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3D GPR Model in the Military District of San Giacomo Degli Spagnoli (Palermo)

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Abstract: The georadar method was used to try to find some anthropic structures in a large square inside the Carabinieri barracks in the former military complex of San Giacomo degli Spagnoli in Palermo (Italy). These investigations are part of a broader context of a study of the entire area. The purpose of the investigations is to try to understand if under the ground there are the remains of an ancient horse passage that connected the Royal Palace of Palermo with the sea gate of the city. Furthermore, in the Middle Ages, on the site of the present square, there were most likely two churches, which no longer exist, as evidenced by numerous historical testimonies. One of the two, San Giacomo la Mazara, is known to have was placed right in front of the church of San Paolo, the subject of previous investigations. The investigations carried out on the main square of the military district allowed us to reconstruct a 3D georadar model in which numerous anomalies are highlighted. Some superficial anomalies have been attributed to the presence of sub-services, the deeper ones could be caused by the remains of the medieval underground way or those of the no longer existing medieval churches, but identifying their true nature requires further investigations and archaeological tests.

Keywords: ground penetrating radar; Archaeogeophysics; 3D model; urban archaeology; urban geophysics

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1. Introduction

The monumental ensemble of the former military district of San Giacomo degli Spagnoli (Figure 1) [1] is 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"). The origin of the San Giacomo district is as old as the city of Palermo. This area was part of the paleapolis, the first city nucleus in the Punic–Roman era, which also included the area of the current Royal Palace. The whole area was densely inhabited, as evidenced by some archaeological finds that have come to light over the centuries, including floors with mosaics, ancient wells, and other signs that unequivocally lead back to an ancient urban area [2].

Figure 2 shows a schematic and approximate map reconstructed by Di Giovanni [3] of the hypothetical distribution of the main buildings, streets, and boundary walls of the Galka in the Middle Ages (Figure 2a), compared to today's satellite photo of the same area (Figure 2b).

The schematic map of Figure 2a unfortunately gives us a very rough indication of the position of the buildings which no longer exist today. There are too many inaccuracies and inconsistencies in this map relating to incorrect dimensions and orientations of churches, buildings, and roads. It follows that this map cannot be considered reliable for the identification and delimitation of the investigated buildings, but only for having an overall idea of the topographical context of the Galca district and the areal distribution of the main buildings during the late Middle Ages.

Figure 1. Aerial view of the former military district of San Giacomo degli Spagnoli, in Palermo.

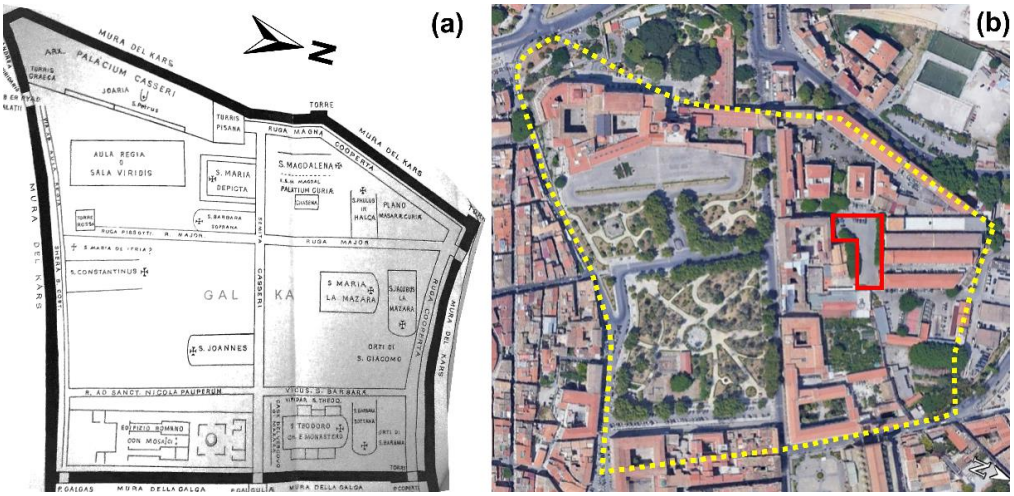

Figure 2. (**a**) Schematic plan of the topographic organization of the Galka district in the Middle Ages [3] (the thick black lines indicating the boundary walls of the Galka); (**b**) Google Earth view of the same area (the yellow dotted lines indicate the approximate position of the boundary walls; the red line surrounds the investigated area).

Already in the Arab period, in which the city had changed its appearance expanding towards the sea, in the Galka quarter there were, among others, two churches, no longer existing today, called San Giacomo la Mazara (a term that must have come from the ancient Arab term "ma'sar", which means mill) and Santa Maria La Mazara. The two churches, although very close to each other [3], were quite distinct and still existed in 1631 [4]. For the church of San Giacomo La Mazara, detailed information is reported on the shape of the plant (Figure 3), which was quadrangular, divided into five ships by four rows of columns [5]—an unusual feature for churches of that period which suggests a pre-existing mosque transformed in the church [4]. From the planimetric sketch (Figure 3), the church should have had a width of about 12 m and a length of about 20 m. Less information is available about the church of Santa Maria La Mazara [3], some remains of which were still visible in the 19th century, according to [6].

