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FROM ARCHAEOLOGICAL SURVEY TO DATA ACCESSIBILITY: A WEBGIS FOR THE ISLAND OF CAPRI

1. Introduction

The island of Capri boasts a long and complex history, underpinned by a rich archaeological heritage. Inhabited since the pre- and protohistoric periods, as evidenced by numerous surface finds and the sites of Grotta delle Felci and Grotta del Pisco (Giardino 1998; Boenzi 2001), the island later became a strategic outpost controlling access to the Gulf of Naples. Capri's enduring fame, however, is primarily linked to the Roman period, when it became imperial property under Augustus and served as the residence of Tiberius and his court from 27 to 37 CE.

This latter historical phase has gained increasing significance over time. As early as the Eighteenth century, antiquarians and scholars began to show a marked interest in Capri's ancient remains, initiating some of the earliest archaeological excavations (Hadrava 1793) and producing the first descriptive accounts of the island's visible monuments (Mangoni 1834; Canale 1887; Beloch 1890; Feola 1894; Fasulo 1895). In the Twentieth century, renewed investigations examined archaeological structures with greater precision, accompanied by more detailed graphic documentation (particularly in the works of Mingazzini 1931 and Maiuri 1956). Yet it was not until the late 1990s that the island became the subject of a comprehensive study aimed at gathering and systematizing historical sources and information relating to its archaeological discoveries (Federico, Miranda 1998).

Nevertheless, despite the extensive existing literature, current knowledge of Capri's archaeological heritage remains fragmented, focusing predominantly on a limited number of sites. In many cases, these are supported only by outdated and incomplete graphic documentation that requires critical reassessment and updating. This underscores the need to further investigate the archaeological heritage of Capri – particularly that dating to the Roman period – by conducting new surveys using modern technologies and gathering additional data, including evidence of no longer visible remains through the systematic examination of archival sources.

With these aims and premises, the project 'Masgaba. An Archaeological Map of the Island of Capri' was launched as the result of a collaboration between the municipalities of Capri and Anacapri, the Institute of Heritage Science of the National Research Council of Italy (CNR-ISPC), and the Apragopolis Cultural Association, under the scientific supervision of the Soprintendenza Archeologia Belle Arti e Paesaggio per l'Area Metropolitana di

Napoli. The project focused on the analysis of visible archaeological sites and remains, which required a revision and updating of existing documentation. These sites were subjected to archaeological survey using the most advanced technologies available. The subsequent study of the sites and their wall structures enabled new interpretations of their original layouts and spatial functions, offering a more comprehensive and integrated topographic understanding (Caratelli 2022; Giorgi 2022; Caratelli, Giorgi 2023, 2024). Accordingly, monuments that have been extensively studied or more recently published, such as Villa Jovis (Fig. 1, n. 26; Krause 2006) and the Grotta di Matermania (Fig. 1, n. 25; Busen, Grüner 2018), were incorporated into the map through the digitisation and georeferencing of their graphic plans. Similar procedures were applied to recent underwater surveys, as well as to prehistoric sites and areas with material surface finds. Smaller-scale structures, variously distributed across the territory, are currently being identified, with precise geolocation on the map planned for each of them.

These activities – designed to provide a graphic representation of all archaeological remains, both at territorial and detailed scales – have been carried out alongside those undertaken by the Apragopolis association and other external experts involved in the project. Their work has focused on collecting archival documentation preserved in various locations in Capri and Naples, as well as on the study of historical sources and records concerning archaeological assets that are no longer visible today.

These consist, in particular, of excavations conducted over time or of accidental discoveries for which reports, written accounts, and, in the most fortunate cases, sketches and photographs are available. These documents describe architectural structures, floor and wall coverings, as well as high value finds such as architectural elements, sculptural decorations, or painted ceramic fragments. Through the analysis of such documentation, it has been possible to trace the area or exact location of most of these discoveries, thereby enabling their integration into the archaeological map.

Further investigations have made it possible to associate archaeological materials of various types, preserved both in storage and in museum exhibition spaces, in Capri and elsewhere, with the island's archaeological sites. In addition, ancient architectural elements and floor coverings that have been reused in places of worship or private buildings throughout Capri and the wider Campania region have been identified (Di Franco, Di Martino 2018; Di Franco 2021). A preliminary version of the archaeological map has been developed and is currently undergoing refinement and expansion. It consolidates the data collected thus far, including the various categories of finds identified and the sites surveyed by CNR-ISPC as part of the project (Fig. 1).

In light of this, there is a pressing need to connect the disparate information gathered and to make the findings accessible to both specialists and the public using modern information systems and the development of a dedicated WebGIS platform. This platform is not solely intended to map ancient remains but to retrieve, update, and systematically organize all collected data. In doing so, it aims to render visible even the 'lost' or 'dispersed' archaeological finds, thereby enriching the historical narrative of the island and contributing to a more comprehensive and up-to-date cartographic representation of the territory. For exemplary models of territorial projects that integrate archaeological data into accessible WebGIS platforms, reference may be made to the SITAR project (Serlorenzi, Jovine 2013), the SITAVR project (Basso *et al.* 2015), the Catania project (Malfitana *et al.* 2016), and the project on Ancona (Iacopini 2023).

2. Archaeological surveying: premises and methods

An extensive operation aimed at cataloguing and gaining in-depth knowledge of the archaeological heritage of the island of Capri – such as that required for the development of a new archaeological map – necessarily entails an equally extensive activity of archaeological surveying. Moreover, a comprehensive and unbiased approach, as advocated here, proves even more essential in a context such as Capri, a place that for decades has been confronted with its powerful *alter ego*: the mythical image of the island perpetuated in the collective imagination by writers, artists, travellers, and the tourism industry. While this myth has made Capri one of the most iconic and sought-after destinations in international tourism, it has contributed to the crystallisation of certain forms and narratives.

