Investigating the Castello Archaeological Park (Cersosimo, Italy) Using a Combination of Geophysical Prospections, Aerial and Terrestrial Photogrammetry

Marilena Cozzolino[1(✉)], Vincenzo Gentile[1], and Paolo Mauriello[2]

[1] Department of Biosciences and Territory, University of Molise, C.da Fonte Lappone, 86090 Pesche, Italy
marilena.cozzolino@unimol.it

[2] Department of Agricultural, Environmental and Food Sciences, University of Molise, 86100 Campobasso, Italy

Abstract. The Castello Archeological Park is located in the Municipality of Cersosimo in the Basilicata Region (Province of Potenza, southern Italy). Significant questions remain unanswered despite earlier archaeological studies that have clarified a number of important aspects of the settlement, including the layout of the southeastern sector of the enclosure wall, the location and the spatial boundaries of two major architectural complexes, and the identification of the southern access gate to the fortified area. Specifically, there are still interrogations about the settlement's internal spatial layout and the complete scope of the defensive circuit. In this article, the initial findings of a multidisciplinary study program aimed at increasing the site's current understanding by combining high-resolution photogrammetric survey and non-invasive geophysical prospection are presented. The study intends to improve knowledge of the settlement's structural layout, find previously overlooked architectural features, and create a thorough geospatial framework to direct further archaeological research by fusing subsurface diagnostic methods with three-dimensional surface documentation.

Keywords: Castello Archaeological Park · Cersosimo · Aerial and terrestrial photogrammetry · Geophysical prospections

1 Introduction

At an elevation of about 723 m above sea level, the Castello Archaeological Park of is located in the upper sector of the Municipality of Cersosimo inside the Province of Potenza (Basilicata, southern Italy) (40°02′42.27′N; 16°21′06.05′E) (Fig. 1). The site is strategically placed on a hill with a view of the Saramento valley, the Lappio stream, and the natural route that connects the inland regions to the Ionian coastal plain and passes through the current center of Oriolo [1]. In line with larger settlement dynamics recorded in Basilicata and northern Calabria during the pre-Roman era, this topographical configuration amply demonstrates the settlement's defensive and territorial control

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function. The settlement's location guaranteed visual command over communication corridors and hydrographic networks.

A fortification system that takes advantage of the terrain's natural shape defines the archeological site. The defensive circuit forms an irregular quadrilateral with a total circumference of around 900 m by adjusting to contour lines and slope breaks. Significant elements of the fortification are still recognizable, despite the fact that some of it has been destroyed by artificial disturbances, vegetation growth, and natural erosion. The southwest corner of the enclosure, where excavations conducted by Lacava in 1969 revealed a postierla, a secondary access gate to the ancient city, corresponds to the best-preserved sector [2, 3] (Fig. 2a, b). Because it sheds light on the settlement's defense tactics and circulation patterns, this feature is very interesting from an architectural standpoint. Furthermore, the first systematic documentation and archaeological investigations of the polygonal masonry walls of Castello Hill was achieved describing the building methods and spatial arrangement of the fortification system. In order to establish the spatial extent of the archaeological remains and confirm the structural continuity of the defensive circuit, De La Genière, on behalf of the Superintendence of Antiquities of Basilicata, conducted further research in 1969 [4]. These excavations greatly expanded our understanding of the settlement's layout by establishing the fortress walls' adaptability to the local geomorphology and recording important architectural features.

Two major architectural complexes, commonly known as Building A and Building B, have been found within the walled perimeter [5]. They are both thought to date to the third century B.C. One of the best examples of a residential complex is Building A, which has a central peristyle courtyard surrounded by symmetrically placed rooms (Fig. 2c, d) [6]. A peristyle court is a comparatively advanced architectural typology that reflects both socioeconomic level and functional structure suggesting a cohesive urban project. Building B was likewise built on a rectangular ground plan. Its architectural arrangement implies either a supplemental residential role or a structure with administrative or community objectives within the walled village, despite the fact that it is less well recorded.

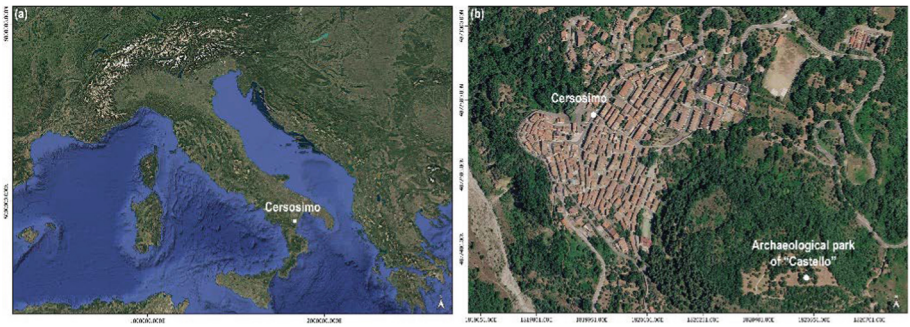

Fig. 1. Location of Cersosimo (PZ) on a Google Earth™ satellite image of Italy (a), location of the Castello Archaeological Park (b).