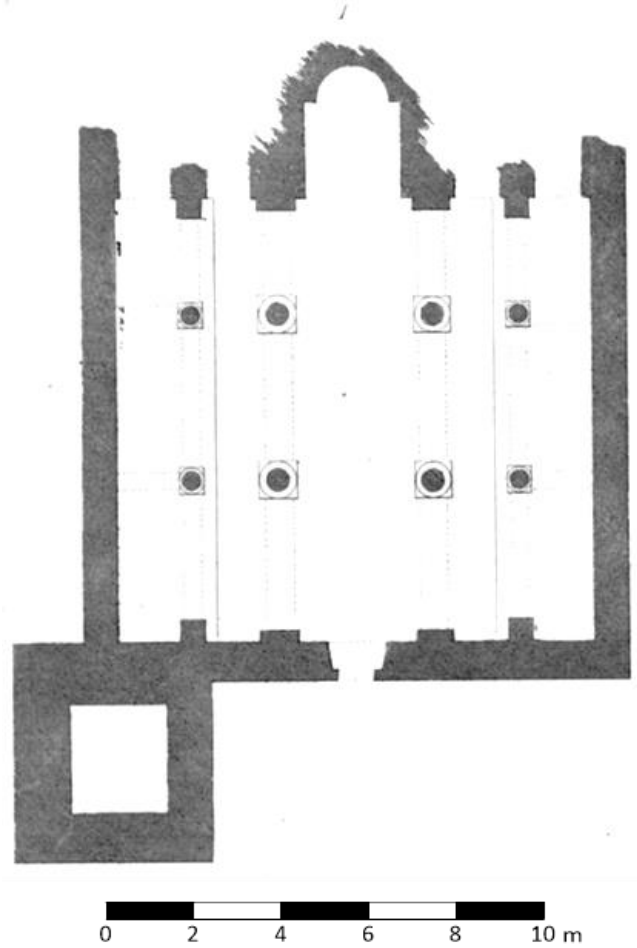

Figure 3. Planimetric sketch of the church of San Giacomo La Mazara (modified from [5]).

In this area, in Norman times, an underground tunnel passed [3,7]. This, passing near the Punic walls, led from the Royal Palace to the old Archbishop's Palace, at that time located behind the current Cathedral. On this ancient road was the entrance to the church of Santa Maria Maddalena, a splendid example of Arab-Norman architecture now completely incorporated into the military district [1].

When, in the fifteenth century, for unknown reasons, the church of San Giacomo la Mazara was demolished, another church named after the same saint was built. The latter became the reference parish of the neighborhood, which, from 1491, took the name of the San Giacomo neighborhood. The area remained one of the popular districts in the center of Palermo until, in the 17th century, it was necessary to find a place to quarter the numerous Spanish troops stationed in the city. Thus, in 1622, the viceroy Emanuele Filiberto of Savoy started the operations of the evacuation of the inhabitants and gave life to a militarized area which, a few years later, would be surrounded by high walls and which continues to exist today [1,6].

The churches present here at the time were abandoned by the respective congregations and therefore also passed into the possession of the army. At that point the transition was complete, and the San Giacomo district began to be called the Spanish quarter. Over the years, the intended use of the area never changed. After the unification of Italy, the complex passed into the hands of the Royal Army and was renamed the San Giacomo barracks. Over time, the Bersaglieri stayed there, and finally the 12th regiment of the Carabinieri "Sicilia", who still use it today [8]. The area now includes the "Dalla Chiesa-Calatafimi" barracks complex, made up of the "Dalla Chiesa" barracks (formerly the "Bonsignore" barracks), headquarters of the Sicilian Carabinieri Legion Command and the contiguous "Calatafimi" barracks, where the 12th Carabinieri Regiment "Sicily" is stationed.

The churches still present in the neighborhood today are Santa Maria Maddalena, San Giacomo dei Militari, and a small thirteenth-century church named San Paolo d'Alga (Figure 4). Of these three historic buildings, the best preserved is undoubtedly the church of Santa Maria Maddalena which, apart from the brief periods of abandonment and neglect, has always maintained its functions and has undergone few upheavals [8]. For the rest, the traces of the ancient medieval quarter have slowly disappeared over the years. The small church of San Paolo D'Alga was in the past first converted into a warehouse, then into a gymnasium [1]. Only recently, the church was investigated by georadar [9], with the discovery of an older and different system of perimeter walls and a consequent restoration project which is still ongoing.

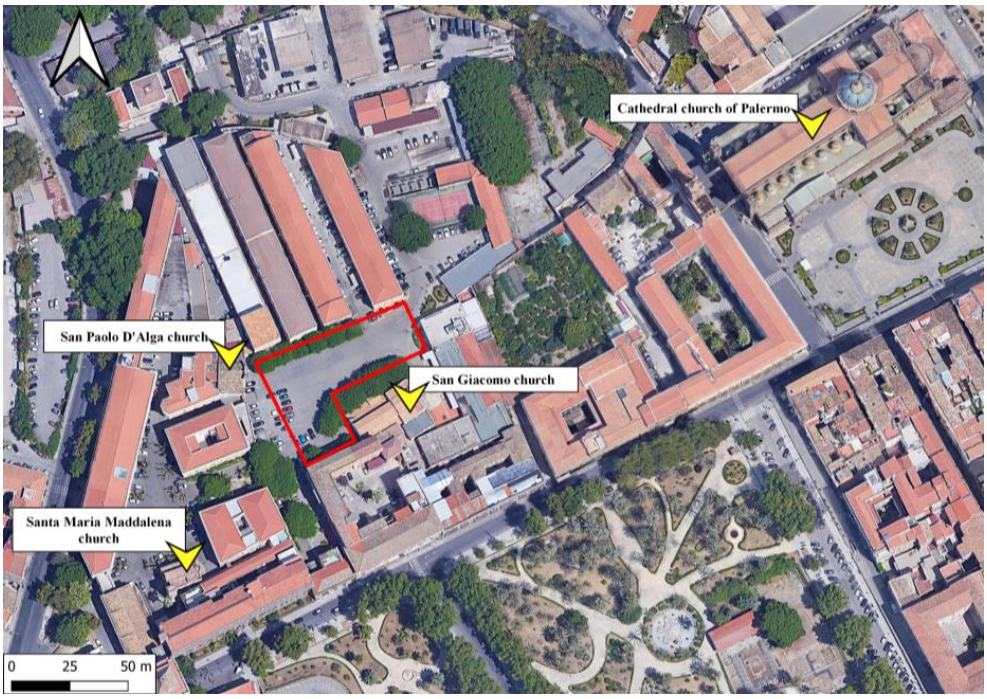

Figure 4. Location of GPR acquisition (red polygon). In the figure, the positions of the churches currently present in the neighborhood are also reported.