In this regard, in order to grasp the gap between myth and reality – including archaeological reality – and to reaffirm the importance of returning to the 'raw data', it is helpful to recall, as noted elsewhere (Caratelli 2022), the emblematic and paradoxical coexistence of the Blue Grotto and the Roman villa at Gradola (Fig. 1, n. 1, 2). These two sites coincide topographically and were closely interrelated in antiquity, with one effectively presupposing the existence of the other. The former, however, today ranks among the most renowned tourist sites worldwide of all time, whereas the existence of the latter is periodically obscured and severely challenged by an exuberant and uncontrollable layer of vegetation. Similarly, with the notable exception of Villa Jovis (Fig. 1, n. 26), which was the subject of two survey campaigns in 1979, coordinated by the Swiss Institute in Rome (Krause 2006), the most recent available plans of Capri's Roman monuments often date back to the 1930s. This coincides with the prolonged, though poorly documented, work carried out by A. Maiuri (1956) and P. Mingazzini (1931).

In light of these considerations, as part of the 'Masgaba' project and following a careful review of historical and archaeological cartography (Giorgi,

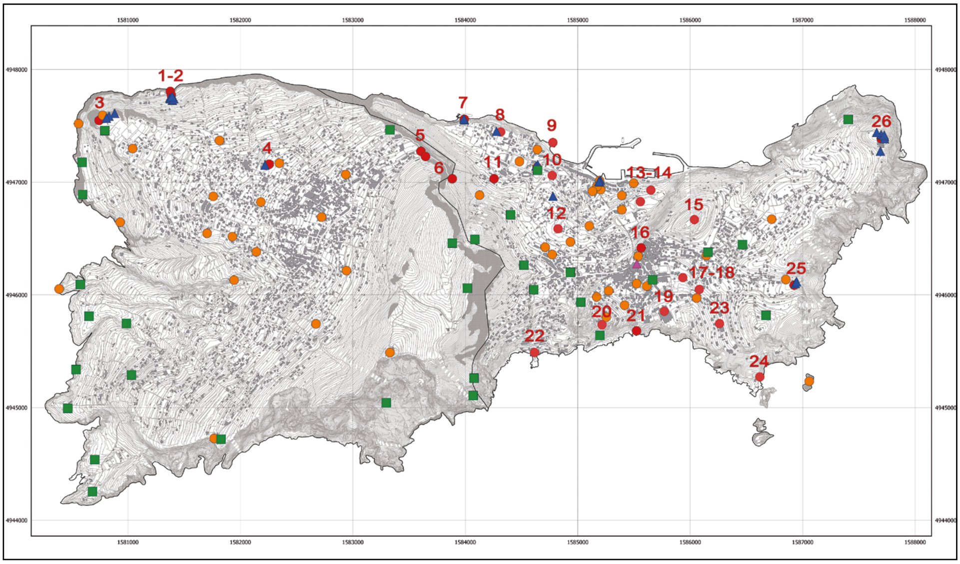

Fig. 1 – Archaeological map of the island of Capri with point elements differentiated by type (conserved archaeological assets with identification numbers in red, no longer visible assets in orange, findings in blue, and outcrop areas and pre-protohistoric sites in green).

Caratelli 2020, 21-33), new surveying campaigns have been conducted. These focused on some of the most significant Roman sites on the island: the Grotta dell'Arsenale, Grotta di Matermania, Bagni di Tiberio, and the Muro greco in the municipality of Capri; and the Villa di Gradola, Villa di Damecuta, and Villa San Michele in the municipality of Anacapri (Fig. 1, n. 21, 25, 7, 16, 1, 3, and 5). With the exception of the Grotta di Matermania, which has recently been re-evaluated through a new and detailed archaeological survey (Busen, Grüner 2018), and the Villa di Gradola, the subject of significant excavation and conservation interventions in the 1980s and 1990s (Ciardiello 2007), several of these sites had never previously been surveyed. Others were only documented through outdated, inaccurate, or otherwise inadequate graphical representations.

In accordance with a well-established practice in archaeology – one that, for several decades now, has provided a broad field of application for the most advanced surveying technologies – the documentation of these sites required a diversified and methodologically integrated approach (Angelini, Gabrielli 2013). Such an approach was necessary to effectively manage and highlight the peculiar characteristics of each archaeological context (enclosed spaces, open-air ruins, multi-level or vertically developed structures, large-scale areas, or, conversely, confined spaces), without compromising the

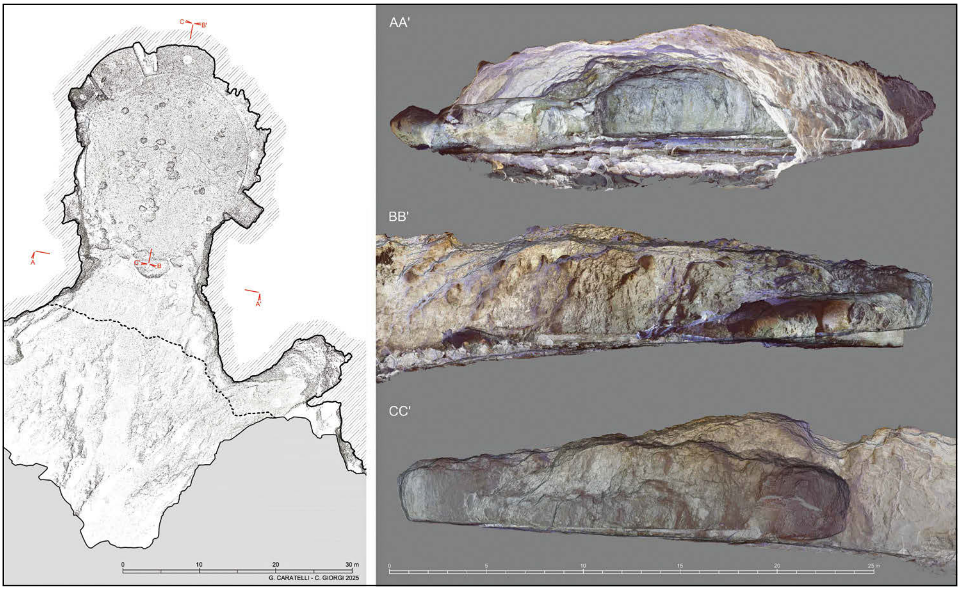

Fig. 2 – Capri, Grotta dell'Arsenale. Plan and sections from the 3D point cloud model.

quality and speed of data acquisition. These aspects are particularly valued in an environmental context such as that of Capri, which is often marked by unavoidable logistical and operational challenges.

