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DIGITAL TOOLS FOR THE KNOWLEDGE, PRESERVATION, AND ENHANCEMENT OF 20TH-CENTURY MILITARY HERITAGE: A CASE STUDY FROM SARDINIA

Andrea Pirinu, Sergio Mocci*, Giancarlo Sanna**

*DICAAR, University of Cagliari – Cagliari, Italy.

Abstract

This study leverages Geographic Information Systems (GIS) and other digital tools to preserve, document, and analyze the 20th-century military heritage of Sardinia. Focusing on the containment arc of Quartu Sant'Elena (CA), constructed in the 1940s to defend against a potential Allied invasion, it examines two key aspects: the defensive coverage provided by individual bunkers and their collective role in ensuring continuous territorial control. Through GIS-based viewshed analysis, the research evaluates the fields of fire and strategic placement of these defensive structures, offering new insights into their design logic and integration within the landscape.

Keywords

Digital technologies, Geographic Information System, Military Landscape, WWII, Sardinia

1. *Digital tools for knowledge, preservation and enhancement of the military heritage*

In recent years, increasing attention has been devoted to the study, protection, and architectural enhancement of the military and landscape heritage associated with twentieth-century wars.

Numerous scientific contributions, along with the activities of cultural associations, have brought to light an exceptional material and immaterial legacy connected to these conflicts, forming a historical and cultural memory that unites the Atlantic, Mediterranean, and Balkan coasts.

Following the foundational studies by Paul Virilio (1975) and Rudi Rolf (1988) on the Atlantic Wall—constructed by the Germans between 1942 and 1944 and stretching from France to Norway—numerous historical and architectural investigations have emerged.

This renewed interest has led to extensive cataloguing efforts, particularly in Spain, where the Pyrenean fortified system has been documented, alongside the strengthening plans for Campo de Gibraltar (Atanasio, 2017), the defenses of Catalonia (Gil et al., 2022), and the fortifications extending from the coast of Murcia to Cartagena, culminating in the inventory of defensive structures along the southern coast of the Valencian Community (Martínez-Medina, 2016).

In Italy, a similar effort has focused on the census, typological classification, and dimensional and landscape cataloguing of bunkers along the Calabrian (Caniglia, 2023, 2024) and Sicilian coasts. This work has also encompassed approximately 1,500 military structures distributed along the Sardinian coastline (Pirinu et al., 2020, 2021, 2022), supported by integrated survey methodologies.

The Sardinian defensive system played a crucial role within Italy's broader defensive strategy, which aimed to protect key maritime and aerial routes in the Mediterranean, effectively serving as an advanced defensive line for the nation.

Maps identifying the precise locations of individual bunkers, combined with detailed measurements and drawings of their geometry and material characteristics, have contributed to comparative research projects focused on other defensive systems along the Mediterranean coastline (Caldarone et al., 2022, 2024) and in the Balkans (Nakić, 2024).

These studies, supported by information technologies, have facilitated the creation of

interoperable digital databases of significant scientific value.

These databases not only promote the dissemination and sharing of this heritage but also contribute to the development of effective strategies for its preservation and management.

The understanding of this network of defensive structures, designed to control vast territories, is greatly enhanced by the integration of both traditional and digital tools for architectural survey and representation. Among these, Geographic Information Systems (GIS) are particularly well-suited for analyzing such a multi-scale, stratified landscape.

GIS platforms, designed to manage continuously updated data in various formats, enable the execution of complex spatial analyses and facilitate the creation of both two-dimensional and three-dimensional representations at varying levels of detail.

The territorial and landscape scales are especially critical in the study of twentieth-century military architecture, as they correspond to the spatial dimensions employed in the planning of defensive systems aimed at controlling communication routes, coastlines, and settlements.

2. Methodology

This study employs a methodological approach that integrates archival research, fieldwork, and digital spatial analysis to develop a comprehensive understanding of the containment arc of Quartu Sant'Elena and its defensive structures. Each phase of the research was designed to systematically collect, verify, and analyze data related to the positioning, orientation, and functionality of the bunkers and their associated fields of fire.