The church of San Giacomo dei Militari, dating back to 1493, was also transferred to the Military Hospital in 1620, thus becoming the parish of the San Giacomo district. Subsequently, it was used for a long time as a garage for the maintenance of military vehicles, until, starting in 2003, it underwent a series of restoration interventions aimed at restoring its original layout.

In 2019 the churches of the San Giacomo quarter were declared UNESCO Heritage and included in the "Arab-Norman Palermo and the Cathedral Churches of Cefalú and Monreale" itinerary.

This work aims to investigate the large square located in the center amidst the most important buildings of the military district, to verify the presence of buried anthropogenic structures and their archaeological imprint. In fact, in this area, there could be the remains of the churches of San Giacomo la Mazara and, most probably, of Santa Maria La Mazara. Moreover, there could also be the remains of the ancient, covered road that connected the Royal Palace to the Cathedral area. The study is moreover focused on the analysis of probable links between these buried structures and those already studied [9], recognized inside the church of San Paolo D'Alga and present on one side of the square. The entire surface of the square was investigated using the Ground Penetrating Radar (GPR) technique.

GPR is a non-destructive investigation methodology that is a great advantage to investigate monumental assets. Many studies on the monumental heritage in which

GPR techniques were applied for different purposes have been undertaken, such as those verifying the structural elements stability of churches [10–12] or the damage degree of other historical buildings [13]. There are, furthermore, many studies focused on the preservation of mural paintings [14,15] and mosaics [16,17]. Another use is related to the detection of previous buried architectural planimetry [18–22] as well as other ancient structures like walls [23] canals, tunnels [24], graves [25], and archaeological features [26], which, nowadays, are not visible on the surface within urban areas.

2. Materials and Methods

The GPR is a geophysical method that uses radiated impulsive electromagnetic waves to obtain information on the subsoil. The relative permittivity of the different subsoil layers is the main property that influences wave velocity. Both magnetic permeability and electrical conductivity furthermore control the amplitude and attenuation of a propagating wave [27]. Indeed, it is noted that wave propagation velocity depends on the dielectric constant and magnetic susceptibility of the media [27,28]. Depending on these physical features, different for any subsoil layer, electromagnetic waves that travel underground are subjected to various phenomena during their passage from one medium to another. Moreover, different kinds of antennae can be used to carry out prospection with different depths of investigation or resolution, depending on the antenna frequency and wavelength.

The main square, which is located inside the barracks, is about 2000 square meters wide (Figure 3). In this area, 158 georadar profiles were acquired, parallel to each other, with an inter distance of 50 cm for a total of about 4250 linear meters.

Geophysical surveys were carried out using a multichannel georadar system (RIS MF HI-MOD system by IDS, which is equipped with a 200–600 MHz multi-frequency antenna, so allowing high performance in detecting anomalies in the subsoil; Figure 5). To optimize the signal during the acquisition phase, test profiles were obtained, which were aimed at choosing the acquisition parameters. All profiles were acquired with both antennae to have both a good surface detail (600 MHz) and an adequate depth of investigation (200 MHz).

Figure 5. A moment of the GPR survey in the large square located in the former military district of San Giacomo degli Spagnoli, in Palermo.

The data were initially processed with ReflexW software [29]. The acquired data are usually noisy, and this makes subsequent interpretation difficult. For these reasons, some pre-processing steps are needed. The data processing operations flow is a completely arbitrary choice, mainly depending on the raw data quality. Parameters elaboration criteria chosen should not excessively affect data originality; this is 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 the time direction and is applied to eliminate time delays related to trigger errors;

(b) Butterworth-type frequency filter: this 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: this is useful for highlighting that low ranges of amplitudes acquired signal against the highest ones. A gain curve is applied in the time domain on the complete profile;

(d) Background removal: this 2D filter allows the elimination of temporal consistent noise, so highlighting signal portions previously covered by noise;

(e) Time cut: this filter allows for limiting or extending each recorded trace in time. This operation is truly worthwhile to eliminate the deeper part of the acquired profile in which the resulting 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 based on hyperboles of reflection present inside a preset bandwidth, is performed [30]. 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 0.12 m/ns. This same value was imposed on all the profiles carried out and used as the average velocity by which to convert times to depths, aware of the fact that for such a large area investigated, the EM velocity can vary locally.

From this, the maximum investigation depth was estimated at about 5 m for the 200 MHz antenna and about 2 m for the 600 MHz antenna.

The processed data were used to calculate the depth slices (Figure 6), one every 40 cm, using a lateral interpolation between the profiles and taking for each depth slice the maximum amplitude along the vertical of the data. Before depth slice extrapolation, the data were normalized.

