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The "Annunziata" Garden in Cammarata (Sicily): Results of integrated geophysical investigations and first archaeological survey

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ABSTRACT

A multi-method geophysical investigation was carried out in the context of a recovery project for the "Annunziata" Garden located in the town of Cammarata (Sicily), near to the homonymous church (Chiesa dell'Annunziata). In this area, according to the scarce historical sources, there was a Benedictine convent, probably demolished in the 18th century, but the area was probably inhabited even in earlier periods. Preliminarily, a series of 2D electrical resistivity tomographies (2D-ERT) were carried out approximately parallel to each other, some of which highlighted resistivity anomalies that could be attributed to buried archaeological structures. Consequently, in a smaller area where these anomalies were evident, a 3D electrical resistivity tomography (3D-ERT) and Ground Penetrating Radar (GPR) parallel profiles were carried out aimed at a detailed 3D reconstruction of the subsoil. Despite the unclear correspondence between the 3D-ERT inverse model and the GPR one, the 3D ERT confirmed the anomalies found with the previous 2D-ERT surveys, better defining its contours and geometries. The geophysical reconstructions served to indicate to the archaeologists the most promising areas for excavation tests that were carried out subsequently and confirmed the presence of archaeological structures, such as defensive walls whose origin and dating are still the subject of further archaeological studies.

1. Introduction

Geophysical techniques employed in archaeological research and Cultural Heritage conservation have gained popularity over time (Deiana et al., 2018a). This trend is driven by several factors. Firstly, these methods are considered efficient, practical, and cost-effective tools for archaeological exploration and the preservation of cultural heritage (Barone et al., 2019) because they can significantly reduce the need for extensive excavation and minimize physical labor (Cozzolino et al., 2018). Furthermore, these techniques are non-invasive and non-destructive, enabling the investigation of sites while ensuring their preservation (Martinho and Dionísio, 2014) and providing precise location information about buried archaeological features (Capizzi et al., 2007; Casas et al., 2018). Lastly, they contribute to reconstructing the history of a site by integrating findings with other scientific disciplines, allowing insights into natural events such as earthquakes or volcanic eruptions that may have impacted the site's development (Bottari et al., 2018a, 2018b).

Cammarata, located in Southern Sicily, is an ancient town with roots in the medieval era, deeply intertwined with Sicily's history from the Arab period onward. The specific area of interest is a garden recognized locally as the "Annunziata" Garden (Fig. 1, left), located behind the "Annunziata" Church (Fig. 1, right). Historical records indicate the presence, between 1500 and 1700, of a Benedictine convent that was left deserted due to unspecified reasons. Recently, management of this site has been undertaken, realizing a project aimed at restoring the area and making it accessible to the public. The educational project "The Garden Rediscovered", is promoted by the school "Giovanni XXIII", in partnership with the "Archimede" school, both of Cammarata, and in collaboration with the Superintendency of Cultural and Environmental Heritage of Agrigento and the Municipality of Cammarata.

As part of these efforts, comprehensive geophysical surveys, including 2D- and 3D-ERT and GPR, were conducted to identify the main geophysical anomalies of possible archaeological significance, with the

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aim of pinpointing areas suitable for archaeological investigation to uncover any remains of the convent or traces of previous human-made structures. This effort also aims to clarify the nature of the event that led to the destruction of the Benedictine convent and its abandonment in 1700.

1.1. Historical framework

The town of Cammarata (Sicily) is situated at an elevation of 689 m above sea level on the slopes of Mount Cammarata (1578 m). The present settlement has medieval origins, although archaeological traces in the Cammarata area indicate habitation during Roman times as well.

Historical information about Cammarata and the monastery to which the garden under study likely belonged are reported by De Gregorio (1986). The Norman conquest of Cammarata is believed to have occurred in 1077, although the first official document related to Cammarata is the Norman Diploma of 1141, demonstrating the town's existing feudal structure. However, accounts from the Arab conquest of the territory suggest the presence of an inhabited center in Cammarata as early as the 9th century (Tirrito, 1983).

The "Annunziata" Garden belonged to a female Benedictine monastery in the town's lower and oldest part. The origins of the "Annunziata"

