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Michele RUSSO, Marta ACIERNO (Eds.)



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Michele Russo, Marta Acierno
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The digital survey for the construction of information models of fortified architecture on the island of Capri

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Abstract

The paper addresses the issue of island fortifications on the island of Capri in the Gulf of Naples. Through the study and digitization of some exemplary cases, the research proposes a re-reading of the Capri landscape in connection with the defense systems that have shaped its image. Over the centuries the island has been the protagonist of important defensive events in the Mediterranean for which different architectures have been created along the coast to comply with the aim of decreasing the offensive effectiveness of the opposing actions, taking advantage of the natural characteristics of the territory and modifying them with appropriate technical solutions. From this perspective, as a first cognitive approach, aerial remote sensing was used which made it possible to obtain a large-scale orthophoto. The processing of the acquired data provided a fundamental basis for the initial mapping of the defensive system, allowing the fortified structures to be framed in the general morphological context of the island, distinguishing them both by type (towers, castles, strongholds, etc.) and by state of use or those still present from those that have disappeared as well as the transformed artefacts. There is no shortage of architecture that has been lost over time, such as the tower built at the Certosa di San Giacomo. Following this, various digital survey techniques were integrated for the construction of three-dimensional models, restoring the morphology of selected fortified architectures on the island of Capri, chosen as distinctive artefacts for the different categories. From these models, a precise analysis of the characteristics of the architectures examined was conducted, from a priority semantic decomposition to an interpretation of the same in geometric, material and construction terms, in order to prepare an initial documentary apparatus. The ultimate goal is the construction of a 'schedule' of forts.

Keywords: Capri, integrated survey, mapping, information models.

1. Introduction

In the context of the evolution of technologies applied to the documentation and valorisation of cultural heritage, digital surveying is now established as a fundamental discipline, capable of integrating different approaches and instruments. The aerial remote sensing activity conducted on the island of Capri fits into this context, through the use of a multi-sensor platform composed of a hyperspectral sensor and a very high-resolution photographic camera, mounted on a Tecnam P2006T Special Mission Platform (SMP) aerial platform. This advanced configuration allows the acquisition of data with very high spectral resolution, which is fundamental for the non-invasive analysis of cultural and landscape assets, detecting information not visible to the human eye and integrating it into the operational flows of the three-dimensional survey. Within the theme of the Digital Heritage conference, the use of hyperspectral sensors is an innovative element to complement the most consolidated 3D technologies, such as laser scanners and photogrammetry. Hyperspectral data, georeferenced and returned with point clouds and 3D models, enable advanced modeling, contributing to the creation of increasingly accurate digital twins. This multidimensional approach opens new possibilities in representation, virtual and augmented reality, and in the conceptual modeling of assets, expanding the capacity for interpretation, conservation and use of cultural heritage in a digital key.

2. A possible workflow for the study of Capri's fortifications

The research aims to undertake a structured study of the distinctive fortifications of Capri. This study must be approached through an integrated methodology, an established practice in scientific research, which combines historical and architectural analysis with advanced survey and digitisation tools. The objective is to build a solid and accessible knowledge base to support the understanding, protection, and enhancement of a complex and little-known heritage. From a methodological standpoint, the proposed approach is organised into several phases:

- I) Integrated screening and mapping;
- II) Multi-informative indexing;

III) Digitisation and 3D knowledge models;

IV) Systematisation in a database.