Following the aforementioned 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. The algorithm used builds a 3D matrix of geolocated data and allows the easy application of mathematical operators. In this case, the square of the envelope of the radar signals has been used to emphasize the highest reflection amplitudes. Subsequently, the 3D matrix was normalized. Finally, the Voxler software (Golden Software) was used for the 3D rendering of the data. Although the data were acquired with a resolution along the direction of the ground penetrating radar profile of 0.03 m (one track every 3 cm), the construction of the model was forced to reduce the resolution to obtain a data matrix manageable by the rendering software used (Voxler). The enormous amount of data acquired did not allow for the exploitation of the graphic performance of the 3D model. Furthermore, the high resolution, which could be used for reconstructions of high-definition surface targets, was not necessary for the intended purpose of the investigation. In fact, the underground passages should be such as to allow the passage of a man on horseback, according to what is reported in various historical texts [31]. Its dimensions should therefore be such as to allow a lower resolution of the model. For this reason, the 3D model grid has been reduced to the dimensions of 0.5 m $\times$ 0.5 m $\times$ 0.1 m.

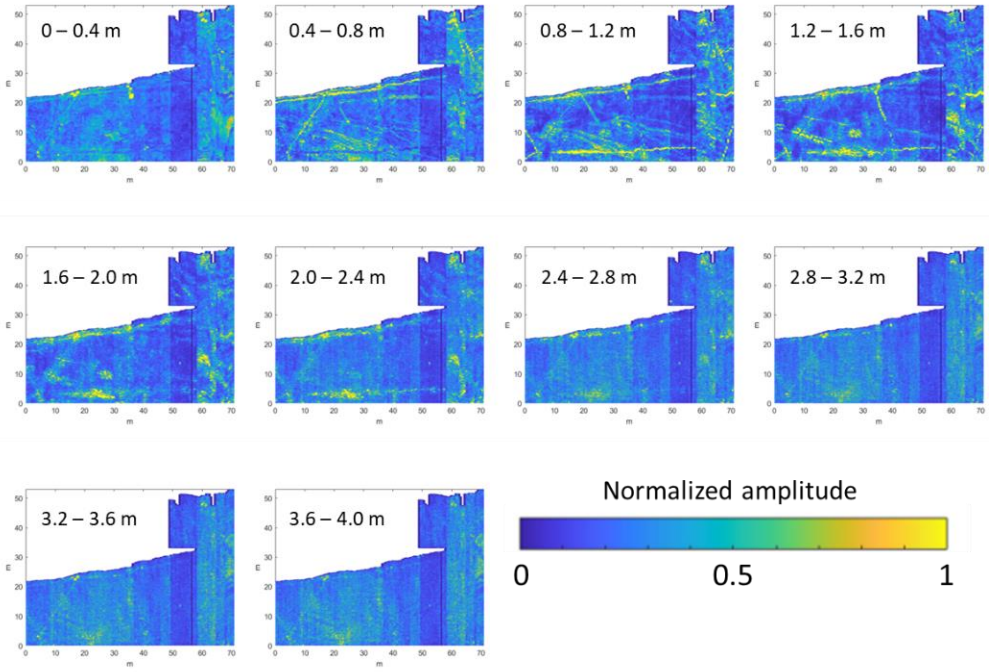

Figure 6. Depth slices obtained from GPR data acquired at the military district of San Giacomo degli Spagnoli, in Palermo.

The 3D model was realized using both the data acquired with 600 MHz (up to 2 m) and 200 MHz (from 2 m up to 5 m) antennae. The interpolation was performed with the Inverse Distance Weighting method, proposed by Shepard [32], which uses a weighted average based on the distance of the points from the observation point.

3. Results

The 3D georadar profiles obtained show several anomalies that may be related to subsoil structures. Figure 7 shows an example of a GPR profile in which various anomalies are visible. These could be caused by archaeological remains but also by subservices and recent structures.

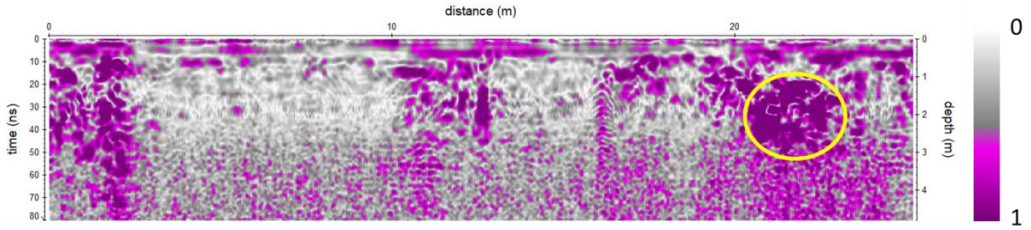

Figure 7. 2D GPR profile (X = 24 m). The yellow circle shows an anomaly that is not related to the presence of underground utilities.

The graphic rendering of the 3D model allows us to better follow the alignments of the anomalies and to discriminate anomalies of different types in terms of shape, size, depth, and direction of elongation (Figure 8). Many of the anomalies have an aligned shape and can certainly be interpreted as sub-services of the barracks, which are also reflected in the presence of numerous surface manholes. However, some anomalies do not seem to be related to the presence of these sub-services. These show depths greater than one meter and, above all, a lateral extension of about 2 meters.