2.1 Archival research

The initial phase involved an extensive review of archival documents, including the prototypical designs developed by the Italian Military Engineers during the Second World War. These documents provided critical information on the structural typologies, spatial distribution, and armament configurations of the defensive positions.

A key resource for this phase was the IGM (Istituto Geografico Militare) maps at a scale of 1:25.000, which were instrumental in identifying the original locations of the bunkers (Fig. 1).

The map legends detailed the type of weaponry assigned to each casemate or loophole, forming a preliminary framework for understanding the intended defensive coverage of the containment arc.

Simultaneously, a detailed analysis of the technical characteristics of the armaments was conducted, focusing on their effective ranges, firing angles, and mechanical limitations. This analysis drew from military manuals, archival records, and secondary literature on the specific weaponry used during the war, providing essential data for evaluating the defensive capacity of each position and its role within the broader network.

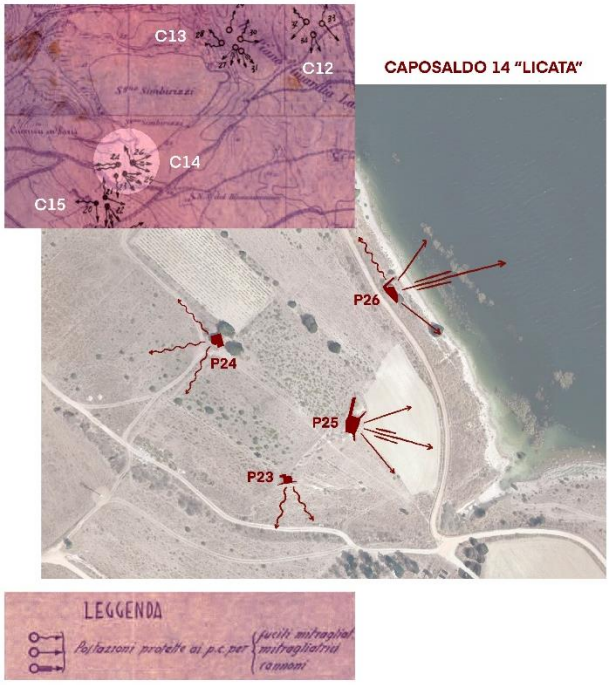

Fig. 1: Weapons and defensive cover of the Stronghold "Licata" as described in the historical IGM map

2.2 Fieldwork and survey

The second phase involved on-site verification and surveying of the defensive structures to validate and refine the data collected from archival sources. Each bunker was geolocated with high precision using GPS technology, ensuring accurate positioning within the modern landscape.

The dimensions and orientation of the firing loopholes were measured to verify their alignment with the original design prototypes. Particular attention was given to:

- Horizontal firing angles, to confirm or adjust the theoretical fields of fire derived from archival sources.
- Vertical firing angles, to assess the elevation and depression capacities of the weapons.

This phase also documented any deviations from the original designs, whether due to adaptations to the local topography or modifications made during construction.

These deviations provided valuable insights into how standard prototypes were customized to meet the specific requirements of the terrain and strategic objectives.

2.3 Creation of the database

The data collected during the archival and fieldwork phases were systematically organized into a geodatabase. This structured and interoperable database includes:

- Geospatial coordinates of each bunker.
- Details of each loophole, including its orientation, horizontal and vertical firing angles, and the assigned weaponry.
- Effective firing ranges and their corresponding coverage areas.
- Hierarchical relationships between individual bunkers, their associated strongholds, and the larger containment arc.

The creation of this geodatabase enabled the management of large datasets, facilitating detailed spatial analyses and cross-comparisons of different defensive positions.

2.4 Integration into a Geographic Information System (GIS)

In the final phase, the geodatabase developed during the previous stages was imported into a Geographic Information System using QGIS.

This integration allowed for the execution of advanced spatial analyses, such as viewshed analysis (Nijhuis et al. 2011, Nijhuis 2016), which evaluates the visibility and coverage of each defensive position, and database queries to assess the relationships between individual bunkers, weaponry, and their corresponding fields of fire.