The first phase, based on the preliminary localisation of the island's fortified structures, involves a detailed analysis that integrates mapping with historical sources such as cartography, historical iconography, and the interpretation of aerial and satellite imagery. Subsequently, for each fortification, a record sheet is compiled documenting its typology (coastal towers, small forts, etc.) and its period of construction. Distinguishing fortifications from different historical phases allows for a better understanding of the relationship between architectural forms, changing defence strategies, and shifting political contexts. For this reason, the catalogue also addresses materials and construction techniques, following shared cataloguing standards. The survey plays a central role in collecting the information required for the records and in supporting further analysis, both broadly and in detail for individual examples. The integrated use of reality-based survey techniques enables the creation of 3D digital models which, as is well known, represent important knowledge systems, useful for both scientific analysis and the communication of results. These models, once properly processed and enriched with metadata, allow for the exploration of various levels of information, for example, the relationship between the fortification and the landscape context, patterns of deterioration, and transformations undergone over time. Finally, to enable data querying and comparative analysis, it is essential to integrate all previously gathered data into an interoperable digital platform, based on relational databases and Geographic Information System (GIS) environments. In this way, the proposed approach overcomes a fragmented reading of Capri's fortifications, instead highlighting their role in island and Mediterranean history, and providing useful tools not only for research purposes but also for public engagement with the studied heritage.

3. Survey and Integrated Mapping of Island Fortification Systems

In the Mediterranean, islands have always served as strategic outposts for maritime control. Capri, due to its geographical position and morphology, has been at the center of a dense network of

coastal fortifications, developed from the classical period to the 19th century in response to shifting defensive needs. The island's rugged terrain – with steep slopes and jagged coastlines – favored the placement of military architectures that harmonize with the landscape, exploiting natural features as elements of protection (Cirafici, 2007). Across the Mediterranean, island fortifications generally followed two main models: hilltop strongholds located inland to control agricultural basins (typical of the early medieval period), and coastal watchtowers (developed in the modern era, especially in the Kingdom of Naples from the 16th century), aimed at detecting pirate incursions and coordinating defensive responses (Mangoni, 2012). Capri is no exception: although the island already hosted fortified sites during the Roman era, such as the so-called Villa Jovis, it is mainly from the late Middle Ages to the modern period that a complex system was established, now only partially preserved. As part of this research, a systematic survey of the territory was carried out using drone orthophotos and GIS analysis, which proved useful in identifying both surviving and lost fortification structures (Botto et al., 2021). The inventory led to the identification of 14 fortified sites distributed along the coastline and in the island's interior highlands. These were then classified by type (watchtower, coastal fort, casemate), period (medieval, viceregal, Bourbon), and preservation state (intact, partial, lost). A first phase of mapping, based on orthophoto analysis and historical sources, enabled the classification of Capri's main defensive architectures. These fortifications fall into three main categories:

3.1. Watchtowers (16th-18th centuries)

Generally isolated and positioned on strategic promontories (such as Tragara, Punta Cannone, or Marina Piccola), they served to visually monitor maritime routes. Many have now disappeared or been converted into residences, such as the Torre Saracena, destroyed in the 19th century.

3.2. Coastal forts (early 19th century)

Built during the French and Bourbon periods (1806-1815), these structures followed modular and geometric principles, with trapezoidal or rectangular plans, local limestone masonry, and

artillery platforms. Among the best preserved are Forte Orrico, Pino, Mesola, and Vigliena.

3.3. Internal outposts and control structures

Less visible and often integrated into agricultural or forested areas, some structures around Monte Solaro and near the Certosa di San Giacomo played a secondary role in surveillance and communication, though they are now only partially legible. This initial survey phase made it possible to compile a catalog of Capri's fortifications, an essential tool for the conservation and valorisation of the island's military architectural heritage, considered as a functional system but also as an identity-bearing component of the island's cultural landscape (Cirafici, Masiello & Palmieri, 2025) (Fig. 1).