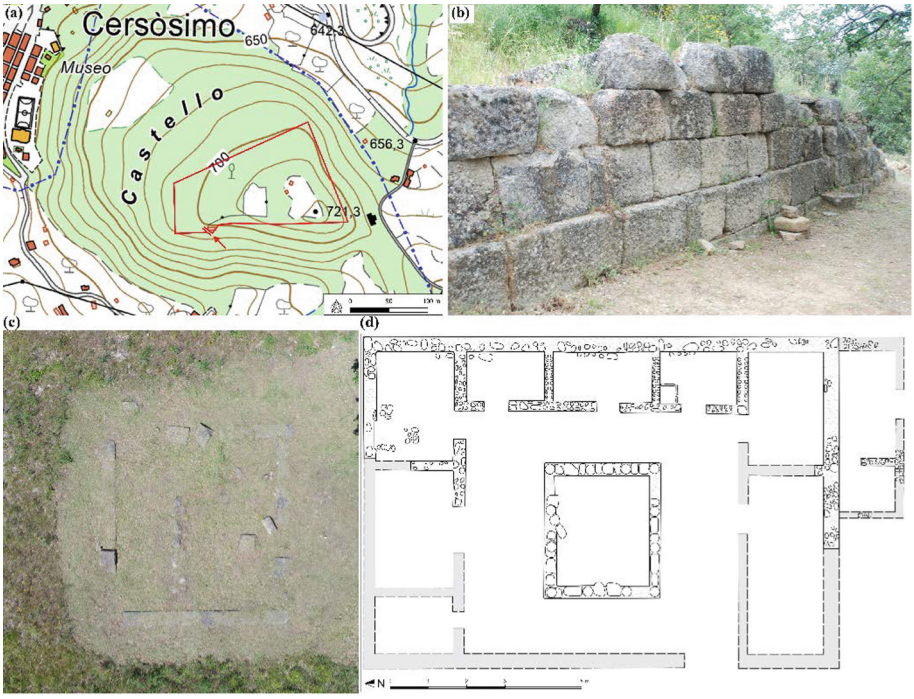

Fig. 2. Wall circuit (a), pòstierla (secondary access gate to the ancient city) (b), peristyle of Building A (c), vector survey and reconstructive hypothesis of Building A (d).

At least three main stages of habitation have been recognized by archaeological research. The first two stages are ascribed to the third century B.C., which coincided with the maximum stage of architectural investment and urban expansion. The site seems to have been abandoned after this prosperous period, most likely as a result of larger geopolitical changes brought about by Roman conquest in southern Italy. The consolidation of Roman rule resulted in the reorganization of territorial control structures and the progressive decline of pre-existing hilltop fortifications, as seen in many fortified communities throughout Basilicata and Calabria. Only in the Middle Ages Castello was interested by a return to habitation, albeit at a far lower intensity than during the previous stages.

Even with the significant contributions of earlier archaeological expeditions, there are still some features of the site that are not fully understood. There are still questions about the complete extent of the defensive circuit, even though the southeast section of the enclosure wall has been fairly thoroughly documented, including the location of the southern entry gate and the boundaries of Building A and Building B. Specifically, the wall's continuation toward the northwest and north has not been proven. The identification of structural alignments in these places has been complicated by erosion processes, abundant vegetation cover and a lack of new excavation campaigns.

The interior structure of the settlement is a second unsettled matter. The spatial arrangement of other residential, commercial or community constructions is still mostly

speculative, despite the fact that the two primary buildings have been documented. More research is needed to determine whether terracing systems, open spaces, circulation routes and potential infrastructure components (such drainage systems or storage facilities) are present. Rebuilding Castello's socio-political structure, functional zoning, and settlement hierarchy within the larger regional context of fortified centers requires an understanding of the internal urban plan.

Given these unanswered problems, combining high-resolution photogrammetric data with non-invasive geophysical surveys has been proposed as methods for filling in the gaps in the archaeological record. Without immediately turning to large-scale excavation campaigns, it was possible to refine theories about the continuity of the defensive circuit and to suggest more thorough reconstructions of the settlement's internal spatial organization.

2 Integrated Geophysical and Photogrammetric Methodology

Adopting integrated and non-invasive techniques that may combine high-resolution surface recording with subsurface excavation is becoming very useful for the study of complex archaeological environments. Developments in digital photogrammetry and geophysical prospection have significantly changed the practice of archaeology by allowing researchers to identify buried structures, reconstruct spatial organization and record architectural features with a degree of accuracy and thoroughness that was previously impossible without extensive excavation [7]. These technologies support minimally damaging research methods that are in line with modern cultural preservation and sustainable site management principles, in addition to improving interpretive capacity [8].

The current study uses a multidisciplinary approach that combines aerial and terrestrial photogrammetric surveying with frequency-domain electromagnetic (FDEM) prospection. The main goal is to create an extensive spatial dataset that can help with long-term documentation and conservation planning, enhance archaeological interpretation, and direct future excavation strategies. By combining subsurface geophysical diagnostics with three-dimensional modeling and georeferenced cartographic products, the research establishes a multi-scale analytical approach that bridges landscape-level assessment and detailed architectural reconstruction.

In this context, geophysical surveys offer spatially continuous data on subsurface electrical variability, allowing to identify anomalous zones that might be connected to buried archaeological objects. Structure from Motion (SfM) and Multi-View Stereo (MVS) techniques are used in photogrammetry to produce high-resolution three-dimensional models, orthophotos, and Digital Elevation Models (DEMs) that accurately depict topography and building remnants. Consistency, metric reliability and interoperability between many information sources are ensured by integrating these datasets into a single Geographical Information System (GIS).