For these reasons, the survey of all sites was carried out through varying combinations of laser scanning and digital photogrammetry, with images captured both from the ground and by drone. In particular, the base three-dimensional models – on which the overall metric reliability fundamentally depended – were produced using a terrestrial laser scanner (FARO Focus 3D S120). The device was configured with relatively high-resolution settings (ranging between 1/4 and 1/5, depending on specific requirements) and a high scan quality (generally set to 4x), in order to ensure a significant reduction in noise. Given the abundance of 'unique features' within the surveyed environments, scan alignment was consistently performed using automated procedures (FARO SCENE software), which yielded mean registration errors of only a few millimetres, never exceeding 5 mm, and often ranging between 2 and 3 mm, particularly in enclosed settings, with limited numbers of scans and within relatively small areas.

Nevertheless, to gain a clearer understanding of the specific challenges encountered and the solutions adopted, it is useful to provide a more detailed account of the selected activities undertaken. For example, the complex geometry of the Grotta dell'Arsenale (Fig. 1, n. 21), characterized by a predominance of natural (and therefore irregular) surfaces, weakly illuminated by ambient light filtering through the entrance, was surveyed through the execution of 25 colour scans, at least 16 of which were conducted inside the cave itself. These were distributed according to the site's unique morphology and the layout of the surviving wall structures (Fig. 2). This approach, combined with the instrument's ability to sample points in all directions (both horizontally and vertically, with the natural exception of the 'shadow cone' beneath the tripod), allowed for the creation of a complete and highly accurate 3D point cloud survey. For the first time, this survey revealed significant planimetric and structural features that had been entirely overlooked in previous investigations (Giorgi 2022, 72-73; Caratelli, Giorgi 2023, 797-798; 2024, 4).

Moreover, given the challenging natural lighting conditions inside the cave (dim light and backlighting), and the limited quality of the camera sensor integrated into the laser scanning instrument, it was necessary to supplement the laser survey with a series of photographic captures in order to generate a photo-realistic 3D model with acceptable texture resolution. These images were subsequently processed using digital photogrammetry software. This integration proved particularly valuable in documenting surfaces exhibiting clear evidence of anthropogenic activity, such as wall structures, wall coverings, traces of rock-working, or voids resulting from the detachment of decorative elements, as well as holes intended for the placement of architectural components or, more likely, for functional lighting purposes within the space.

The three-dimensional model, produced from approximately 200 photographs, was scaled and oriented by identifying homologous points (common points between the photographs and the laser scans), and was ultimately merged with the point-based model generated from the laser scanner data. The resulting 3D model made it possible to comprehensively represent both the interior of the cave and its surrounding environmental context – including the sea-level access point and a small adjacent cavity near the entrance – with varying levels of detail and resolution. These were nonetheless sufficient to ensure a user-friendly and intuitive interaction with the digital model, ultimately enabling a satisfactory interpretation of the site. Finally, the intention to make the cave accessible to a broader audience – given that it can still be reached relatively easily only by sea, as was likely the case in antiquity – led to the creation of a virtual tour based on the 3D model. This tour simulates the visitor's entry and a brief exploration of the interior, allowing for the observation of the preserved ancient masonry and surviving surface treatments.

The same integration between laser scanning and photogrammetric surveying was replicated at all other sites, with the addition, when necessary, of a series of drone-captured photographs. In fact, on three occasions – at

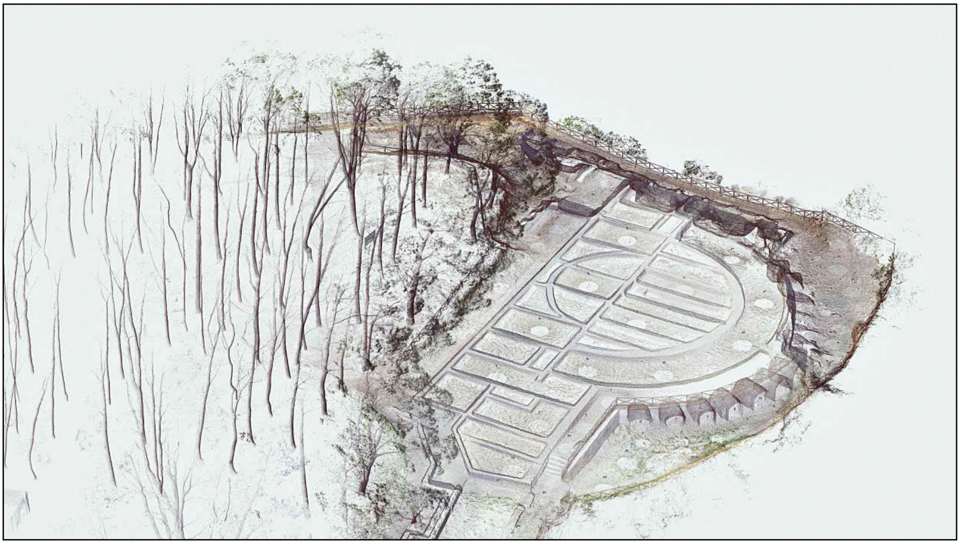

Fig. 3 – Capri, Villa di Damecuta. Northeast isometric view of the 3D point cloud model ('clear view' mode by FARO Scene software).