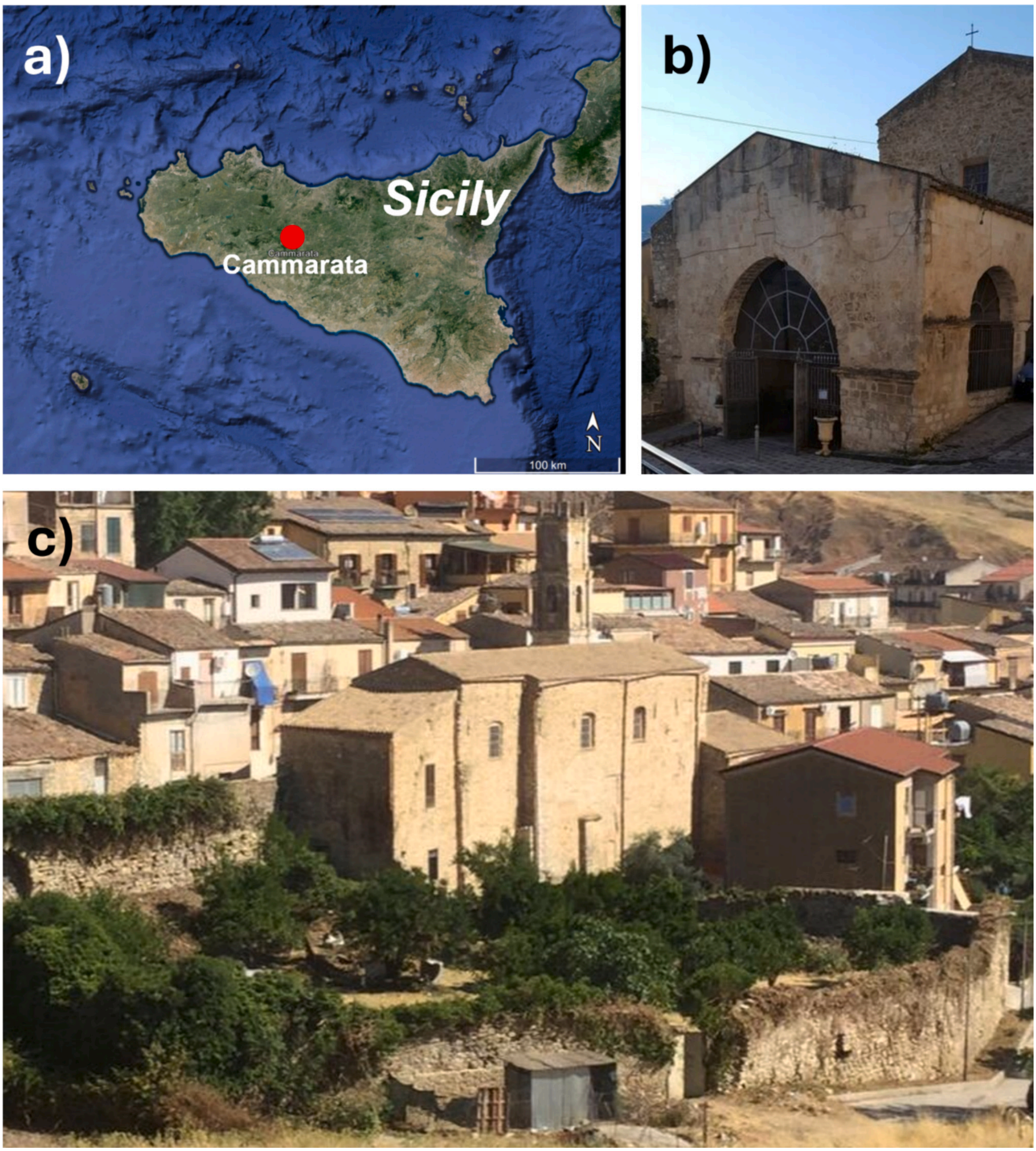

Fig. 1. a) Location of the town of Cammarata, in Sicily; b) view of the the Church of the Annunziata and c) of the Annunziata Garden located behind the Church.

monastery, associated with the homonymous church (still existing), are not clear to this day. The local historian De Gregorio (1986), citing information from "Sicilia sacra" by Rocco Pirri (1733), places its foundation between approximately 1435 and 1500.

Monasteries were typically built near watercourses, and the entire monastic complex was oriented to channel water towards fountains and the kitchen. The monastery "Annunziata" likely stood along the transhumance route periodically used by Cammarata's flocks during warmer months, following the course of the Turibolo stream, a tributary of the Platani river, which still flows near the Garden today, though it is now concealed in reinforced concrete. The Turibolo stream is mentioned several times in pastoral visit accounts to the monastery, conducted between 1540 and 1732. One of these accounts mentions the existence of a well and a garden adjacent to the convent (De Gregorio, 1986).

The monastery building was abandoned in 1792, likely due to its poor structural condition. Today, from the Monastery complex the only buildings remained are the "Annunziata" Church, a single-nave rectangular structure, and the Garden under study, enclosed by a well-preserved wall displaying multiple construction phases. There are no material traces of the monastery building remaining, making it uncertain which area it occupied. The garden may be the most tangible evidence of its existence. Notably, a "ruined monastery" is indicated on the Bourbon cadastral map of 1837–1853 at the same site.

From the earliest available aerial photograph, dating back to 1957, we can infer that the monastery complex extended towards the northeast area where a small building is currently situated. A portion of this complex encroached into the present-day garden area and likely also extended downstream of the current road that connects to the garden, as evidenced by a break in the continuity of a wall along this road. Furthermore, the eastern wall continued to extend northward. Aerial photographs allow also for the identification of a well, likely referenced in medieval records.

Analysis under the restoration project involved instrumental surveying to create a site plan of the garden, utilizing the remaining elevation of its enclosing walls (Fig. 2, left). These findings have enhanced our understanding of the garden's layout, characterized by a symmetric profile of the masonry structures, interrupted only by a curvilinear section along the southwest half of the perimeter. Inside the garden is a functional rectangular basin, likely used for collecting water from the stream, although its precise historical era remains undetermined at present.

Observations reveal an architectural layout within the garden featuring an apse positioned towards the southwest perimeter, flanked by two wings that mirror each other in inclination relative to the apse. Additionally, there are two nearly parallel wall fronts. This configuration deviates from the typical design seen in Benedictine monastery gardens and may instead reflect an Arab influence.

1.2. Geological framework

The Cammarata region is situated on the slopes of Monte Cammarata (1578 m above sea level), located at the southeastern end of the Sicani mountains (Mascle, 1979). The soils in this area are derived from sedimentary deposits within the paleogeographic region known as the "Sican basin" (Catalano and Montanari, 1979a, 1979b). The geological formations that are visible include Mesozoic-Cenozoic calcareous-marly layers, consisting of glauconite calcarenites deposited during the lower Miocene, followed by the "Marl of S. Cipirrello" Formation (ranging from the lower Miocene to lower Tortonian). Subsequently, during the middle Miocene, a complex groundwater system developed, characterized by various formations from the Imerese basin (Montagnola Series, with outcrops of Numidian Flysch visible east of the Platani River, Mascle, 1979).