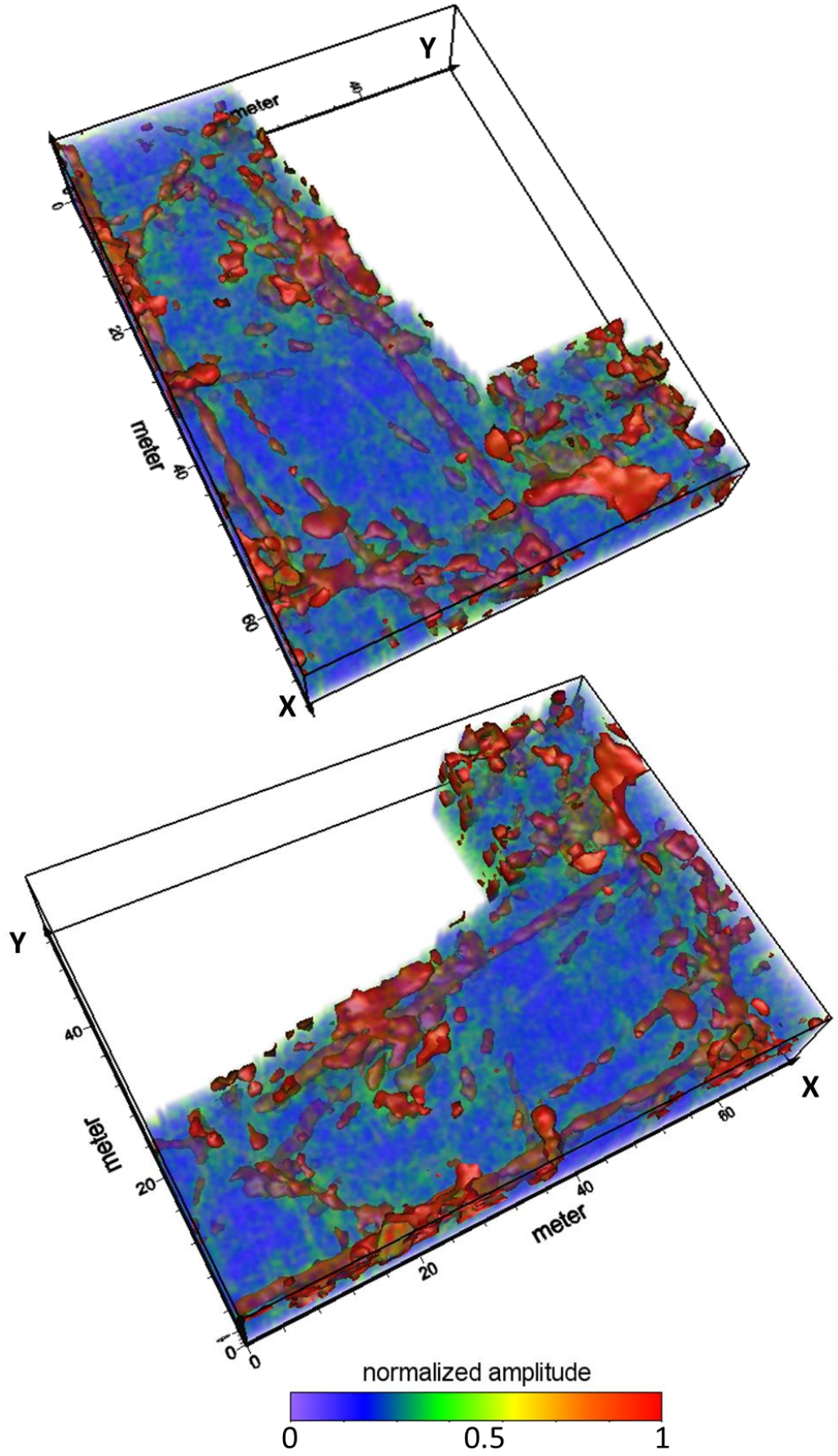

Figure 8. 3D model from different points of view. The volume of data is represented in transparency, while the red isosurface encloses the highly reflective data.

To better distinguish the deep anomalies from the superficial ones, three of the depth slices obtained were joined together to obtain a cumulative depth slice that represents the subsoil area ranging from 0.4 m to 1.6 m, in which the subservices and the most recent structures are located (Figure 9a). From this representation, it is possible to see that although some superficial anomalies, highlighted with red dotted lines in Figure 9b, show downward continuity and can be interpreted with the presence of underground utilities, others alignments, signed with black dashed lines, show non-corresponding forms and trends. One of them, in particular, is in the direction of the church of San Paolo d'Alga (Figure 10) and could, therefore, be related to the first stretches of tunnels that have recently been identified below this church [9], and which could, therefore, develop in the same direction. These latter could be traces of the ancient, buried walkway that connected the ancient quarter with the plain where the cathedral stands today [3] or, more probably, with the ancient seafront door of the town [7]. In fact, the lateral amplitudes of some anomalies, exceeding 3 m, would be compatible with those necessary to allow passage on horseback. This underground walkway may have partially collapsed and been filled with landfill over the centuries. This would justify the imperfect lateral continuity of the largest anomalies found. Finally, anomalies with a depth greater than 3 meters were highlighted (Figure 11). They could be caused by the remains of the foundation walls of ancient buildings. It should also be noted that there are two distinct areas of the studied zone in which the deep anomalies are grouped, separated by about 20 m. The first area is located in the northeastern part of the investigated area, near the present church of San Giacomo dei Militari, and could be part of the remains of San Giacomo la Mazara that would seem to continue beyond the investigated area. The second area is located in the western part of the investigated area. This part of the square, located near San Paolo d'Alga, could preserve the remains of Santa Maria la Mazara. These preliminary hypotheses are based on the arrangement of the churches according to the schematic map shown in Figure 2 [3], which, as mentioned above, gives us a very approximate idea of the spatial distribution of the main buildings of the neighborhood in the Middle Ages. Therefore, these assumptions should be verified by extending the investigations to other free areas and, above all, by carrying out excavation tests.