The theoretical background, data collection procedures, processing workflows, and analytical techniques used in this study are explained in the following sections. In order to ensure scientific reproducibility and provide a reference framework for similar applications in archaeologically complex situations, special attention is paid to methodological choices, instrumental parameters and quality control procedures.

2.1 Geophysical Survey: Inductive Electromagnetic Prospection

Before systematic excavations are realized, geophysical prospection techniques provide a non-invasive methodological framework for an indirect detection and a first characterization of archaeological deposits. Over the past few decades, different experimental applications proved the effectiveness of geophysical surveys in identifying buried anthropogenic remains from a broad range construction typologies of various chronological phases [8–11].

Magnetic methods, among the most commonly used techniques, have proven especially successful in identifying features linked to thermally altered materials, combustion structures, filled ditches, pits, and masonry remains [12–14]. This is due to the quantifiable difference in magnetic susceptibility and remanent magnetization between archaeological targets and surrounding sediments. Frequency-domain electromagnetic (FDEM) techniques have also become more and more important for the identification of subsurface heterogeneities associated with human disturbances, given their ability to quickly evaluate spatial variations in apparent electrical conductivity and magnetic susceptibility [15, 16]. Also, electrical techniques including resistivity and induced polarization surveys have been widely used to identify buried stone foundations, voids, compacted surfaces and stratigraphic discontinuities [17–19]. Furthermore, ground penetrating radar (GPR) has significantly advanced high-resolution subsurface imaging by using dielectric permittivity contrasts to recreate 2D and 3D stratigraphic geometries [20–22].

The choice of the best geophysical method depends intrinsically on a number of interconnected factors [23]. These include the geological, pedological and hydrological setting, the surface accessibility, the vegetation cover, the logistical conditions, the spatial extension of the survey area, the expected geometry, the size, the burial depth and the physical characteristics of the target features. Signal attenuation, penetration depth and anomaly resolution can all be influenced by soil texture, moisture content and natural heterogeneity. As a result, the methodology selection requires a careful initial analysis of the expected physical differences between archaeological structures and the host sedimentary matrix, in addition to an assessment of operational limitations and the intended spatial resolution.

In the examined case study, the frequency-domain electromagnetic (FDEM) method was considered to be the best approach to reach the research goals in the frame of the specific environmental circumstances. The site is characterized by superficial lithological heterogeneity consisting in an alternation of sandy and clay-rich strata. Because the clay mineral abundance and the grain-size distribution have a significant impact on electrical conductivity, these contrasts are very important for electromagnetic research. Additionally, as recorded ancient objects in the site are mostly bricks, ceramic fragments and limestone blocks, the contrasts from the nearby strata is significant and offer an advantageous framework for the use of FDEM measurements.

The exploratory aspect of the study was another point in favor of the FDEM approach. The research area was completely unexplored and had not previously undergone thorough subsurface geophysical mapping. A technique that could quickly cover large areas while retaining sufficient sensitivity to changes in macro scale conductivity was considered ideal in this situation. In this case, the main goal was to identify broad zones with notable electromagnetic abnormalities rather than to reconstruct architectural geometries in detail. Following their delineation, these macro areas could be examined using targeted excavation techniques and higher resolution methods (such as dense-grid resistivity or GPR surveys).

The FDEM approach is theoretically founded on the concepts of electromagnetic induction [24]. A primary low-frequency alternating electromagnetic field is produced by a transmitting coil and travels beneath the surface. This primary field creates eddy currents in conductive bodies when it comes into contact with them. A spatially separated receiving coil detects the secondary electromagnetic field created by these currents. The two orthogonal components of the observed secondary field are the quadrature (imaginary) component and the in-phase (real) component. While the quadrature component is mainly associated with the bulk electrical conductivity of the subsurface materials and is commonly expressed in parts per million (ppm) relative to the primary field, the in-phase response is especially sensitive to highly conductive or metallic objects and to changes in magnetic susceptibility [24].

The quadrature component and the apparent electrical conductivity of the studied volume can be linearly correlated under low-induction-number conditions. Given the hypothesized inverse relationship between conductivity and resistivity, apparent resistivity values can be obtained from this quantity. While resistivity is reported in Ohm $\times$ meters (Ω m), electrical conductivity is generally expressed in milli Siemens per meter (mS / m), which is equivalent to 10^{-3} Siemens per meter. An approximation of the two parameters' relationship is as mS / m = 1000 / Ohm m. This conversion improves the dataset's interpretability within a larger geophysical context and makes comparison with electrical resistivity survey results easier.

The GSSI Profiler EMP-400 [25], a multi-frequency FDEM instrument intended for near-surface research, was used to collect data for this study. In order to maximize sensitivity to fluctuations in shallow conductivity, measurements were taken in continuous acquisition mode with vertically aligned dipoles at various operating frequencies between 2 and 15 kHz. Given that skin depth in FDEM surveys is strongly dependent on local ground conductivity and subsurface heterogeneity, any depth-slice representation would necessarily be highly approximate and potentially misleading if presented as a quantitative depth model. For this reason, we have chosen to retain the unique 15 KHz frequency-based interpretation without introducing additional derived depth-slice products.