The specific area being investigated, which is relatively flat, is situated at the base of the relief upon which the historic center of Cammarata was established. The morphology of this area conforms to the structural arrangement of the lower Miocene glauconite calcarenites (Aquitanian-Burdigalian), which exhibit a southeastward dip at an inclination ranging between 30° and 45°. The calcarenite complex, situated between Oligo-Miocene marly clays and subsequent Middle Miocene gray marls, consists predominantly of sandstones interspersed with marly-sandy layers (Broquet et al., 1967; Catalano and Montanari,

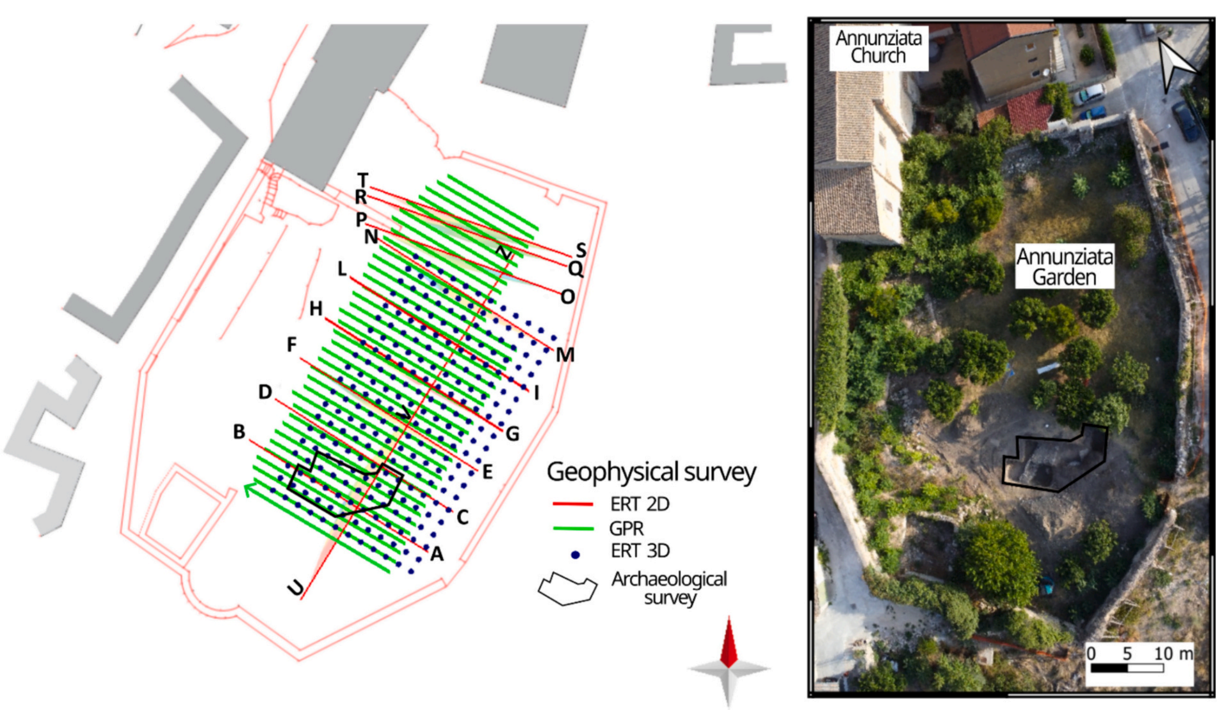

Fig. 2. Site plan of the "Annunziata" Garden (left), depicting the traces of 2D electrical resistivity tomographies (red lines), GPR profiles (green lines), the positions of electrodes used for 3D electrical resistivity tomography (blue points). And the boundary of the archaeological survey (black perimeter). This latter is also marked in the corresponding drone photo (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1979b).

The area targeted by the investigations (with an average altitude of 558 m above sea level) is expected to contain calcarenites beneath the wall that separates it from the inhabited center to the northwest. However, the presence of backfill material makes it challenging to ascertain from the surface whether these lithotypes still exist underground, or if they have been replaced by the subsequent Middle Miocene gray marls. Notably, these marls are extensively exposed on the hydrographic right side of the Turibolo stream, which originally flowed along the sandstone-marl contact but is now confined within a reinforced concrete underground channel.

2. Geophysical surveys

Over the past few decades, geophysical methods have become indispensable tools in archaeology and Cultural Heritage studies (Gaffney, 2008; Deiana et al., 2018a), owing to their non-invasive nature, speed of execution, and cost-effectiveness (Martorana et al., 2023). Additionally, combining multiple geophysical techniques has proven effective in overcoming inherent limitations of individual methods (Scudero et al., 2018).

The methods here used, Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR), are among the primary geophysical techniques commonly utilized in archaeology and cultural heritage studies (Martinho and Dionísio, 2014). ERT (Loke et al., 2013) aids in identifying dense masonry blocks or buried voids (Noel and Xu, 1991; Berge and Drahor, 2011a, 2011b), while GPR (Annan, 2009) relies on the reflection and refraction of electromagnetic pulses induced by electromagnetic property variations that can be caused by the presence of masonry blocks or metals in the near surface soil (Conyers, 2006; Goodman and Piro, 2013). These two techniques are efficient and particularly effective for compact, shallow archaeological features, which are typical targets in archaeological investigations (Berezowski et al., 2021).

Given that each technique provides unique insights based on different physical properties, their integration enhances survey capabilities, offering a more comprehensive assessment of archaeological characteristics (Capizzi et al., 2007; Casas et al., 2018; Deiana et al., 2018b).

The geophysical investigations described in this study were conducted in different steps, within the Annunziata Garden, to elucidate the subsurface geological characteristics and identifying buried archaeological structures within the area. The study employed a first step consisting in 2D ERT lines, and a second step consisting of a 3D ERT tomography, carried out in a more limited zone of an approximate area of 500 square meters, integrated by Ground Penetrating Radar (GPR) measurements (Martorana and Capizzi, 2023).

2.1. Electrical resistivity tomography

Electrical resistivity tomography (ERT) is a valuable technique for detecting structures with significant resistivity contrasts compared to surrounding anthropic sediments, which typically exhibit moderate to low resistivity due to their clay content. Archaeological features of stone materials exhibit higher resistivity than the surrounding soil, making them easily discernible through resistivity surveys. Additionally, void spaces underground (such as tunnels, chambers, tombs, etc.) are identifiable due to the high resistivity of air. Conversely, areas with high water content, such as wet zones, exhibit low resistivity (Griffiths and Barker, 1994).