Villa Damecuta, the Bagni di Tiberio, and the Muro greco (Fig. 1, n. 3, 7, and 16) – due to the size of the sites and their multi-level structure, the use of an ultralight drone (DJI Mini 2, equipped with a 12-megapixel camera) proved to be essential. The Damecuta plateau, for instance, which stretches 150 m long and is at least 50 m wide at its westernmost point (the area, for reference, occupied by the well-known panoramic semicircular structure, conventionally referred to as the 'Rotonda del Belvedere'), was surveyed at different times, with 124 laser scans and approximately 600 drone photographs taken (Fig. 3). This approach, despite the presence of the island's dense vegetation, enabled the partial survey of the eastern sector, where Maiuri (1956, 63) believed he had identified an 'imperial *cubiculum*', which is currently closed to visitors for safety reasons. Finally, the main wall facings were also surveyed using a series of ground-based photographs taken with a digital camera (Canon EOS 5D Mark II, with a full-frame 21.1-megapixel sensor and a fixed 28 mm lens), which provided higher resolution images and thus a more detailed representation of the masonry (Fig. 4).

The use of laser scanning in combination with drone technology allowed for the rapid and precise documentation of the so-called Bagni di Tiberio (Fig. 1, n. 7). The site represents the maritime district of the villa, undoubtedly imperial, known as the Palazzo a Mare (Fig. 1, n. 8), which occupied a large area of the island along the northern slope (Maiuri 1956,

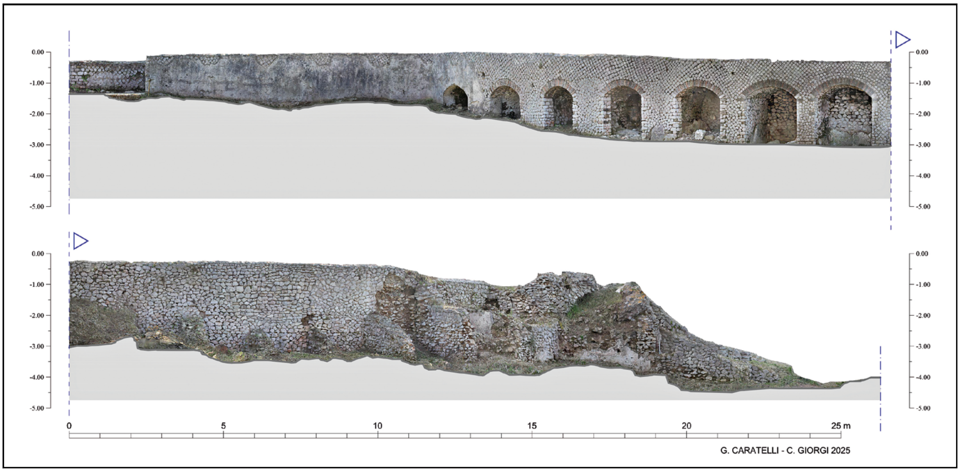

Fig. 4 – Capri, Villa di Damecuta. Photogrammetric elevation of the hemicycle, North view.

68-72; Di Franco 2015; 2022, 27-39). In fact, the overall readability of this monumental residence, with the possible exception of the large semi-circular exedra built in tuff *opus reticulatum* and brickwork, facing the sea, has been severely compromised due to relentless coastal erosion and the presence of intrusive modern constructions, which frequently reuse, cover, or conceal the ancient walls. Moreover, considering that a significant portion of these walls still lies below sea level and has recently been subject to underwater surveys, as mentioned in the introductory paragraph, it was necessary to produce comprehensive graphic documentation that integrated the emerged sector with the submerged one.

In this regard, the use of laser scanning (49 colour scans, organized into three clusters) allowed the creation of an extremely precise 3D point cloud model, which provided the metric reference base for subsequent photogrammetric surveying by drone. This tool, given the lack of scaffolding set up for the occasion, enabled the survey of areas and sectors that would otherwise have been inaccessible. The reasons are due to the height, which in the case of the large exedra reaches almost 13 m, as well as the presence of the sea, which borders the archaeological complex, and areas lacking reciprocal visibility.

The height issue, combined with the lack of sufficient space to take photographs and the presence of obstructions (modern structures and vegetation), also significantly influenced the surveying of the so-called Muro greco (Fig. 1, n. 16). It is a section of the ancient city wall, now incorporated into the Angevin fortifications, that likely served both defensive and substructural functions, connecting the hills of San Michele and Castiglione, in the area still occupied

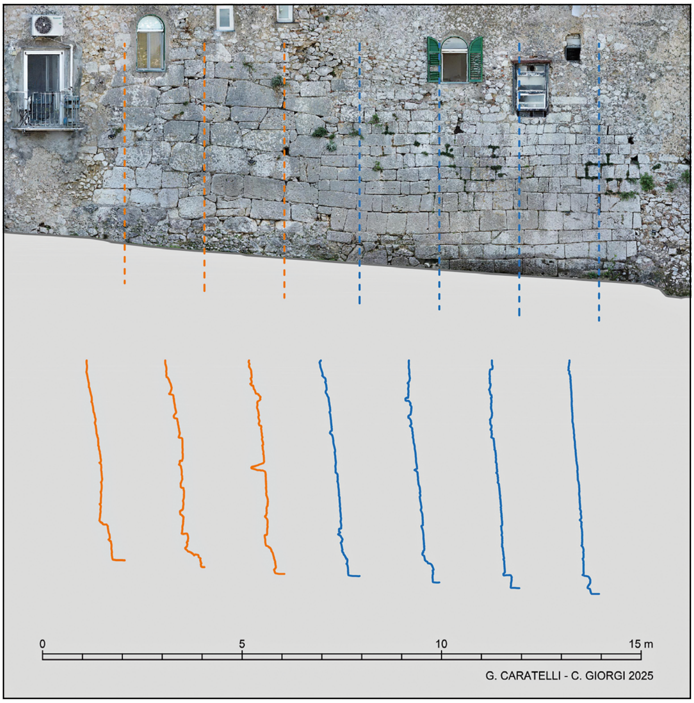

Fig. 5 – Capri, so-called Muro greco. Photogrammetric elevation and cross sections.

by the modern city of Capri. The wall, consisting of two sections (one of which, the south-western section, is currently inaccessible, although a rare photograph from 1905 is reproduced in Douglas 1930, 57), both divided into two formally distinct segments that are not perfectly aligned, presents several issues. While the question regarding the classification of the wall facings can now be considered definitively resolved, as the two segments comprising each section can easily be classified within the scope of polygonal masonry of the 3rd and 4th styles (according to Lugli 1957; De Magistris 2005, 56), the chronological issue remains largely unresolved. On the one hand, the absolute chronology is uncertain, fluctuating between excessively high dates (which are no longer sustainable) and the end of the Middle Republican period (3rd century BCE). On the other hand, there is no longer agreement even on the relative chronological sequence, which in one of the most recent and well-supported positions has been surprisingly questioned, even suggesting the contemporaneity of the two segments (De Magistris 2005, 60), rather than the conventional and almost assumed later date for the 4th-style polygonal section.