By overlaying historical cartography onto modern topographic maps and orthophotos, the GIS provided a dynamic environment for comparing the defensive layout across different temporal contexts, offering insights into the strategic functionality and evolution of the containment arc.

3. Military Heritage of World War II in Sardinia

Between 1942 and 1943, a network of reinforced concrete bunkers was established in Sardinia, forming a system designed to control beaches, lagoons, isolated coves, and major urban centers across the island.

These structures were conceived by the Italian Military Engineers following precise graphic models (Fig. 2) and strategically positioned, as documented in the records preserved at the Archive of the Infrastructure Department of the Army in Cagliari and the 1:25.000 scale IGM (Istituto Geografico Militare) maps housed at the AUSSME (Historical Office of the General Staff of the Army) in Rome.

Designed to integrate seamlessly with the local topography and characterized by the predominant use of simple geometric forms - such as circles, squares, or their combinations - these bunkers constitute a stylistic and constructive catalogue of significant interest.

This interest arises not only from their optimal positioning for territorial control but also from their capacity for mimesis, achieved using local materials that often form the external cladding of these small industrial objects made of reinforced concrete.

In addition to the standardized forms prescribed by the design abacus prepared by the military engineers, there are unique solutions that suggest functions beyond their military purpose. Some bunkers resemble civilian or rural dwellings, water supply tanks, churches, or even nuraghe - ancient megalithic structures that remain a distinctive feature of Sardinia's landscape (Fig. 3).

The armament housed within each bunker, as specified in the IGM maps, included various types of weaponry, such as machine guns, heavy machine guns, and anti-tank guns.

Each weapon system had specific roles and capabilities, defined by parameters such as range and firing angles. These parameters are critical for the analysis conducted in a key defensive sector of the island: the containment arc of Quartu Sant'Elena, located near Cagliari, the island's capital. This sector represents a significant component of Sardinia's broader territorial defense strategy during World War II.

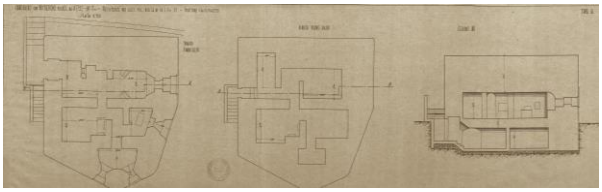

Fig. 2: Drawing representing a multi-weapon station (source: Army Infrastructure Department, Cagliari)

Fig. 3: Selection of models with predominantly circular plant, present along the coasts of Sardinia (photos by the authors 2017-2024)

3.1 The Protection of the Territory of Cagliari: The Containment Arc of Quartu Sant'Elena

The containment arc of Quartu Sant'Elena, composed of defensive structures smaller in scale compared to those of the Atlantic Wall, was designed to counter an Allied landing and to protect the urban, agricultural, and industrial areas surrounding Cagliari.

This defensive network comprises 107 reinforced concrete structures, mostly abandoned but still in a decent state of preservation.

In addition to these bunkers, other military structures, such as observation posts located in Cala Regina, Nuraghe Diana, and the Old Fortress, as well as the coastal batteries "C165" of Capitana and "Faldi" at Torre Mortorio (Grioni & Carro, 2014), form part of this system.

These fortifications are arranged along two lines: the first near the coastline and the second positioned further inland on nearby hills.

The containment arc of Quartu Sant'Elena is organized into 19 strongholds, each equipped with a variety of weapons chosen based on their specific defensive function, creating a continuous line of defense.

This line extends from the eastern checkpoint No. 1 "Agrigento" to the westernmost checkpoint C19 along Poetto Beach, where four bunkers are flanked by an anti-tank barrier designed to prevent both landings and the advance of vehicles from the coastal road of Carbonara (Figs. 4-5).

Fig. 4: Stronghold Agrigento - anti tank barrier

The defensive structures in this area generally adhere to the models described in archival documents, with some variations introduced to improve camouflage and blend into the landscape. The positions in Quartu Sant'Elena are predominantly of the "multiweapon" type, designed to accommodate various types of weaponry.

This necessitated the construction of custom-designed loopholes and casemates.