In order to provide uniform spatial sampling and sufficient lateral resolution for anomaly detection, five research areas were methodically covered by parallel survey profiles placed in a regular grid with 1 m spacing (Fig. 3). Previous excavation findings in the studied area show the existence of relatively small to medium-sized subterranean structures, such as pits, wall foundations, and linear features, which are usually between a few meters and a sub-meter in width. A balance between survey resolution, site coverage,

and the anticipated sizes of the archaeological features based on earlier studies led to the selection of a 1 m profile spacing.

For eliminating experimental drift and artificial noise, raw conductivity data underwent typical filtering and quality control processes during the processing phase. A despiking process based on a moving-window method was used to eliminate outliers. In particular, data points that deviated more than ±2.5 standard deviations from the local mean were classified as noise and removed from additional examination. This cut-off was chosen to balance the preservation of true subsurface variability with efficient noise reduction. After making some initial adjustments, the filtering was applied, and the outcomes were visually examined to make sure that important geophysical features had not been unintentionally eliminated. In order to make geological and archaeological interpretation easier, the apparent conductivity measurements were transformed into resistivity values. Then, the processed data were interpolated using a contouring software and were shown as two-dimensional resistivity maps. A common logarithmic scale was used for map presentation due to the wide range of resistivity values found throughout the site, which reflects significant lithological heterogeneity. This method allowed to more clearly distinguish between conductive clay rich zones and more resistive sandy or anthropogenic characteristics, as well as to better represent both low and high magnitude anomalies.



Fig. 3. FDEM acquisition areas (magenta color), postierla (gate) (A), Bulding A (B), polygonal wall (C), Building B (D), terrace wall (E).

2.2 Photogrammetric Survey

Nowadays, photogrammetry is a crucial methodological element in heritage management and archaeological site recording thanks to developments in digital imaging, computational power and automated image processing techniques [26–33]. In order to extract three-dimensional spatial information from two-dimensional image datasets, photogrammetry is fundamentally based on mathematical and computer vision techniques. Specialized algorithms reconstruct dense point clouds, estimate intrinsic and extrinsic camera parameters, and calculate the spatial coordinates of detected features within a single reference system by identifying homologous points across several overlapping images. Structure from Motion (SfM) and multi-view stereo (MVS) approaches are the main theoretical foundation of contemporary digital photogrammetry [34–37]. In order to simultaneously estimate camera locations, orientations and 3D point coordinates, SfM algorithms automatically identify unique key points in individual photos, match these features across image pairings, and repeatedly solve the bundle adjustment issue. This method improves operational flexibility in field situations by enabling the reconstruction of complicated geometry even in the absence of pre-calibrated camera systems.

Multi-scale documenting of the archaeological site was made possible by the integration of aerial and terrestrial photogrammetry inside a single SfM based approach, which combined high resolution architectural detail with landscape level spatial coverage. In order to ensure thorough multi scale recording of the research region, two separate datasets were created: 151 frames from the aerial survey and 147 frames from the terrestrial survey. In addition to supporting stratigraphic study and archaeological interpretation, this thorough digital reconstruction supports long-term heritage preservation, virtual dissemination, and quantitative spatial assessment within an interdisciplinary research framework.

2.2.1 Aerial Photogrammetry

A remotely piloted aircraft system (RPAS), namely a Yuneec H520 platform, was used to conduct aerial surveys. It was equipped with a 1-in. CMOS sensor camera with a fixed focal length of 26 mm and a resolution of 20 megapixels. To provide adaptive navigation in response to environmental constraints, that is the presence of dense forest cover and varied topographic conditions, manual flight control was implemented. A rectangular grid flying pattern was used for image acquisition in order to optimize redundancy and coverage. To enhance the quality of three-dimensional reconstruction, both nadiral and oblique images were gathered, particularly along vertical structures and morphological discontinuities. Geometric precision was maintained while operational safety was ensured by dynamically adjusting the flight altitude to avoid obstructions and maintain the ideal ground sampling distance (GSD).

2.2.2 Terrestrial Photogrammetry

A mirrorless Sony Alpha 5100 digital camera with a 23.5 × 15.6 mm CMOS sensor, a 24-megapixel resolution and a variable focal length lens (16–50 mm), was used for complementary ground-based photogrammetry. The capture of terrestrial images was primarily intended to document the old city's entrance gate, which is distinguished by vertical architectural details that necessitate meticulous reconstruction. In both longitudinal and transverse orientations, images were taken along horizontal bands with an average overlap of about 80%. This high level of redundancy is crucial to guarantee strong key point matching, reduce reconstruction gaps and enhance geometric stability during bundle modification.