The resolution of ERT largely depends on the spacing between electrodes, typically ranging from 1 to 2 m for archaeological surveys. ERT can investigate depths exceeding two meters, although with reduced resolution.

Although ERT is slower and more expensive compared to other geophysical methods in archaeology, it is employed for identifying wet zones, investigating greater depths, or in combination with methods like GPR and magnetometry to resolve ambiguities. Previously, electrical resistivity measurements were limited to mapping apparent resistivity or resistance of the subsoil using fixed-geometry four-electrode arrays for detecting anthropic structures in large archaeological sites (Noel and Xu, 1991; Gaffney, 2008). However, modern advancements allow for the creation of 2D and 3D resistivity images through inversion, enabling more precise identification of archaeological features before excavation.

In archaeology and cultural heritage studies, ERT surveys have been used for various purposes including characterizing tumuli (Hegyi et al., 2021), mapping layers of human settlements (Deiana et al., 2020), locating buried voids (Bottari et al., 2022), walls, and foundations of monuments (Tsourlos and Tsokas, 2011; Cozzolino et al., 2020), identifying and characterizing tombs and crypts (Berezowski et al., 2021), and studying geological or geomorphological aspects of archaeological sites (Capizzi and Martorana, 2014; Bottari et al., 2017, 2018a, 2018b). ERT also plays a crucial role in cultural heritage preservation, particularly in assessing and restoring historic buildings constructed on older structures (Di Maio et al., 2012; Cafiso et al., 2023).

The locations of the 2D-ERT lines conducted in the Annunziata Garden in Cammarata are shown in Fig. 2. The surveys were designed to extensively investigate the area within the perimeter wall of the garden, taking into consideration the presence of trees and masonry structures. Apparent resistivity measures were carried out using the MAE X612-EM+ resistivity meter. Most of the geoelectric surveys were carried out perpendicular to the main wall of the garden, six in the SE-NW direction, spaced about 5 m apart from each other, another three closer together in the northernmost area, with an ESE-WNW direction and finally two contiguous geoelectric surveys perpendicular to the first ones, with a SW-NE direction. For each electrode line, 16 equidistant electrodes were placed with an inter-electrode spacing of 1.5 m, covering a length of 22.5 m. For each line 83 apparent resistivity measures were carried out using the linear dipole-dipole array.

The pseudosections obtained were initially examined to eliminate outliers mainly caused by high contact resistances at the electrodes, and the remaining apparent resistivity data were inverted using RES2DINV software. The inverse models obtained exhibit RMS errors of less than 20%. The electrical resistivity sections obtained, shown in Fig. 3, reveal a maximum investigation depth of approximately 4 m. The resistivity distribution is quite heterogeneous across all models, ranging from a minimum of 10 Ωm to a maximum of 300 Ωm. Clear lateral as well as vertical variations are observed, allowing for the delineation of broad zones with higher resistivity values (above approximately 60 Ωm) from a generally more conductive background. The resistive areas are predominantly concentrated, with some exceptions, in the southernmost part of the surveyed area. Based on this observation, it was decided to further investigate this zone in greater detail by conducting a 3D ERT in a limited area (Fig. 2).

The resistivity measurements related to 3D ERT were performed using the multichannel resistivity meter MAE X612-EM+. It leveraged its ability to simultaneously measure multiple voltages relative to a single electric current dipole, in order to obtain a substantial amount of data for a 3D model. A total of 240 electrodes were deployed on the ground in a regular grid pattern measuring 20 × 12 electrodes, covering an area of 28.5 m × 16.5 m. The spacing between electrodes was kept constant at a minimum distance $a = 1.5$ m along both perpendicular directions. Data collection involved sequentially connecting 4 rows of 12 electrodes each time, using a dipole-dipole electrode configuration with dipole lengths ranging from 1.5 m to 6 m (a to $4a$) and dipole orders n from 1 to 10. The measurements were carried out by simultaneously connecting 48 electrodes in 4 rows, each with 12 electrodes, using an electrode step of 1.5 on all the 48-electrode array. A 3D roll-along was used by shifting the array of three rows at a time to ensure overlap on the fourth row. This method resulted in a total of 3500 measurements.

The acquired data underwent preliminary filtering to remove outliers and values exhibiting a standard deviation exceeding 20% from the

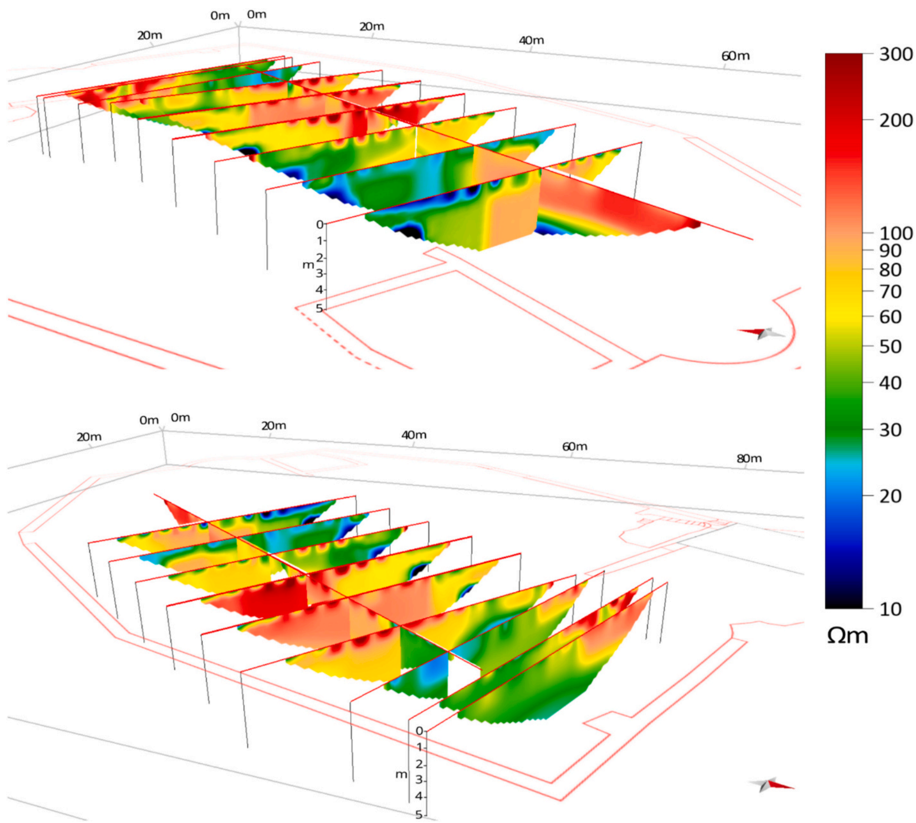

Fig. 3. 3D-rendering, with different points of view, of the 2D ERT surveys performed in the "Annunziata" Garden in Cammarata.