The laser scanning survey of one of the two sections (the longer one, located to the northeast), supplemented by a series of ground-based and drone photographs, as well as a thorough examination of the wall structures, has created the conditions to offer some new observations regarding the relative chronology of the two masonry styles. The point cloud generated by the laser scanner has finally allowed for the analysis of the external profile of the wall face, which had never been considered before. This profile clearly shows that the two segments of 3rd and 4th style polygonal masonry present two distinct batter profiles, which are unlikely to correspond to the same construction project (Fig. 5).

In other words, it seems rather unlikely that the two sections, if they belong to a single project (and thus are contemporaneous, as suggested in De Magistris 2005), would have been constructed with such different characteristics. Furthermore, a more detailed analysis of the junction between the two segments equally reveals (through logic-based reasoning) the later chronology of the 4th-style polygonal segment compared to the other. Specifically, when examining the first block (starting from the left) of the ninth course (counting from the bottom) of the 4th-style polygonal wall, it is immediately apparent that it has a triangular shape due to the necessity of filling the triangular gap created by the presence (and thus the anteriority) of the adjacent polygonal block. If the latter had not yet been laid, there would have been no reason to shape the block at the start of the ninth course into a triangular form; instead, as in the case of the lower courses, a new alignment would have begun with a standard quadrilateral block.

Naturally, if this analysis is correct, it must be acknowledged that the segment built in 4th-style polygonal masonry is, consistent with what one might expect based on a purely formal evaluation of the wall facings, chronologically later than the one in 3rd-style polygonal masonry. However, in the absence of further data – above all, datable materials obtained through stratigraphic investigations – and lacking a comprehensive analysis that also includes the south-western section, which is currently inaccessible, the reasons for this structural 'abutment' remain largely hypothetical. Nevertheless, they could plausibly be interpreted as evidence of an ancient restoration of a pre-existing wall circuit originally built in 3rd-style polygonal masonry.

It goes without saying that, if this hypothesis is accepted, one must also assume a significant chronological gap between the two construction phases, the extent of which remains unknown. If the more recent segment is dated to the 3rd century BCE, in the context of the first two Punic Wars (as has already been convincingly argued by De Magistris 2005, 64, who dates the two sections to the years around 250 BCE), then the segment in 3rd-style polygonal masonry could plausibly be pushed back as far as the 4th century BCE.

3. From GIS to WebGIS

3.1 *The GIS of the island of Capri*

Given the need to develop an information system for the island that would include a relational database with spatial functionalities, a local project was implemented from the outset using the open-source software QGIS. This system has served as the primary tool for the storage of heterogeneous data, which can be integrated within the cartographic space and used to query and manipulate georeferenced geometries in point, linear, and polygonal formats. The initial data entered, in addition to the cartographic layers, concerned areas subject to archaeological and landscape protection constraints. This data entry operation proved essential for determining the actual extent of protected areas and for providing critical support for territorial planning.

Since no web-based geographic consultation platform is currently available at the local or national level for these protected areas, generally identified using point data, an analysis of the acts of administrative decree issued over time was carried out. All available identifying information was then entered, and, where possible, the specific cadastral parcels under protection were identified. The spatial analysis conducted revealed that only 3% of the island's territory is subject to this type of restriction (Giorgi, Caratelli 2020).

Subsequently, new schematic plans of the surveyed archaeological features were integrated, indicating the boundaries of the investigated sites, the identified wall structures, and the preserved ancient pavement surfaces. In addition, data collected by other specialists involved in the project, such as those described in the introduction, were geolocated, including prior terrestrial and underwater surveys, point references to no longer visible finds, and areas where archaeological materials emerge at the surface. The system, which is currently under development, has already enabled the production of the first archaeological maps of the territory (Fig. 1), in addition to generating preliminary analytical data on the examined heritage assets.

3.2 *The logical structure of the WebGIS and its contents*

The developed GIS fully meets the original objectives of the project, which included, as previously mentioned, the complete mapping of the island at various scales of representation, territorial analysis, a re-examination of the archaeological heritage, and the dissemination of results through publications containing all the data collected by the different participants and the new graphic elaborations produced. Subsequently, however, the decision was made to undertake an additional path, complementary to the local GIS, by developing a WebGIS that would facilitate the consultation of research and be expandable with future studies. To this end, an interactive web application was developed to improve the accessibility and usability of the data.

Moreover, while GIS is an extremely useful tool for historical and spatial analyses, it has certain limitations in managing multimedia data as well as large amounts of textual information. The WebGIS will be directly accessible from the homepage of the website (https://isoladicapri-gis.ispc.cnr.it), which introduces the project, highlighting its objectives, thematic areas with specific in-depth analyses, and the involved parties. Within the web application, the archaeological sites are represented on an intuitive and easy-to-consult initial map layer. These sites are differentiated based on their type, with markers characterized by different symbols and colours, allowing immediate distinction between preserved and visitable archaeological remains, those no longer visible but documented by historical sources, and areas of material concentration or outcrop, identified over time through surveys and excavations.

The system also allows the visualization of all finds in their original discovery location, including both dispersed items documented through photographs or drawings and those currently held by cultural institutions responsible for their conservation. In some archaeological contexts, the research conducted as part of the project has made it possible to reconstruct the sculptural furnishings in their original form and position. A significant example is provided by the sculptures found inside the Blue Grotto (Di Franco 2022), now at the Archaeological Museum of Capri, at the Certosa di San Giacomo (Fig. 6).