2.2.3 Photogrammetric Processing Workflow

Agisoft Metashape software (LLC, St. Petersburg, Russia) [38] was used for image processing, utilizing a SfM approach combined with dense stereo matching techniques. In order to guarantee geometric accuracy, model optimization and geospatial consistency, the processing pipeline adhered to a specified set of procedures:

1. Image Alignment (Sparse Point Cloud Generation). In this first stage, the software estimated the relative camera locations and orientations and automatically identified homologous features across overlapping images. Both exterior and interior orientation parameters were determined using bundle adjustment optimization. Focal length, main point coordinates and lens distortion coefficients (radial and tangential) are examples of interior parameters that characterize the camera system's inherent optical properties. The camera's spatial position and orientation within the reference system are defined by the exterior orientation parameters, which are composed of three translational components (X, Y, and Z) and three rotational parameters (given as Euler angles). This step results in a sparse (discrete) point cloud that depicts the scanned scene's initial geometric structure (Fig. 4a).
2. Dense Point Cloud Construction. Using multi-view stereo matching, which is based on creating depth maps for overlapping picture pairs, dense reconstruction was accomplished. During bundle adjustment, depth maps were calculated using the previously obtained orientation parameters, guaranteeing geometric coherence through iterative refinement. From its associated depth map, each image contributed to partial dense point clouds. Additional noise filtering was performed to overlapping regions once these partial reconstructions were combined into a single dense point cloud. In order to maintain radiometric fidelity, color information was directly sampled from the original images, while surface normals were computed via local plane fitting inside pixel neighbors. A high-resolution 3D depiction of the surrounding landscape and archaeological buildings was produced by the dense cloud that resulted (Fig. 4b).
3. Ground Control Point (GCP) Integration and Georeferencing. GCP markers were used to ensure accurate model scaling and spatial location. A total station survey's coordinates were imported into the photogrammetric project and manually linked tothe locations of the related images. The model could be converted from a relative coordinate framework to an absolute georeferenced system by using GCPs. This stage

is crucial since model scaling, orientation, and overall spatial accuracy can be greatly impacted by mistakes in GCP identification or coordinate input (Fig. 4c).

4. 3D Mesh Generation and Optimization. Surface reconstruction methods were used to transform the dense point cloud into a triangulated surface model (mesh). Metric analysis is made easier and continuous surface representation is made possible by this modification. Optimization techniques, such as mesh smoothing and decimation filtering, were used to increase computing efficiency and decrease geometric noise. These procedures produced a lighter, easier-to-manage 3D model that is appropriate for viewing and analysis without sacrificing structural integrity by reducing the number of polygons while maintaining crucial morphological characteristics (Fig. 4d).
5. Texture Application to the Mesh. Applying color content to the mesh was the last stage. A photorealistic 3D model can be created by applying photographic photos to the model thanks to the texture algorithm. Ultimately, texture maps (Fig. 5a), a georeferenced Digital Elevation Model (DEM) (Fig. 5b, c) and orthophotos (Fig. 5d) were produced.

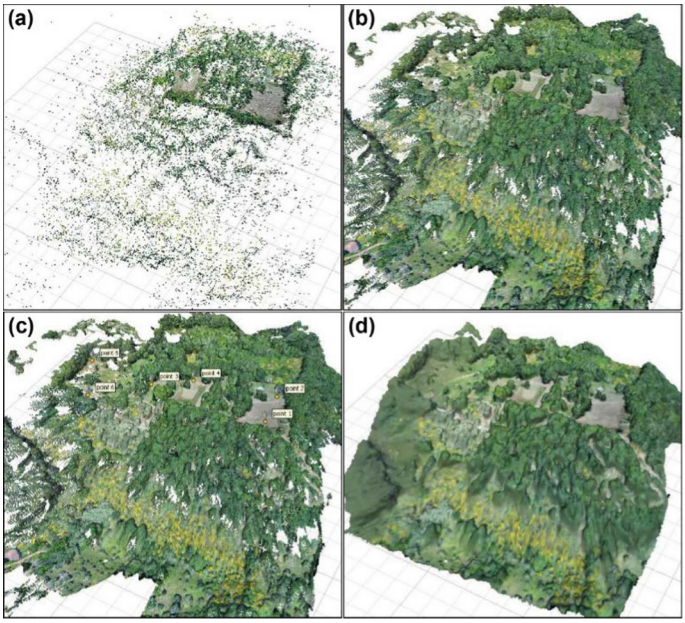

Fig. 4. Photogrammetric Processing Workflow: Sparse Point Cloud Generation (a), Dense Point Cloud Construction (b), Georeferencing Ground control points (c), 3D Mesh Generation (d).

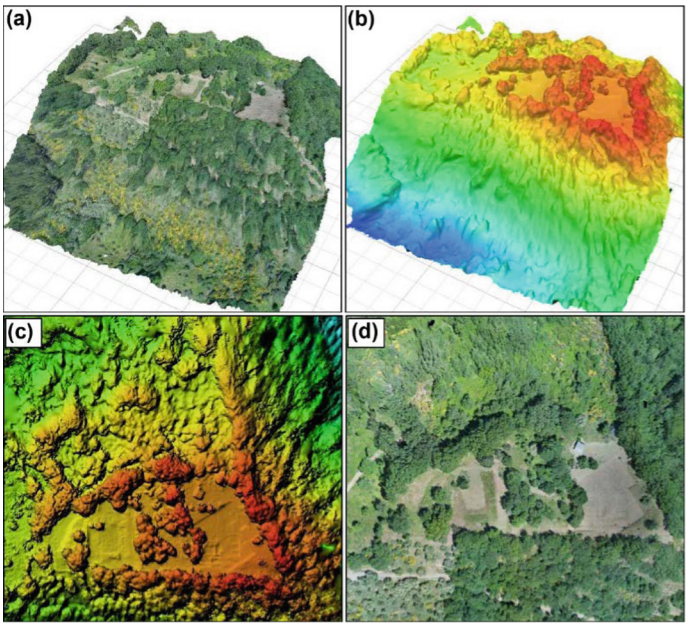

Fig. 5. Photogrammetric Processing Workflow: texture (a), digital elevation models (b, c) and ortophoto (d).