mean. The apparent resistivity measurements were then processed using RES3DINV software, yielding a 3D inverse model with an absolute error of 8.4%. Visual representation of the electrical resistivity model was generated using Voxler (Golden Software) (Fig. 4a), depicting resistivity values ranging between 2 Ωm and 200 Ωm, with an average of approximately 30–40 Ωm. Specific areas exceeding 60 Ωm were identified as high-resistivity zones and emphasized in the volume rendering using an isosurface representation (Fig. 4b).

2.2. Ground Penetrating Radar

Ground Penetrating Radar (GPR) employs electromagnetic waves, typically within the frequency spectrum of 10–3000 MHz, to delineate structures and concealed objects in the subsurface (Annan, 2009). Owing to its rapid data collection and superior resolution imaging attributes, this technique is among the most endorsed non-invasive methodologies to detect near surface buried structures (Persico, 2014) and, for this reason, is frequently utilized in archaeological explorations (Goodman and Piro, 2013), where it has demonstrated its efficacy in detecting the location of archaeological remains, thereby facilitating the planning of future excavations (Trinks et al., 2010; Leucci et al., 2016; Casas et al., 2018; Rizzo et al., 2018).

GPR investigations were conducted using RIS MF HI-MOD instrument by IDS, characterized by a dual antenna at frequencies of 200 MHz and 600 MHz. Considering the subsoil lithology, the 200 MHz antenna would have allowed for a maximum investigation depth of about 6 m, while the 600 MHz antenna would have ensured good surface resolution, compatible with the purposes envisaged by the study. In the investigation area, 36 profiles were acquired, in parallel lines and interdistance of 1 m (Fig. 2). Unfortunately, the presence of numerous olive trees in the garden prevented us from acquiring with a smaller interdistance, that would have certainly ensured a better lateral resolution of the 3D GPR model, in order to guarantee the most appropriate coverage of the surface and a realistic interpolation of the data. The time range of recording was set at 100 ns for the 200 MHz antenna and 50 ns for the 600 MHz antenna. From the slopes of the hyperbola branches present in the data, the electromagnetic wave velocity was estimated, obtaining an average value of 0.10 m/ns. This value was used to estimate the reflection depths of the buried targets. The GPR data were processed using a standard sequence (Conyers, 2006; Goodman and Piro, 2013) to eliminate the coherent and incoherent noise present in the original data (static correction, Butterworth-type frequency filtering, energy decay, background removal, Kirchoff migration).

From the processed GPR data, a 3D model of the subsurface was created, using a Matlab code to obtain a 3D matrix of geolocated data representing the normalized envelope of the maximum reflection amplitudes for each cell of the model. Finally, the Voxler software was used for the 3D rendering of the model (Fig. 5). In particular, the first two meters of depth in the 3D model were reconstructed from data acquired using the 600 MHz antenna, while the deeper part of the model (from two meters up to six meters) was achieved from the 200 MHz antenna.

3. Joint analysis and interpretation

From the 2D ERT results (Fig. 3), it is evident the presence of a heterogeneous cover, 1-2 m thick, that overlies soils with variable resistivity. In this regard, the four tomographies that fall in the SW area show a resistive subsoil that, about halfway through the section, laterally passes towards NW to more conductive soils. The tomographies further north do not show this lateral variation, but rather show resistive surface anomalies (maximum thicknesses of 2.5 m) in the easternmost part.

The 3D ERT was carried out in the southern part of the garden where the 2D profiles had shown clear lateral contrasts between conductive and resistive zones, possibly caused by the presence of buried archaeological structures.

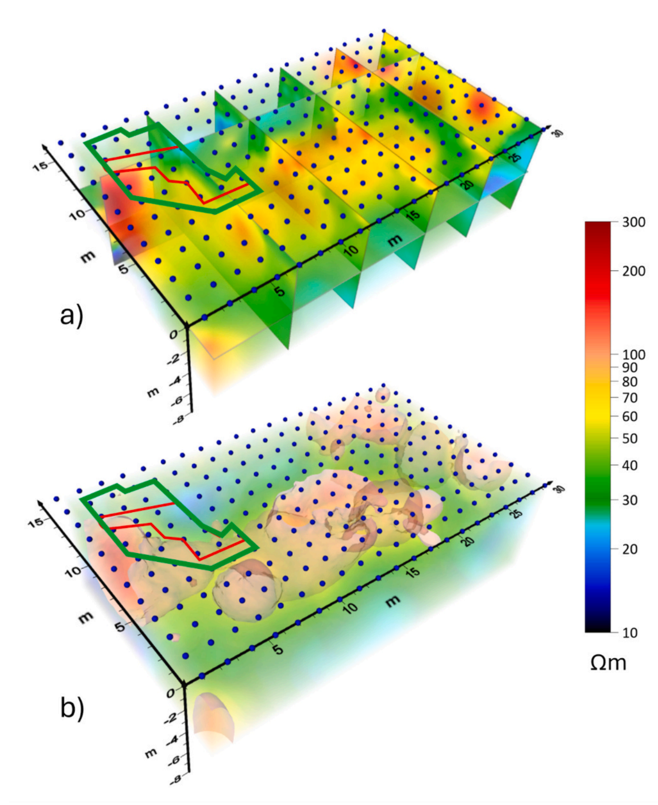

Fig. 4. Three-dimensional electrical resistivity tomography of the subsoil of the "Annunziata" Garden: a) volume rendering of the inverse model of electrical resistivity; b) the orange isosurfaces comprise the volumes with resistivity greater than 60 Ωm. The green polygon delineates the excavation test pit. The red line indicates the edges of the unearthed wall structures. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