In addition to the markers identifying the location of various types of heritage, all site plans of the archaeological sites surveyed by CNR-ISPC have been imported from QGIS. Here, users can explore the immersive site through specific interactive points on the map, which link to spherical images obtained through laser scanner surveys. Informationally, each archaeological site is described through a series of fields containing essential data, including the name, chronological period, location, a brief description, and bibliographical references. The latter is interactive: clicking on the short citations shows the full reference. For the archaeological materials found on the island, further fields are provided to specify the material, dimensions, state of conservation, current location of archive, and representative images of the item.

For the archaeological remains still preserved, a second level of in-depth information is available, featuring a more detailed entry structured according to criteria similar to those used in institutional cataloguing systems. Within the same interface, multimedia content is also accessible, including photographs of the current state of the site, historical images, and archaeological graphic documentation produced during the project. This includes detailed plans, thematic maps, reconstructive hypotheses, technical drawings of specific areas or functions, as well as videos and photographs taken during

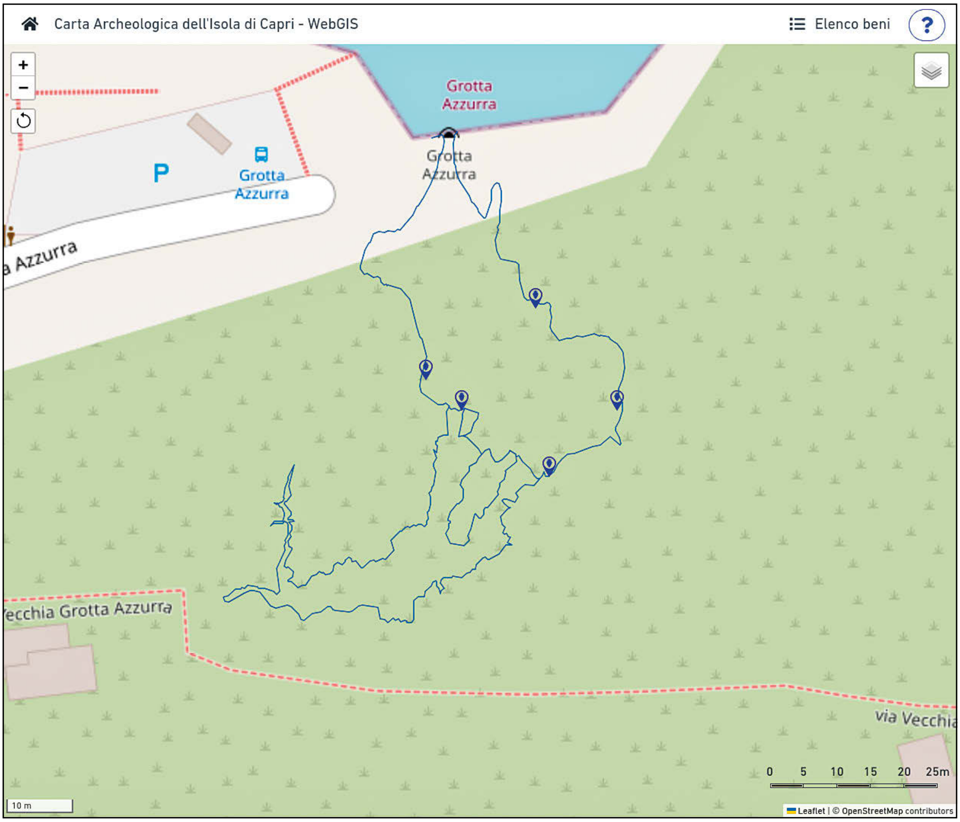

Fig. 6 – Web version of the archaeological map. Grotta Azzurra and related sculptures in their original locations.

photogrammetric campaigns on land and by drone, in addition to perspective views of the 3D models developed. Navigation of the 3D models created by CNR-ISPC will be facilitated and made available by integrating the system with specific applications.

The archival documentation is gathered in a dedicated section, where available documents are accessible in PDF format, as well as the scientific publications produced within the 'Masgaba' project (Fig. 7). The development of the WebGIS is currently underway, with advanced search functionalities directly on the map to be included. This will allow users to locate items through keywords related to specific characteristics, such as types of masonry or floor coverings, find contexts of discovery, and other criteria. Selectable filters will also be available from predefined lists, such as historical period

Fig. 7 – Example of summary data sheet with active bibliography and other tabs with additional information and multimedia content (Villa di Damecuta).

and chronology, as well as free-text searches, leveraging the capabilities of the existing relational database.

3.3 *WebGIS software architecture and development*

Once the structure of the WebGIS had been defined in terms of features, components, graphical layout and user interaction mode, an outline of the software architecture necessary for development was prepared. The main requirement taken into consideration was the exclusive use of open-source technologies, which would guarantee software reuse thanks to its distribution through open licenses, so the WebGIS would not be tied to proprietary solutions that are usually restrictive. The application of open-source software in the context of GIS, WebGIS and Web Mapping projects has been a well consolidated practice for several years. Their adoption has been facilitated both by the increasing availability of open software libraries and tools that can be reused and potentially modified, and by the standardization work carried out by the Open Geospatial Consortium (OGC) (Sarup, Shukla 2012; Castronova *et al.* 2013; Veenendaal *et al.* 2017). The most common software architecture in this context is the 'classic' client-server model. In this case, the client is the web browser (Chrome, Firefox, Safari, etc.), which renders an interactive map implemented using JavaScript libraries, usually Openlayers and Leafletjs, while the server manages georeferenced data via a combination of relational database – mainly PostgreSQL with the PostGIS extension – and dedicated code written in a backend language such as Python, PHP, Java, etc. (Agrawal, Gupta 2017; Uyaguari *et al.* 2018).