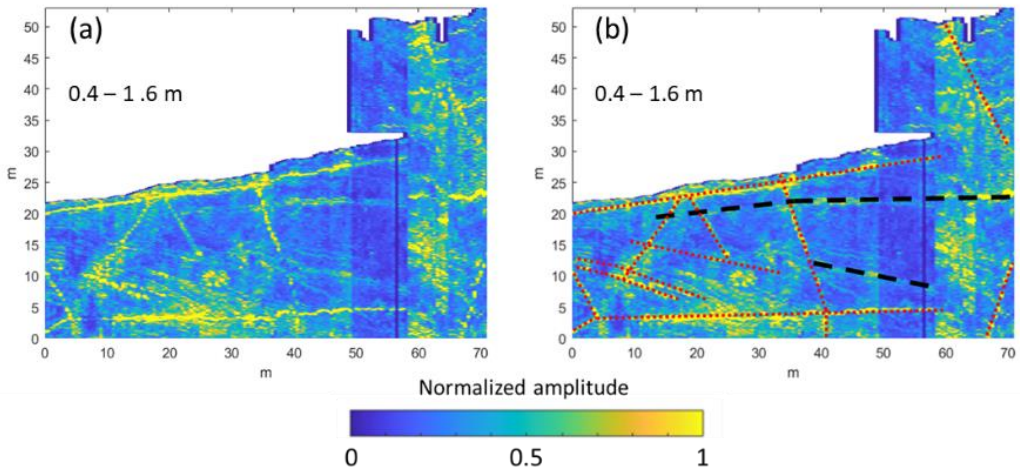

Figure 9. (**a**) Cumulative depth slice with depths from 0.4 m to 1.6 m; (**b**) the same depth slice in which the subservices are highlighted (red lines). The black lines indicate larger alignments, which do not have the characteristics of subservices.

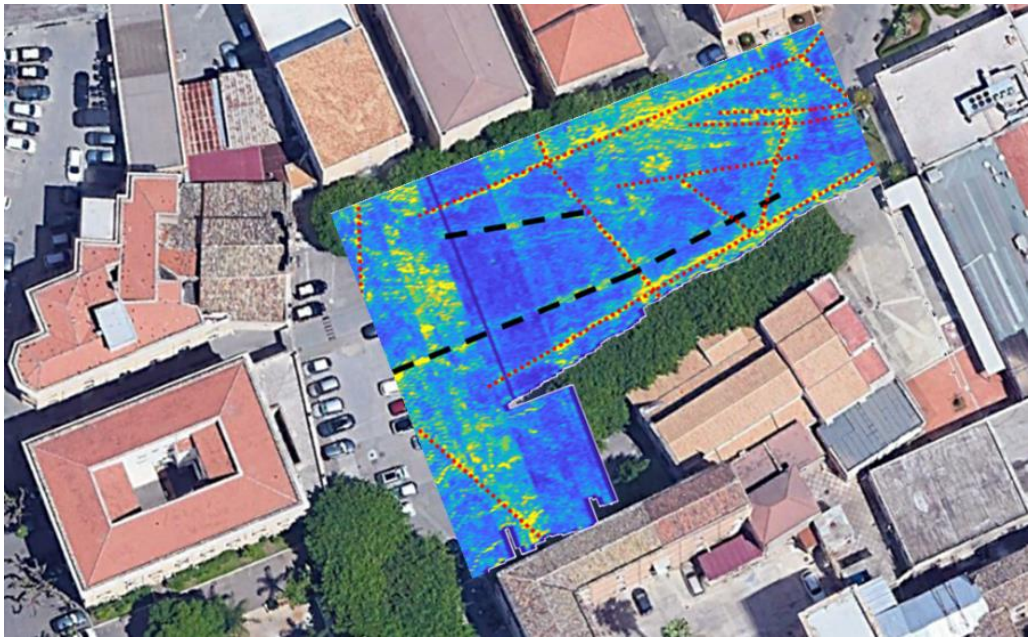

Figure 10. Cumulative GPR depth slice with depths from 0.4 m to 1.6 m superimposed to the orthophoto of the central area of the military district of San Giacomo degli Spagnoli. The subservices are highlighted by red lines. The black lines indicate larger alignments, which do not have the characteristics of subservices.

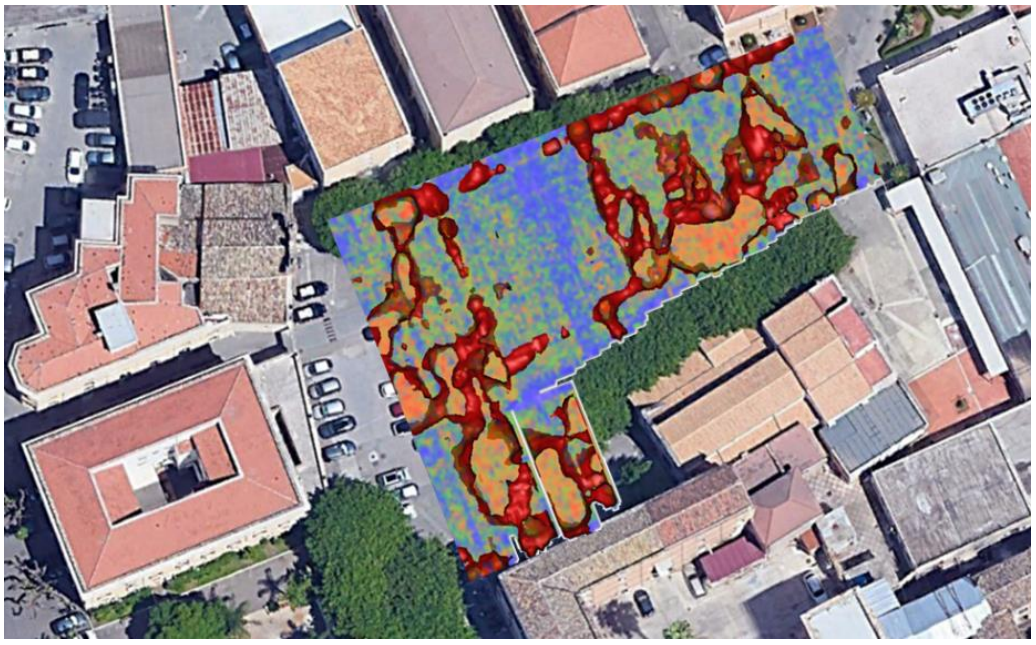

Figure 11. Ground penetrating radar 3D model superimposed to the orthophoto of the central area of the military district of San Giacomo degli Spagnoli. The red isosurface shows anomalies at a depth greater than 3 meters which could represent the foundations of San Giacomo La Mazara and Santa maria la Mazara churches.