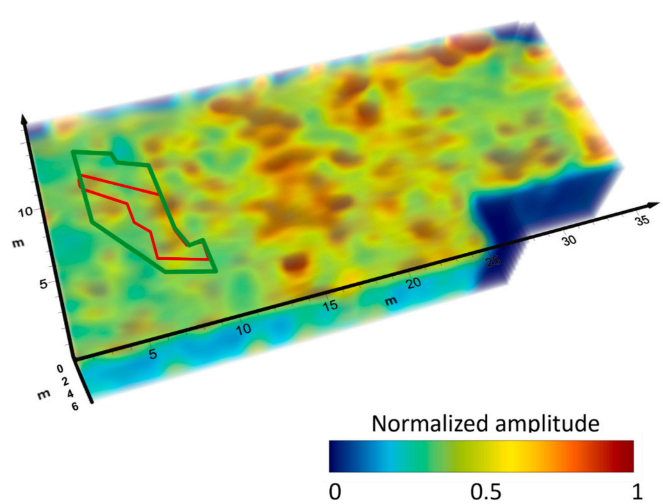

Fig. 5. Ground Penetrating Radar survey of the subsoil of the "Giardino Dell'Annunziata": 3D GPR model. The green polygon delineates the excavation test pit. The red line indicates the edges of the unearthed wall structures. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Upon examination of the 3D ERT model (Fig. 4), an elongated resistive anomaly is discernible. This anomaly, which aligns sub-parallel to the garden walls, deepens marginally as it extends from the apse towards the northwest (Fig. 6). Characterized by resistivity values exceeding 60 Ωm but not surpassing 200 Ωm, this anomaly is unlikely to be voids, but more likely to be calcareous stony material, more resistive than the surrounding sandy marls and fill soils. The resistive anomaly ceases in the northern region where additional, more superficial and localized resistive anomalies are observed at the model's extremities. These could also be the result of disturbed archaeological remains. At the center of the surveyed area, an anomaly of approximately circular shape is noticeable. This anomaly, which originates from the surface and extends to a depth of about 3 m, intersects the previously described elongated structure (Fig. 6). Historical data suggests that this last anomaly could be attributed to a large medieval masonry well (De Gregorio, 1986) that was later abandoned and filled with non-cohesive material.

Analyzing the results of the GPR surveys (Fig. 5), an electromagnetic anomaly corresponding to the elongated electrical resistivity anomaly shown in the 3D ERT is not evident. Even though some alignments of high reflectivity are still noticeable in correspondence with it, they only appear in the most superficial part of the model. Considering the 200 MHz antenna GPR section (Fig. 7) that cuts perpendicularly through the ERT section shown in Fig. 6, an anomaly with high reflectivity is observed, whose position and lateral extent correspond to the wall structure uncovered by the archaeological assay.

Another superficial GPR anomaly, clearly visible in the center of the investigated area, would approximately confirm in size and shape the vertically elongated anomaly visible in the 3D ERT model ($x = 12$–16 m, $y = 3$–7 m). However, we cannot exclude that these superficial anomalies, along with others distributed throughout the area, may originate from the roots of the numerous olive trees present in the garden. The aforementioned considerations strengthen the hypothesis that the resistivity anomalies shown by the 3D ERT models are not due to natural or anthropic cavities, which would be clearly visible to the GPR investigation, but are rather caused by the presence of stone materials with electrical permittivity not dissimilar from that of the surrounding sediments and that, consequently, would not give well recognizable anomalies in the GPR model. In any case, the presence of possible ancient riverbed of the Turibolo Stream, or water supply artificial channels builded by the monks and subsequently filled with waste material or stonework can be supposed. These materials would have dielectric properties of the surrounding lithologies, albeit slightly higher resistivity.

4. Archaeological excavations

The area in which the well-localized and elongated anomaly shown by the 3D ERT is clearly visible was considered the most promising in order to carry out some archaeological surveys that would test the hypotheses derived from the geophysical interpretation. In September 2023, a preliminary exploratory excavation commenced to investigate the origins of this detected geophysical anomaly. A 4 m × 3 m excavation was conducted in a first area where the previous discussed laterally elongated resistive anomaly is nearest to the surface (Fig. 8a). The excavation area was subsequently expanded when the wall structure was uncovered to define its width and orientation, which was confirmed to be the same as that of the anomaly. The perimeter of the excavation area is indicated in Fig. 2.

At a depth of 1.3 m, an anthropogenic structure, likely a defensive wall, was discovered. This wall exhibited varying widths and a complex construction due to multiple phases of development (Fig. 8b). The initial phase, located at the extreme southwest of the excavation, measured 1.5 m in width. The stone elements originated from the gray limestones typical of the Monte Cammarata nucleus (Scillato Formation, Upper Lias).

The masonry structure is a dry-stone wall constructed using medium-sized stones for the outer curtain and a mixture of rubble and landfill for the core. The wall runs in an east-west direction and, according to geo-analyses, extends to the eastern limit of the post-medieval curtain wall.