4. Aerial survey at a territorial scale for the digitization and elaboration of information models

As part of the advanced documentation of the fortification system on the island of Capri, airborne remote sensing at territorial scale is one of the most promising frontiers for the extensive and non-invasive investigation of archaeological sites and historical architecture integrated into the landscape. The use of Benecon's Platform allowed us the acquisition of high-resolution, multi-source data, essential for the identification, mapping, and study of cultural heritage in complex contexts like Capri Island. The island, renowned for its historical and landscape stratification, boasts numerous fortifications and defensive structures dating from Roman times to modern times, often poorly documented or partially hidden by Mediterranean vegetation (Fig. 2). The aerial hyperspectral survey, combined with 3D models obtained from photogrammetry, allows not only to identify material traces not visible with traditional methods, but also to collect diagnostic data useful for characterizing the context in which these structures are located. A particularly innovative element concerns the analysis of hyperspectral data in the Red Vegetation and Near Infrared channels, specifically sensitive to the spectral response of vegetation. This type of survey allows us to monitor vegetation cover, but also to identify anomalies in the growth of the vegetation itself, which often reveal the presence of buried or partially buried structures.



Fig. 1- Reconnaissance and integrated mapping for fortification systems on the island of Capri (graphic elaboration by the authors, 2025)

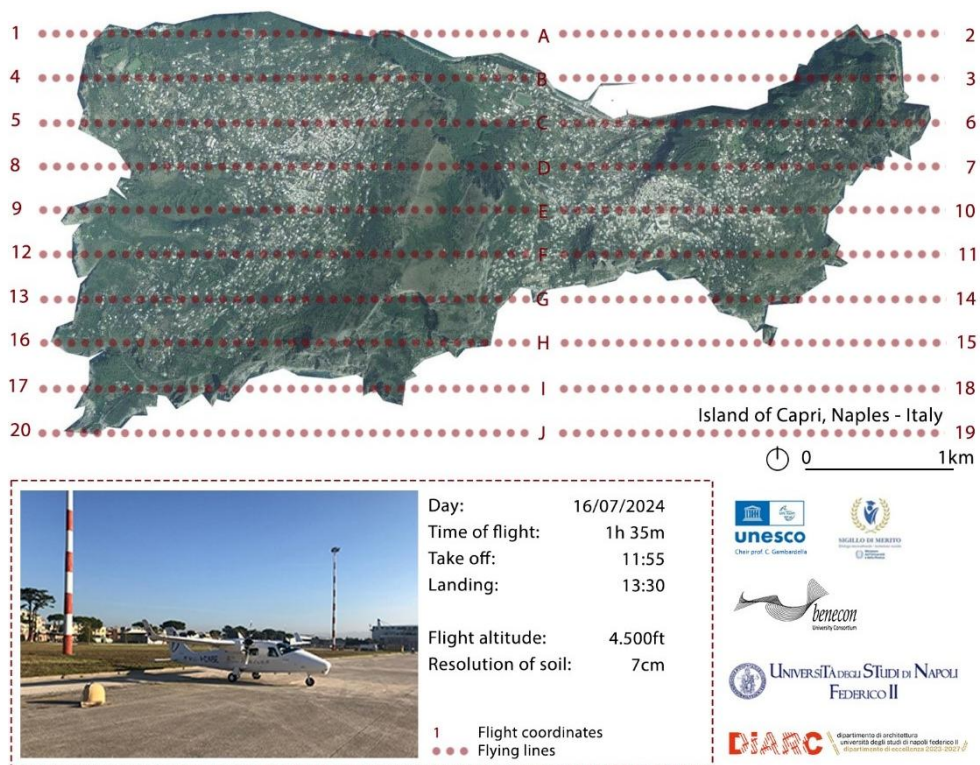


Fig. 2- Airborne sensing plan with flight route; Benecon I-CABE aircraft, equipped with CASI-1500 hyperspectral sensor and PhaseOne 150MP optical sensor (graphic elaboration by the authors, 2025)

In the case of fortifications, the analysis of the Red Vegetation Index (RVI) or the NDVI (Normalized Difference Vegetation Index) allows us to recognize patterns consistent with the presence of ancient walls or foundations, invisible to the naked eye but detectable thanks to the differentiated behavior of the overlying vegetation.

Particularly emblematic is the case of Villa Jovis, one of the largest and most preserved Roman imperial villas, located on the eastern tip of the island. Thanks to the aerial survey conducted with the CASI-1500, it was possible to extend the analysis beyond the emerged archaeological area, mapping potential structural remains in the surrounding territory.