3 Results

The existing state of information regarding the archaeological site in the Castello area has been significantly improved and updated through a multi-scale analytical method that integrates data from non-invasive geophysical investigations and aerial photogrammetry obtained using remotely piloted aircraft systems (RPAS) within a single spatial framework. To ensure long-term accessibility and interoperability, all processed datasets have been georeferenced and stored within a Geographical Information System (GIS) (QGIS Development Team (2024), Open Source Geospatial Foundation Project, http://qgis.osgeo.org, accessed on 15 December 2025). Several types of spatial maps have been created and arranged as theme layers within this digital infrastructure (Fig. 6) offering a solid foundation for upcoming comparative studies and conservation condition monitoring.

To examine the spatial distribution of heights throughout the research area, a georeferenced Digital Elevation Model (DEM) was created. The detection of topographic anomalies that may be connected to defensive buildings, terrace systems and buried structure is made possible by this extensive elevation dataset. Cadastral maps, orthophotographic mosaics, and DEM-derived contour models were among the topographic bases used to create and reconcile updated archaeological plans of previously recorded remains. By combining the analysis of geophysical datasets with a comparison with established architectural patterns, interpretive designs of buried ancient sites were developed. The

resistivity distributions and electromagnetic contrasts found during the geophysical survey serve as the main foundation for these reconstructions, which are supported by morphological alignments seen in the DEM and orthophotos.

Specifically, the combined analysis reveals a number of noteworthy geographical patterns (Fig. 7). The pattern of high vegetation in the settlement's southern portion seems to follow the enclosure wall's assumed path. In archaeological settings, vegetation growth frequently serves as an indirect indicator of buried masonry by reflecting structural discontinuities and variations in subsurface moisture retention. The access gate and the previously identified excavated portion (shown in blue) are connected by the first dashed white line (Fig. 7), which suggests that the defensive structure may continue along this alignment.

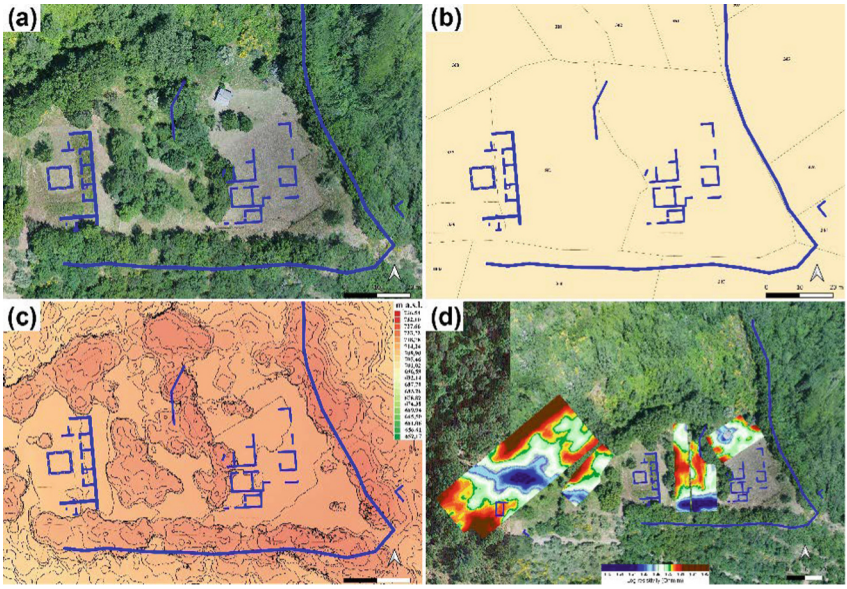

Fig. 6. Examples of spatial maps created and arranged as theme layers within Geographical Information System: orthophotographic mosaic (a), cadastral map (b), DEM-derived contour model (c) and resistivity map relative to the frequency of 15 kHz (d) with indication of previously recorded remains in blue.

The readability of traces was helped by the creation of high-resolution orthophotos of the gate (Fig. 8), the most important architectural features of the archaeological site, acquired during the terrestrial survey. The resulting outputs offer geometrically corrected and metrically precise representations of the entry gate for direct measurement, material investigation and stratigraphic reading of masonry units. These products are very useful for architectural documentation and conservation planning. The three-dimensional model was used to derive detailed architectural elevations in addition to orthophotos. The structure's true scale and geometric proportions are preserved in these elevations, which are vertically projected views of the building. Improved architectural interpretation, long-term heritage management, structural monitoring and virtual dissemination

initiatives are all aided by the incorporation of these data into the Castello area's larger GIS database.

A number of probable terrace walls, indicated by dashed white lines numbered 2 through 6, can also be found on the general interpretative map (Fig. 7). These traits are in agreement with the slope stabilization and artificial leveling methods used in fortified hilltop towns. Particularly interesting is the space between sections 4, 5 and 6. Together with the eastern border wall, these alignments produce a broad and level platform. The morphological consistency and the spatial organization of this area indicate a probable functional planning and a deliberate terracing. If the substantial scrub vegetation that currently obstructs surface vision is cleared, this area, given its size and topographic regularity, likely offers a large deal of archeological potential and merits targeted research.