4. Conclusions

The GPR investigations have allowed the reconstruction of a 3D geophysical model of the subsoil which shows structures consistent with those expected based on the events reconstructed from the limited historical information. The built 3D GPR model shows numerous linear anomalies. Most of these anomalies are superficial (up to 1 meter deep) and are probably due to the presence of underground pipes, also confirmed by the presence of some manhole covers in the square. However, some depth anomalies and their width (even 2 meters) are not compatible with the presence of pipes. These anomalies could be caused by the remains of the medieval underground way or the no-longer-existing medieval churches. The deep anomalies are less clear, probably due to collapses and alterations of the structures. Their identification at the moment can only be indicative and useful for the design of assays and excavations to verify the presence of building foundations or possible walkways. The archaeologists will evaluate which of these anomalies deserve to be investigated with a direct excavation assay. In this context, the 3D model obtained under the square inside the barracks could therefore be very useful for future archaeological investigations since it provides a synthetic view of the location and dimensions of the most important structures present in the subsoil, allowing them to be correlated with the archaeological remains already identified below the buildings that overlook the square. Finally, the planning of further GPR investigations in the open spaces adjacent to the one investigated will help to provide a clearer picture of the distribution of archaeological remains in the Galca district.

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References

1. Palermo, G. *Guida Istruttiva per Potersi Conoscere Con Facilità Tanto Dal Siciliano, Che Dal Forestiere Tutte le Magnificenze, e Gli Oggetti Degni di Osservazione della Città di Palermo*; Reale Stamperia: Palermo, Italy, 1816; Volume 4.
2. Bellafiore, G. *Edifici di Età Islamica e Normanna Presso la Cattedrale di Palermo*; Ministero dei Beni e delle Attività Culturali e del Turismo, Bollettino d'Arte: Rome, Italy, 1967; Volume 52, pp. 178–195.
3. Di Giovanni, V. *La Topografia Antica di Palermo dal Secolo X al XV: Memorie di Vincenzo di Giovanni*; Tip. e Legatoria del Boccone del Povero: Palermo, Italy, 1889; Volume 1.
4. Di Marzo, G. *Delle Belle Arti in Sicilia per Gioacchino di Marzo: Dai Normanni Sino Alla Fine del Secolo XIV*; Di Marzo, S., Ed.; Biblioteca Nazionale di Palermo: Palermo, Italy, 1858; Volume 1, p. 375.
5. Serradifalco, D.L.F.P. *Del Duomo di Monreale e di Altre Chiese Siculo Normanne Ragionamenti Tre per Domenico Lo Faso Pietrasanta duca di Serradifalco*; Roberti, T., Ed.; Palermo, Italy, 1838.
6. Mortillaro, V. *Guida per Palermo e Pei Suoi Dintorni del Barone V. Mortillaro*; Letterario, T.d.G., Ed.; Biblioteca Nazionale Centrale di Roma: Rome, Italy, 1836; p. 76.