This integrated approach allows not only to deepen our knowledge of the site itself, but also to reconstruct the territorial network of fortifications and infrastructures connected to the *villa*, such as sections of walls, visual control

systems, and strategic access points. The collected data is organized within a territorial database of Capri's fortifications, based on GIS systems and enriched with information layers derived from hyperspectral sensors. This digital archive could represent a fundamental tool both for scientific research and for planning protection, monitoring, and enhancement interventions. Each georeferenced element can be accompanied by metadata relating to the type of structure, state of conservation, vegetation cover, and the detected spectral characteristics, enabling comparative analyses over time and fostering the development of 3D reconstructions and augmented reality applications.

Ultimately, the hyperspectral aerial survey at a territorial scale applied to the Capri context opens new perspectives for understanding the historical and landscape heritage, integrating technology, digital modeling, and environmental analysis into a single operational platform (Fig. 3).



Fig. 3- Portion of georeferenced orthomosaic (UTM N33) from the island of Capri with focus on Fortino Orrico and Villa Jovis (graphic elaboration by the authors, 2025)

5. GIS georeferenced databases and data management systems for the fortified heritage of Capri

The island of Capri preserves a complex system of fortifications of exceptional historical interest, composed of coastal towers, panoramic points, city walls and military structures developed in

several phases, from the Roman age to the Middle Ages up to the viceregal period. These artefacts, often located in areas that are difficult to access, represent not only material traces of the defensive strategies that have characterized the history of the island and the entire Mediterranean, but also elements of strong landscape identity (Pane, 1965; Di Tucci, 2018).

Despite this, their state of conservation is in many cases compromised and the fragmentary nature of the information available limits both their protection activities and the possibilities for valorisation. In this scenario, web-based GIS platforms are now configured as strategic tools for the management, promotion and dissemination of cultural heritage, thanks to their ability to integrate 3D models, geospatial data and heterogeneous information content, offering advanced representations of landscape and architecture and encouraging interaction between scholars, operators and the public (Parrinello & Pettineo, 2025). In this perspective, a GIS platform was therefore created for the fortified heritage of Capri aimed at the management and correlation of alphanumeric, raster and vector data, designed according to a model capable of generating multilevel maps that integrate different degrees of knowledge. Therefore, a precise analysis of the characteristics of the architectures examined was conducted, from a priority semantic decomposition to an interpretation of them in geometric, material and construction terms, in order to prepare a first documentary apparatus. The ultimate goal is the construction of a 'schedule' of forts. In fact, within the GIS platform, three-dimensional models, in particular point clouds, were imported via a dedicated geodatabase in LAS Dataset format, guaranteeing the management of large volumes of data reality-based and a multiscale visualization within the ArcMAP platform. At the same time, a preliminary thematic filing was initiated, conducted in parallel with the surveys, to facilitate the insertion and structuring of information in the attribute tables of the system. The cards collected data on location, toponym, coordinates, accessibility, historical framework (era, transformations, events), architectural characteristics (type, materials, construction techniques, state of conservation), photographic and graphic documentation (surveys, orthophotos, 3D models), as well as functional and dimensional elements, organized in tabular form and connected to polygon-type vector elements, so as to also reconstruct the planimetric distribution of the individual structures. The table was organized into attribute fields, associating each fortification with a unique code to allow correlation operations and maintain an archive that can always be consulted and updated (Acquaviva et al., 2022; Repola, 2025). The first results, represented in thematic maps, allowed us

to interpret the relationships between the different phases of development of the defensive system, highlighting connections between the sites and the island landscape. The project was eventually set up for online publication via WebGIS, with the aim of engaging local communities and visitors through interactive maps and narrative paths that integrate historical content and immersive visualizations. From this perspective, information systems become knowledge and communication hubs, capable of networking complex data and transforming them into resources for research, protection and cultural tourism. The digitalisation and valorisation of Capri's fortified heritage thus represent a step towards an integrated management and use strategy, which combines conservation and sustainable development (Fig. 4).