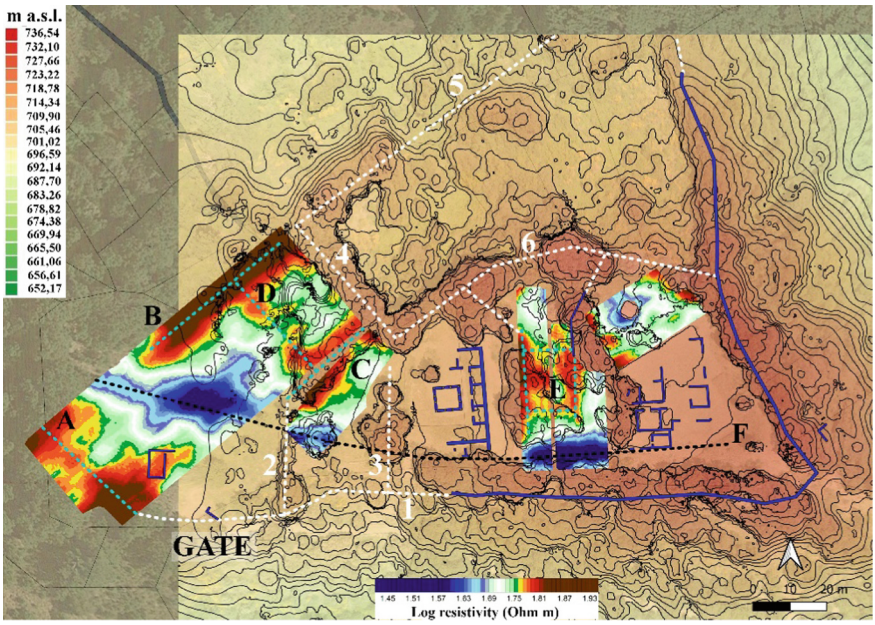

Fig. 7. Interpretation of results considering the DEM-derived contour model, the resistivity map relative to the frequency of 15 kHz and previously recorded remains.

The analysis of resistivity data provides more evidence for these spatial projections. High resistivity readings indicate a symmetrical and structured distribution with respect to the known architectural remnants and the probable terrace walls. Such regularity is frequently associated with compacted anthropogenic layers seen in highly conductive sedimentary matrices or stone-built buildings. The suggested city wall restoration (section 1) at point A (Fig. 7) is represented by a distinct resistive band. Its geometric continuity strongly suggests that this anomaly may be connected to the underground extension of the defensive construction.

