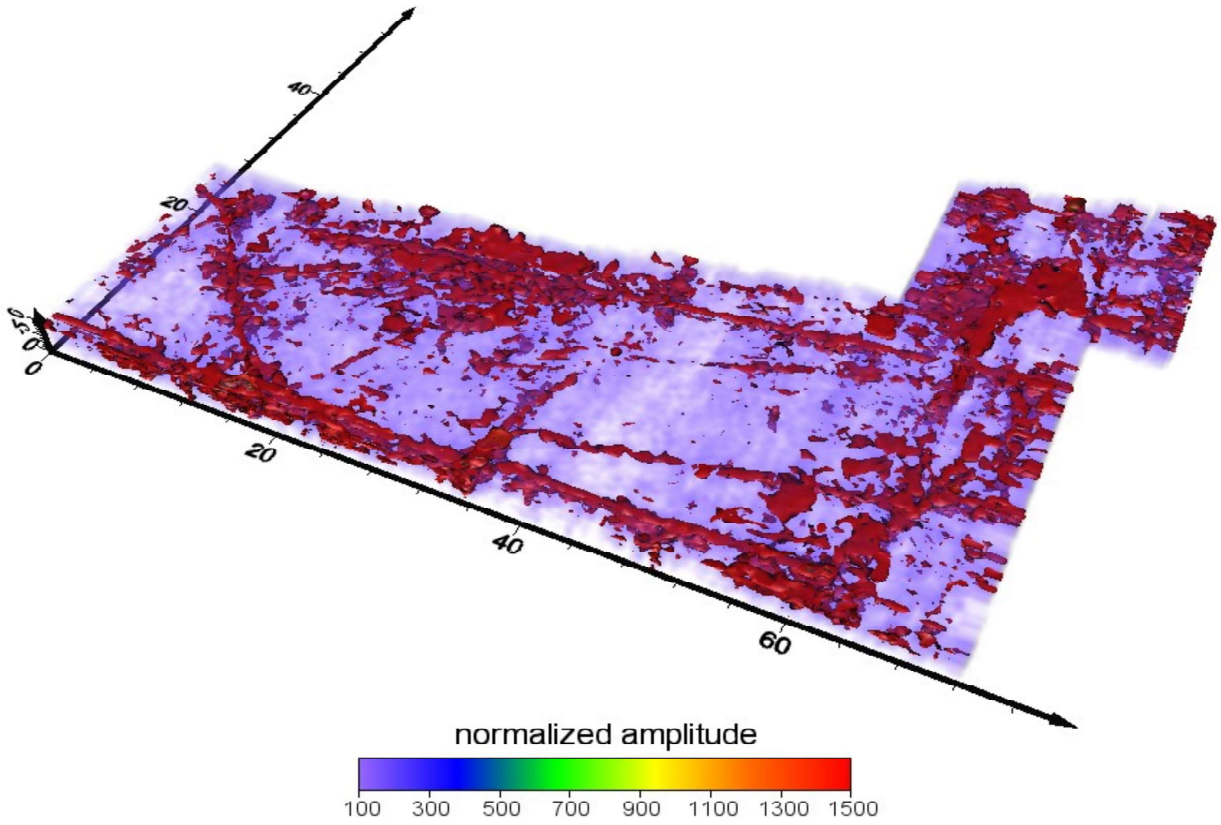

Figure 2. 3D GPR model.

Following this processing flow, all the processed data were used to realize a 3D model of the subsoil, using a code implemented in MATLAB to analyze and manage a large amount of data, calculating the average over voxel of 0.5 m x 0.5 m x 0.1 m. Finally the Voxler software (Golden Software) was used for the 3D rendering of the data. The model was realizing using both the data acquired with 600 MHz (up to 2 meters) and 200 MHz (from 2 meters up to 5 meters) antennas.

The interpolation was performed with the Inverse Distance Weighting method, proposed by Shepard (1968), which uses a weighted average based on the distance of the points from the observation point. Figure 2 shows the 3D model obtained.

1. Conclusions

The built 3D GPR model shows numerous linear anomalies. Most of these anomalies are superficial (up to 1 meter deep) and probably due to underground pipes, also confirmed by some manhole covers in the square. However, some anomalies are not related to the presence of underservices and their width (even 2 meters) is not compatible with the presence of pipes. The archaeologists will evaluate which of these anomalies deserve to be investigated with a direct excavation essay.

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