6. Conclusions

The study conducted on the fortified architecture of the island of Capri has revealed the strategic and identity-bearing value of these structures, which, although often overlooked, are in fact central to the construction of the island's cultural landscape, of which they constitute a significant heritage. The integrated approach adopted, combining survey techniques and GIS, has enabled not only the mapping and classification of existing structures but also the development of three-dimensional models and advanced information systems capable of supporting multidisciplinary analyses. Thanks to the use of digital technologies, it is possible to carry out investigations that extend to buried or hard-to-access remains, captured within a system of relations and networks that offers new possibilities for interpreting and enhancing the defensive heritage. The creation of an inventory of fortifications and the integration of data into geographic information platforms allow for a form of engagement that is both more informed and more inclusive, as it is aimed not only at the scientific community but also at the general public and institutional decision-makers. In this regard, the work carried out provides a structured foundation for future research, conservation, dissemination, and sustainable management activities. Indeed, the case of Capri may serve as a replicable model for other Mediterranean island contexts, where the relationship between territory, landscape and defence systems assumes similarly identity-defining forms. Therefore, the

digitization of fortified architecture, when supported by interoperable tools, proves to be an effective strategy for transforming a fragmented and fragile heritage into an active resource for knowledge and cultural enhancement.

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managed in the cartographic database jointly by the team of the authors of the article.

Notes

Although this contribution is the result of shared work, V. Cera authored paragraph 2, M. Camerino authored paragraph 3, R. Parente authored paragraph 4, M. Falcone authored paragraph 5. The ‘1. Introduction’ and ‘6. Conclusions’ paragraphs are edited by M. Campi and C. Gambardella.

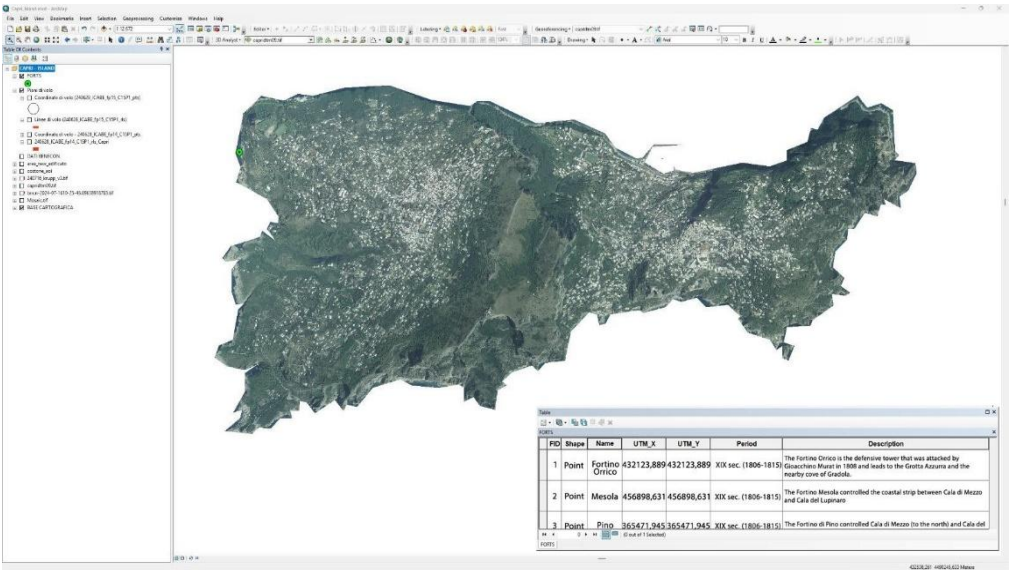


Fig. 4- GIS georeferenced databases for the fortified heritage of Capri (graphic elaboration by the authors, 2025)

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