An additional component often included in these systems is GeoServer, an OGC-compliant open-source software that can provide the various web mapping services defined by OGC standards (such as Web Map Service and Web Feature Service), in addition to managing geospatial data stored in the PostgreSQL / PostGIS database (Sadoun *et al.* 2022). The first practical consideration concerned the choice of programming language to use mainly for server-side code, since for the frontend client the use of JavaScript and HTML5 is almost necessary. Given existing experience with it and its comparative ease of use, PHP 8.3 was selected (latest stable version at the time of development), paired with the Symfony web framework used in 'reduced' mode only to implement a JSON REST API (so leaving out frontend features). Symfony provides a structured basic configuration that implements the Model-View-Controller (MVC) paradigm for developing web applications and defining HTTP JSON endpoints in a very simple and straightforward way. The chosen Database Management System (DBMS) is PostgreSQL to represent georeferenced data and their geometries through the PostGIS extension. Database entities are represented in Symfony as object classes defined by Doctrine, an Object-Relational Mapper (ORM) for PHP (https://www.doctrine-project.org/projects/orm.html). GeoServer was not included in the software architecture because, currently, the WebGIS does not provide either WMS/WFS services or spatial analysis features. However, it is still possible to add it in the future or to implement a simple dedicated web mapping service, based on the existing backend.

3.3.1 Database structure

The first step in the development of the WebGIS was the definition of the structure of the relational database, that is, the data model that should have represented the information gathered for the archaeological cartography and to be shown via the web map. The main entities represent the corresponding categories of assets, namely archaeological assets (sites and monuments still visible today), finds, not-preserved assets and outcrop areas. Each one of these entities has a Point-type geometric property to represent geographic coordinates, to distribute their markers correctly over the web map. For the archaeological assets surveyed by the project, georeferenced lines and polygons are also available. Currently, these are added to the map as GeoJSON layers (see *infra*, §3.3.2), but in the near future they will be inserted into the database using the

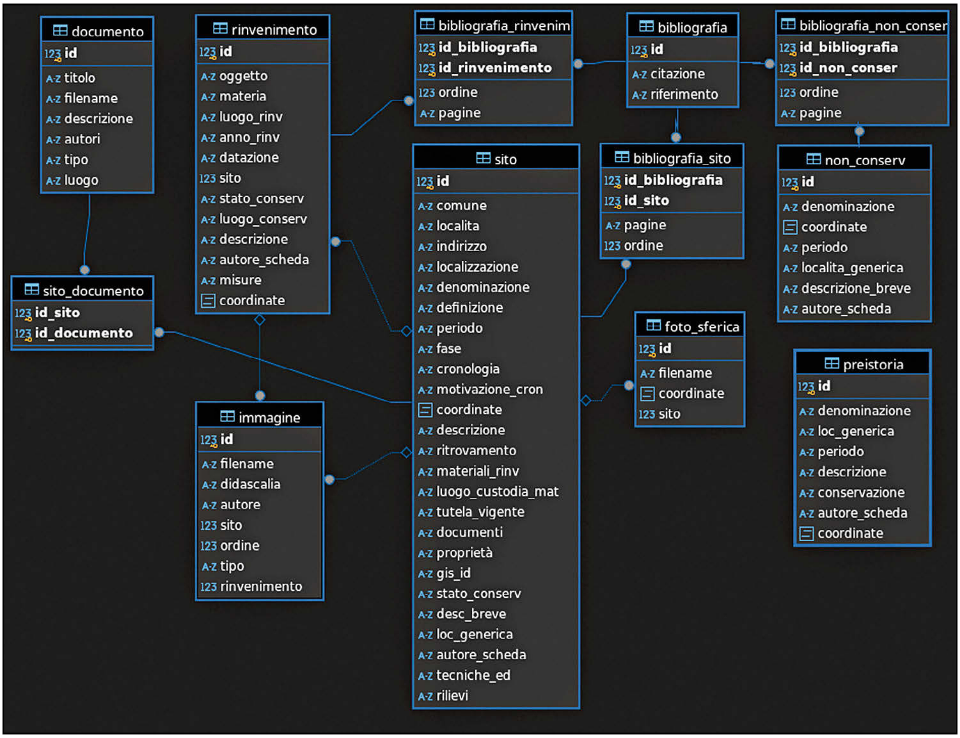

Fig. 8 – E.R. diagram of the WebGIS database.

LineString and Polygon geometric types defined by PostGIS, so they can be associated directly to the corresponding records. In addition to these, the database includes other entities to represent metadata associated with images and other media, bibliographic references and spherical photos, with their respective relationship tables that relate them to archaeological asset records (Fig. 8).

3.3.2 Interactive web map

The WebGIS frontend publicly available to users consists of the interactive map that can be used with any modern web browser, with interaction features developed specifically for the project. The map was implemented using Leafletjs, an open-source JavaScript library, with three base maps that can be selected individually: OpenStreetMap showing physical features on the surface, Mapbox as a satellite view of the territory, and cadastral cartography, exported from QGIS in GeoJSON format (https://geojson.org), as described in more detail below (Fig. 9). The initial default view has a zoom level that can contain the entire island of Capri within the browser's viewport, adapting

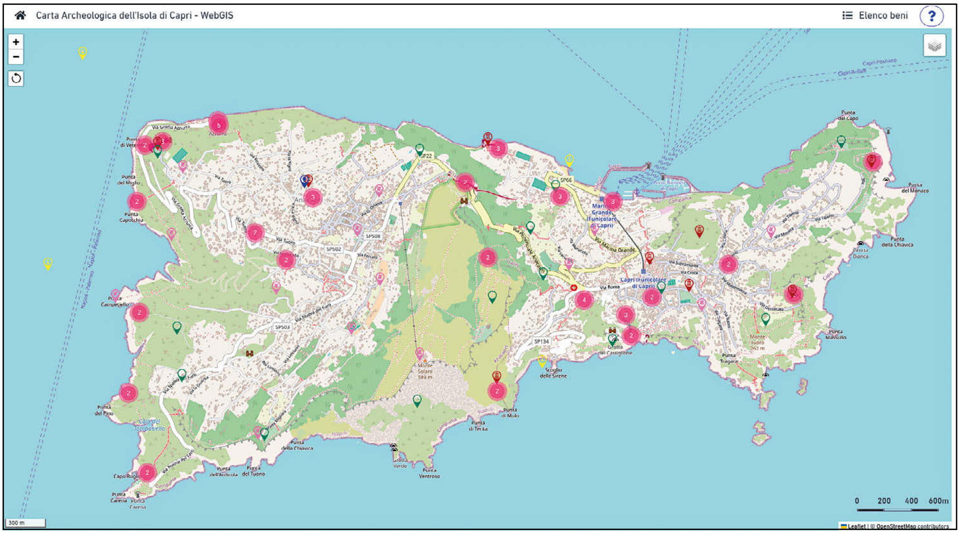

Fig. 9 – Interactive web version of the archaeological map.

to different screen sizes (responsive design). The zoom level can be changed using the controls on the map's left side, with a fixed limit in zooming out so as not to get too far from the island area. Getting back to the initial view is always possible using the reset button.