7. Inveges, A. *Annali della Felice Città di Palermo, Prima Sedia, Corona del re, e Capo del Regno di Sicilia*; Dell'Isola, P., Ed.; Palermo, Italy, 1651; Volume 3.
8. Guiotto, M. *La Chiesa di S. Maria Maddalena in Palermo*; Ministero dei Beni e delle Attività Culturali e del Turismo, Bollettino d'Arte: Rome, Italy, 1949; Volume 34, pp. 361–367.
9. Capizzi, P.; Marrone, M.; Nero, C.A.; Bonfardeci, A.; Canzoneri, A.; Carollo, A.; Martorana, R.; Romano, F. Georadar Investigations in the Church of San Paolo (San Giacomo Dei Militari, Palermo). In Proceedings of the NSG2021 2nd Conference on Geophysics for Infrastructure Planning, Monitoring and BIM, European Association of Geoscientists & Engineers, Bordeaux, France, 29 August–2 September 2021; Volume 2021, pp. 1–5.
10. Ranalli, D.; Scozzafava, M.; Tallini, M. Ground penetrating radar investigations for the restoration of historic buildings: The case study of the Collemaggio Basilica (L'Aquila, Italy). *J. Cult. Herit.* **2004**, *5*, 91–99. [CrossRef]
11. Masini, N.; Persico, R.; Rizzo, E. Some examples of GPR prospecting for monitoring of the monumental heritage. *J. Geophys. Eng.* **2010**, *7*, 190–199. [CrossRef]
12. Pérez-Gracia, V.; Caselles, J.O.; Clapés, J.; Martinez, G.; Osorio, R. Non-destructive analysis in cultural heritage buildings: Evaluating the Mallorca cathedral supporting structures. *NDT & E Int.* **2013**, *59*, 40–47.
13. Binda, L.; Zanzi, L.; Lualdi, M.; Condoleo, P. The use of georadar to assess damage to a masonry Bell Tower in Cremona, Italy. *Ndt E Int.* **2005**, *38*, 171–179.
14. Pieraccini, M.; Mecatti, D.; Luzi, G.; Seracini, M.; Pinelli, G.; Atzeni, C. Non-contact intrawall penetrating radar for heritage survey: The search of the 'Battle of Anghiari' by Leonardo da Vinci. *NDT E Int.* **2005**, *38*, 151–157.
15. De Giorgi, L.; Lazzari, M.; Leucci, G.; Persico, R. Geomorphological and non-destructive GPR survey for the conservation of frescos in the rupestrian churches of Matera (Basilicata, southern Italy). *Archaeol. Prospect.* **2020**. [CrossRef]
16. Capizzi, P.; Martorana, R.; Messina, P.; Cosentino, P.L. Geophysical and geotechnical investigations to support the restoration project of the Roman 'Villa del Casale', Piazza Armerina, Sicily, Italy. *Near Surf. Geophys.* **2012**, *10*, 145–160. [CrossRef]
17. Martorana, R.; Capizzi, P. Joint investigation with Ground Penetrating Radar and Infrared Thermography as a Diagnostic Support for the Restoration of Two Wall Mosaics in the Church of St. Mary of the Admiral in Palermo, Italy. *Heritage* **2022**, *5*, 2298–2314. [CrossRef]
18. Casas, A.; Cosentino, P.L.; Fiandaca, G.; Himi, M.; Macías, J.M.; Martorana, R.; Muñoz, A.; Rivero, L.; Sala, R.; Teixell, I. Non-invasive geophysical surveys in search of the Roman Temple of Augustus under the Cathedral of Tarragona (Catalonia, Spain): A Case Study. *Surv. Geophys.* **2018**, *39*, 1107–1124. [CrossRef]
19. Martorana, R.; Capizzi, P. Seismic and non-invasive geophysical surveys for the renovation project of Branciforte Palace in Palermo. *Archaeol. Prospect.* **2020**, 1–14. [CrossRef]
20. Cozzolino, M.; Di Giovanni, E.; Gentile, V.; Mauriello, P.; Pizzano, N. Ground-Penetrating Radar Survey for the Study of the Church of Saint Cosma in Helerito (Tagliacozzo, L'Aquila, Italy). *Geosciences* **2020**, *10*, 244. [CrossRef]
21. Bottari, C.; Capizzi, P.; Martorana, R.; Azzaro, R.; Branca, S.; Civico, R.; Fucile, M.; Pecora, E. Diagnostic Multidisciplinary Investigations for Cultural Heritage at Etna Volcano: A Case Study from the 1669 Eruption in the Mother Church at the Old Settlement of Misterbianco. *Remote Sens.* **2022**, *14*, 2388. [CrossRef]
22. Cozzolino, M.; Gentile, V.; Giordano, C.; Mauriello, P. Imaging Buried Archaeological Features through Ground Penetrating Radar: The Case of the Ancient Saepinum (Campobasso, Italy). *Geosciences* **2020**, *10*, 225. [CrossRef]
23. Basile, V.; Carrozzo, M.T.; Negri, S.; Nuzzo, L.; Quarta, T.; Villani, A.V. A ground-penetrating radar survey for archaeological investigations in an urban area (Lecce, Italy). *J. Appl. Geophys.* **2000**, *44*, 15–32. [CrossRef]
24. Chìas, P.; Abad, T.; Echeverríaa, E. Terrestrial and Aerial Ground-penetrating Radar in use for the Architectural Researches: Ancient 16th Century Water Supply and Drainage at the Monastery of El Escorial (Madrid, Spain). *Remote Sens. Spat. Inf. Sci.* **2013**, *5*, W2. [CrossRef]
25. Berezowski, V.; Mallett, X.; Ellis, J.; Moffat, I. Using Ground Penetrating Radar and Resistivity Methods to Locate Unmarked Graves: A Review. *Remote Sens.* **2021**, *13*, 2880. [CrossRef]
26. Bellanova, J.; Calamita, G.; Catapano, I.; Ciucci, A.; Cornacchia, C.; Gennarelli, G.; Giocoli, A.; Fisangher, F.; Ludeno, G.; Morelli, G.; et al. GPR and ERT Investigations in Urban Areas: The Case-Study of Matera (Southern Italy). *Remote Sens.* **2020**, *12*, 1879. [CrossRef]
27. Baker, G.S.; Jordan, T.E.; Pardy, J. An introduction to ground penetrating radar (GPR). *Special Papers. Geol. Soc. Am.* **2007**, *432*, 1.
28. Cozzolino, M.; Di Giovanni, E.; Mauriello, P.; Piro, S.; Zamuner, D. *Geophysical Methods for Cultural Heritage Management*; Springer International Publishing: Cham, Switzerland, 2018.
29. Sandmeier, K.J. *ReflexW*, version 8.1. Program for Processing of Seismic, Acoustic or Electromagnetic Reflection, Refraction and Transmission Data. Software Manual. Karlsruhe, Germany, 2016.
30. Tillard, S.; Dubois, J.C. Analysis of GPR data: Wave propagation velocity determination. *J. Appl. Geophys.* **1995**, *33*, 77–91. [CrossRef]

31. Fazello, T. *De Rebus Siculis Decades Duae, Nunc Primum in Lucem Editae. His Accessit Totius Operis Index Locupletissimus*; Mayda, I.M., Carrara, F., Eds.; Palermo, Italy, 1558.
32. Shepard, D. A two-dimensional interpolation function for irregularly-spaced data. In Proceedings of the 23rd National Conference ACM, New York, NY, USA, 27–29 August 1968; ACM: New York, NY, USA, 1968; pp. 517–524.