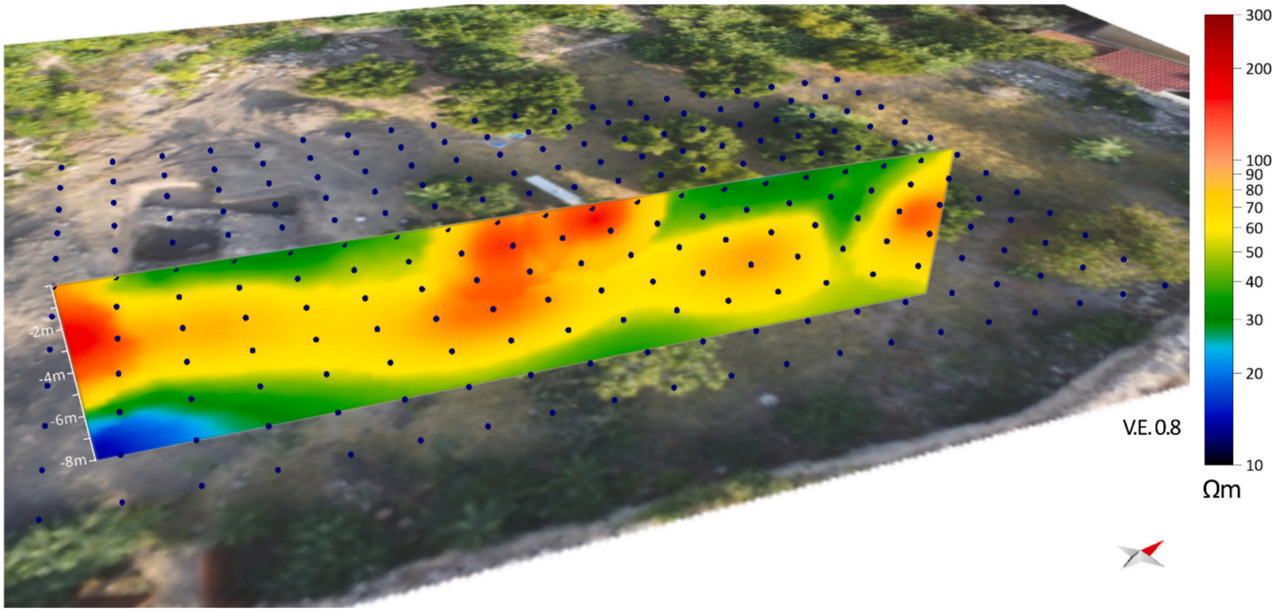

Fig. 6. Vertical section derived from the inverse model of 3D electrical resistivity shown in Fig. 4, which highlights the elongated resistive anomaly according to its direction of elongation and the vertical resistive anomaly that joins it starting from the surface.

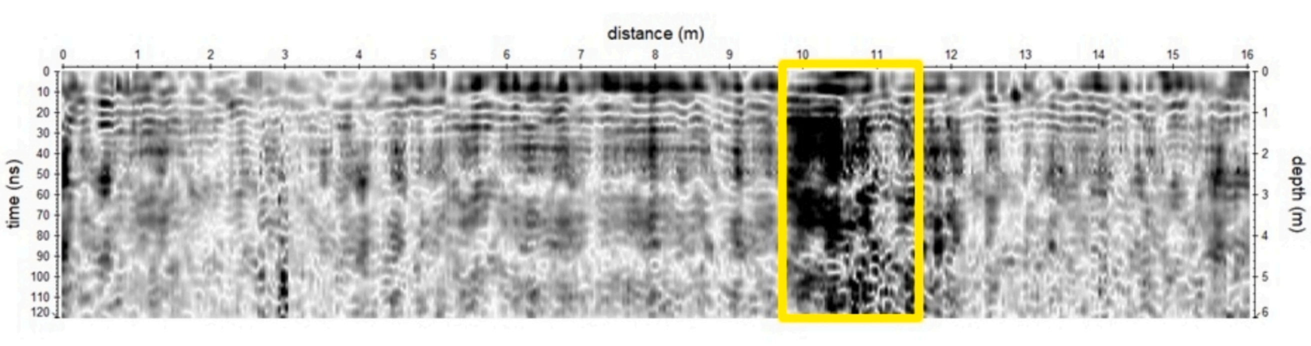

Fig. 7. 200 MHz antenna GPR section, carried out perpendicularly to the ERT section shown in Fig. 6, passing over the excavation and displaying a clear anomaly (yellow line) at the location of the found wall structure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In its western part, it has a thickness of 1.50 m, while in the eastern part, intercepted after the extension of the trial trench, the wall is approximately 3 m thick, in accordance with the average width of the resistive anomaly, although its actual height cannot be determined at present. At the wall's summit, coins dating back to the Frederick II period and abundant terracotta artifacts were uncovered.

In the central part of the trench, southeast of the curtain wall, there are layers of accumulation consisting of soil and blocks of medium to large size, descending to a depth of over 2 m. Here, what appears to be the foundation of the wall was intercepted (large blocks slightly protruding from the wall profile). Notably, the blocks, from the foundation up to 0.60/0.70 m, are larger and more squared, while the rest of the elevation is composed of smaller blocks with significant earth content.

Furthermore, the outermost part of the wall seems to terminate near the center of the trench, suggesting it may have been removed due to ancient rearrangements or destroyed by the frequent landslides in the area. The latter hypothesis could be supported by the layer leaning against the eastern face of the wall, 1.50 m thick, south of the thickest section, comprising accumulations of soil, ceramic fragments, and randomly placed medium to large stones.

Finally, it is conceivable that the construction of this curtain wall occurred in two or more phases, overlooking the Turibolo stream to the east. Current data do not provide reliable answers regarding the chronology of this wall, which appears to be a fortification.

From geo-analyses, it is evident that this anomaly, now identified as a masonry structure, continues in the center of the garden with a NE- SW orientation, suggesting an interruption indicating a possible entrance. This agrees quite well with the boundaries shown by the resistive anomaly along this direction. Moving westward from the trench, the structure persists, indicating it is a defensive wall; however, its limits and actual length remain unknown, although the resistive anomaly would seem to indicate that it extends in this direction for at least the entire area investigated. Therefore, future excavation campaigns should focus on this structure to determine its possible perimeter and, most importantly, establish a timeline.