As mentioned above, in addition to street and satellite layers provided by tiled map services, it is possible to select a cadastral cartography initially created in QGIS, then exported to GeoJSON (with EPSG:4326 coordinates) to add it as an additional base layer using a specific feature of the Leafletjs library. GeoJSON is a text document format generally used to exchange geo-referenced data. It adopts the JSON (JavaScript Object Notation) syntax, with specific properties defined for this context by an open standard. Following the same procedure, layers were imported corresponding to archaeological and landscape constraints, which can also be selected via the same control as the base maps, and to surveys of the archaeological sites, rendered on the map as lines for wall structures and polygons for excavation areas. Regarding the constraints, the GeoJSON includes some text data (e.g., cadastral parcels, location names etc.), in addition to spatial features. These can be viewed in a pop-up table by clicking on the area of the respective constraint.

The main tool to navigate the map is the menu with the list of assets that can be activated by a button to the top right on the navbar. The menu appears on the right side of the viewport, under the button, partially overlapping the map. Each category of assets presented on the map corresponds to a section within the menu, along with the custom icon of the respective marker. Each section is in turn divided by municipality, i.e. Anacapri and Capri, with their individual lists. The items in these lists are interactive: by clicking on one of them the view on the map is zoomed and panned to the corresponding marker, and its label with the name of the asset appears automatically (Fig. 10). By clicking on a marker, a modal overlay is displayed showing several types of content, described above. The modals for each category can be extended to include other kinds of information in the future. All the interactive features were developed with JavaScript using the Stimulus library, CSS 3 with the Bulma framework, and HTML5 for the basic structure of components.

As mentioned before, the structured data in the relational database around which the WebGIS is built is made available to the interactive features of the web map by a dedicated REST API, which returns it as JSON responses. Currently, the JSON fields are not organised according to standard metadata formats, since the schema adopted so far is arbitrary. However, it is possible to map it to standard terms defined by metadata formats (or ontologies) used for Open Data purposes, such as Dublin Core (mainly for bibliographic references) and DataCite. Another foreseeable future development – in addition to providing documented REST API endpoints with the OpenAPI specification – relates to a Linked Open Data approach (Schmidt *et al.* 2022), using JSON-LD and/or RDF/XML as exchange formats for (meta)data, semantically enriching them with standard controlled vocabularies and gazetteers used in the cultural heritage and GIS fields, such as Wikidata, Pleiades and/or GeoNames (Di Giorgio 2015; Nishanbaev *et al.* 2020).

Fig. 10 – Browsing example for the web map using the interactive menu.

4. Conclusions

The ‘Masgaba’ project marked a significant step in the documentation and enhancement of the archaeological heritage of the island of Capri, by using advanced technologies and a multidisciplinary approach. The integration of modern survey methods, such as 3D laser scanning and photogrammetry, enabled the creation of detailed and accurate documentation of numerous archaeological sites that had not been adequately surveyed before. The hypotheses put forward regarding the investigated sites concern the identification of planimetric patterns, the sequence of construction phases, and the reconstruction of certain sectors that are no longer preserved. The adoption of a GIS and WebGIS system, supported by a relational database and open-source technologies, has made it possible to organize, manage, and interactively access geospatial data in a dynamic and user-friendly manner. In particular, the publicly accessible digital map allows for a clear visualization of the different types of archaeological assets on the island, offering detailed information on each site, which can be consulted through dedicated search and navigation tools. Furthermore, the completeness of the data entered has allowed for linking artifacts to their original sites, virtually recreating the relationship between object and context. This system represents not only an important resource for scientific research but also a tool for dissemination to a broader audience, providing immediate and intuitive access to historical and georeferenced information.

Finally, the use of open-source technologies has ensured the sustainability and flexibility of the system, opening the possibility for future expansions and integrations, as well as the addition of new analytical features. In this regard, a significant development of the web application connected to the WebGIS will involve the addition of a data entry functionality via a dedicated interface for external users, who will be able to authenticate to the system with personal credentials (provided by the project), thus enabling continuous updates of the information. The project has, therefore, contributed not only to filling gaps in the archaeological knowledge of the island but also to developing a replicable model for the management and enhancement of cultural heritage through digital tools, which can be applied to other similar archaeological sites. Looking ahead, ‘Masgaba’ has the potential to become a key resource for the conservation, promotion, and enjoyment of the archaeological heritage of Capri, strengthening the connection between research, technology, and cultural heritage.

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ABSTRACT

The project 'Masgaba. An Archaeological Map for the Island of Capri' was launched with the aim of updating and integrating Capri's archaeological documentation, filling the existing gaps in the knowledge of its archaeological heritage using advanced technologies. The methodological approach included new surveys and analyses of sites that required updates in the graphical documentation or had previously been misinterpreted, the analysis of archival sources to recover information on no longer visible archaeological heritage, and the documentation of museum finds that helped improve the understanding of the island's ancient history. A central element of the project is the creation of a WebGIS, which organizes the data into an interactive digital map, providing an overall view of the island's archaeological heritage. The web application allows users to consult detailed records, multimedia content, archival documents, and publications produced within the project. The adoption of open-source technologies has ensured the sustainability of the system, paving the way for future extensions and the possibility of integrating new data.