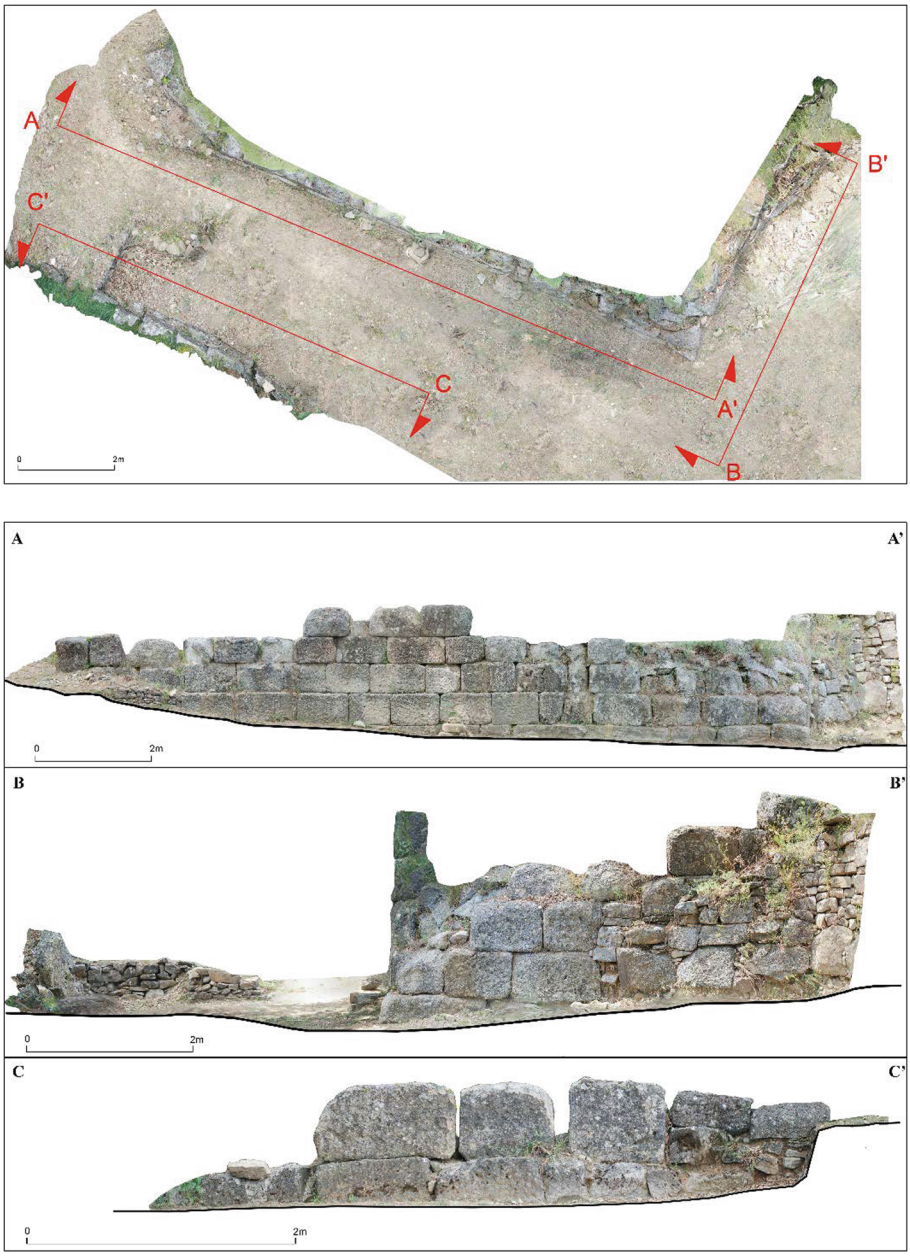

Fig. 8. Orthophoto of the gate (top) with indication of the underlaying architectural elevations A-A′, B-B′ and C-C′ (bottom).

Anomalies B, C, and D designate another possibly significant zone. When combined with the suggested terracing indicated by number 4, these resistive characteristics produce a rectangular area whose purpose and chronology are still unknown. The geometric regularity of this layout may indicate the presence of a building complex, an enclosed functional space or a courtyard. Remarkably, resistive segments B and C show structural integration with the broader architectural concept by converging in the direction of terrace sections 5 and 6.

A possible quadrangular underlying structure is suggested by the spatial distribution of resistivity peaks in the center of the excavation region (Anomaly E). This peculiarity appears to be partially connected to a wall that has already been found during previous archaeological digs along its northern side. This feature could represent an extra room or an extension within the settlement's constructed fabric.

Conversely, areas with low resistivity values, shown by a black dotted line and the symbol F, correspond to an underground pipeline that has previously been found. The lower resistivity in this area is consistent with increased moisture retention and conductive backfill materials, which are frequently associated with such infrastructural components. Evidence from an eastern archaeological test trench and the inferred route from the geophysical survey match, demonstrating the interpretive reliability of the geophysical dataset.

Overall, the combination of high-resolution aerial photogrammetry and non-invasive geophysical prospection has enabled a comprehensive spatial reconstruction of the Castello site. In addition to synthesizing current knowledge, the resulting multi-layered territorial information system generates new hypotheses about the terracing systems, the settlement structure and the defensive architecture. This methodological synergy provides a strong scientific basis for future excavation plans, conservation initiatives and targeted archaeological studies.

4 Conclusions

An improvement in understanding of the Castello archaeological site has been achieved by the systematic integration of non-invasive techniques, such as geophysical prospections and both aerial and terrestrial photogrammetry. This has helped to partially overcome the interpretive limitations inherent in traditional excavation-based investigations alone especially in situations where above-ground structures are discontinuously preserved and there is dense vegetation cover. Anomalies associated with the existence of buried masonry structures, potential manmade terracing systems and other architectural features not yet excavated were supposed through geophysical investigations. One of the main unanswered questions arising from earlier research was addressed by the spatial distribution of resistivity anomalies, which offered credible evidence regarding the continuation of the defensive circuit in the northern and southwestern sectors. Additionally, the identification of regular planimetric layouts within the defended region indicates the presence of additional ordered areas, the functional interpretation of which will necessitate focused stratigraphic verification.

Simultaneously, high-resolution georeferenced three-dimensional models and a Digital Elevation Model (DEM) capable of precisely depicting site morphology and altimetric relationships between archaeological structures and the surrounding landscape

were produced by photogrammetry, which was implemented through both remotely piloted aircraft systems (RPAS) and ground-based image acquisition. More accurate topographic contextualization of archaeological material was obtained by the integration of these outputs into a Geographical Information System, which allowed for extensive data management.

From a historical-archaeological standpoint, the findings help to clarify the site's urban layout by emphasizing a settlement planning approach that is in line with the territorial control and the defensive roles typical of fortified centers in the Lucanian-Calabrian region in the third century B.C. Furthermore, the integrated research indicates that the settlement's internal organization was more intricate than previously recorded, maybe divided into regions with distinct functions.

The insights generated by this study offer a strong scientific foundation for organizing upcoming research projects, directing excavation efforts toward regions with greater archaeological value while reducing the damaging effects of field operations. Furthermore, the created three-dimensional and cartographic documentation serves as a strategic tool for public distribution, site management and heritage protection, supporting scientific communication and conservation planning.

In summary, the Castello site research demonstrates how geomatic and geophysical technologies can not only support but also significantly improve the interpretative and operational strategies of modern archaeological research, confirming the efficacy of an integrated and interdisciplinary approach in the study of ancient fortified landscapes.

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Disclosure of Interests The authors have no competing interests to declare that are relevant to the content of this article.

Declaration The authors used *QuillBot Paraphraser* [https://quillbot.com/] to improve English language during the preparation of this work. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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