Currently, coins found during excavation (Fig. 8c) suggest phases of life and abandonment dating to the 12th–13th centuries, indicating that the structure may be older. However, available data are limited, pending further analysis of all recovered materials and coins and the continuation of excavations to gain clearer insights into the complex, potentially pre-Norman structure. At present, it is uncertain whether the structure belongs to the Islamic, Byzantine, or earlier periods. Samples were collected from all stratigraphic layers to facilitate radiocarbon dating analysis aimed at determining their ages.

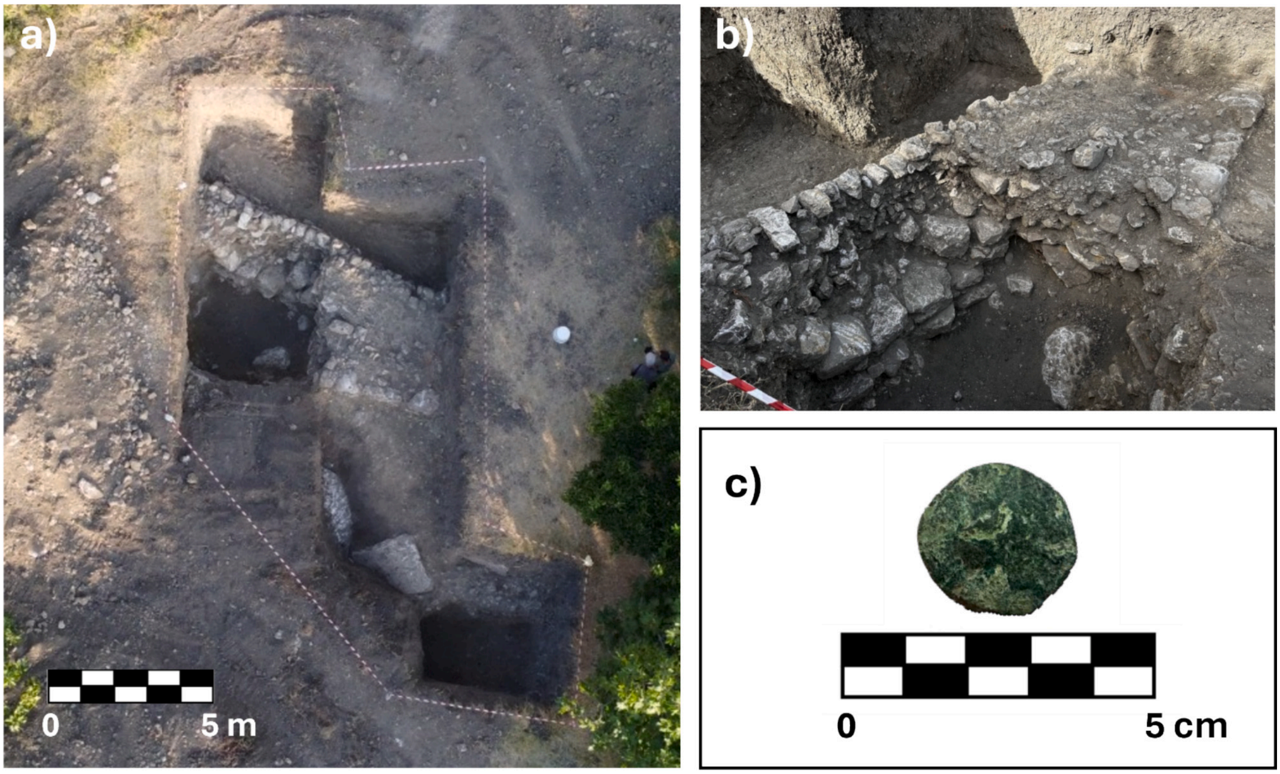

Fig. 8. a) Aerial photo of the excavated area in the Annunziata Garden, from September 2023; b) view of the defensive wall; c) example of a coin found during the excavation.

Finally, dating the garden-surrounding walls would be essential to understand the relationship between the monastery and the area's earlier phases of habitation.

5. Conclusions

Non-invasive geophysical investigations such as ERT and GPR have allowed archaeologists to obtain information about the subsurface without disturbing it. This is particularly important for preserving the integrity of the garden. They have also been fundamental in testing archaeological hypotheses about the site, based on scant historical news.

The information obtained from the 3D ERT and GPR models has significantly contributed to the interpretation of the site in several aspects. The resistive anomalies detected by the 2D ERT and, in more detail, by the 3D ERT model have allowed us to hypothesize the presence of buried archaeological structures or features, such as walls, foundations or other man-made structures that have different resistivity values compared to the surrounding soil. Furthermore, the depth and distribution of these anomalies provided information on the stratigraphy of the site, revealing the layers of occupation and use over time. The knowledge of the location of potential archaeological features was fundamental in planning a first targeted preliminary excavation that confirmed the geophysical hypotheses. This excavation which will be followed by further excavations, as planned by the Superintendence of Cultural Heritage of Agrigento when the results of the ongoing archaeometric analyses will be able to tell us more about the origin of the archaeological remains and allow to draft a possible planimetry, in agreement with the geophysical results, allowing to save time and resources by focusing where there was a higher probability of discovering significant archaeological remains.

The first archaeological excavation carried out in an area of the garden that presented evident geophysical anomalies allowed to bring to light parts of a defensive wall and other structures that, already preliminarily, have proved fundamental for a more precise historical placement and for a greater knowledge of the history of the Annunziata monastery and, in general, of the town of Cammarata. Further information obtained from the geophysical interpretation will be useful to test further hypotheses on the site and therefore plan further archaeological investigations.

CRediT authorship contribution statement

Raffaele Martorana: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Patrizia Capizzi:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Calogero Giambrone:** Writing – original draft, Resources, Project administration, Investigation, Data curation, Conceptualization. **Lisa Simonello:** Writing – original draft, Resources, Formal analysis. **Mattia Mapelli:** Writing – original draft, Investigation, Formal analysis, Data curation. **Alessandra Carollo:** Writing – original draft, Visualization, Software. **Valeria Genco:** Validation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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