These structures often feature convex polygonal layouts, sometimes combined with square forms for access points, and are frequently adapted to the local topography or disguised to resemble non-military structures.

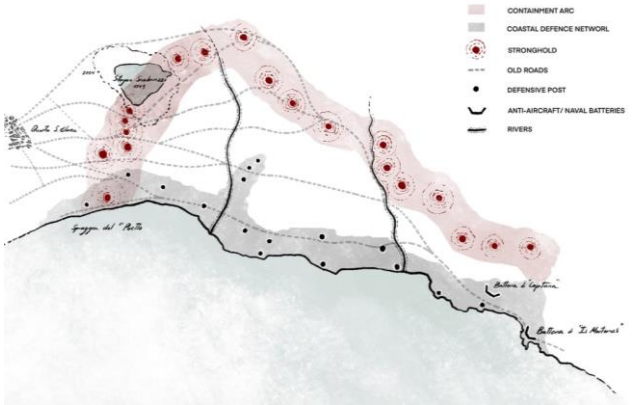

Fig. 5: Strategic positioning of the strongholds (graphic elaboration by the authors)

While this study examines the entire containment arc of Quartu Sant'Elena, particular attention is given to key defensive positions in areas that have remained relatively unchanged since 1942.

Fig. 6: "Works and military roads of the sector of Quartu Beach, San Isidoro and Sinnai" (IGM map, west sector)

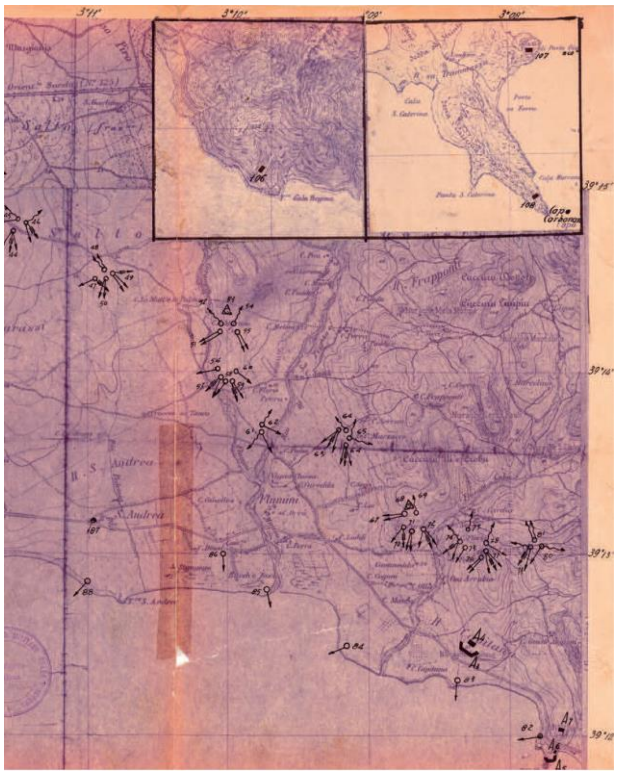

Fig. 7: "Works and military roads of the sector of Quartu Beach, San Isidoro and Sinnai" (IGM map, east sector)

This analysis combines field surveys with the reinterpretation of historical maps and the landscape to categorize the military structures based on their function, armament, and firing angles.

The study is facilitated by the detailed descriptions found in the cartographic documentation produced by Italian military engineers during the 1940s on IGM maps (Figs. 6-7).

These maps not only outline the defensive strategy but also enable a valuable graphic overlay with contemporary aerial photogrammetric surveys, providing information on the artillery assigned to each stronghold and an assessment of the defensive coverage they offered.

The positioning of the strongholds was carefully planned to ensure effective territorial control. Located along the coast and frequently on elevated terrain, such as hills and headlands (Figs. 8-11), these structures were strategically placed to maximize both visibility and fields of fire.

The primary focus of their firepower was directed at critical communication routes and the coastline, which were further secured by smaller outposts. Anti-tank gun emplacements were positioned to target the movement corridors of enemy vehicles, while heavy machine guns provided close-range defense and effective suppressive fire, ensuring comprehensive territorial coverage.

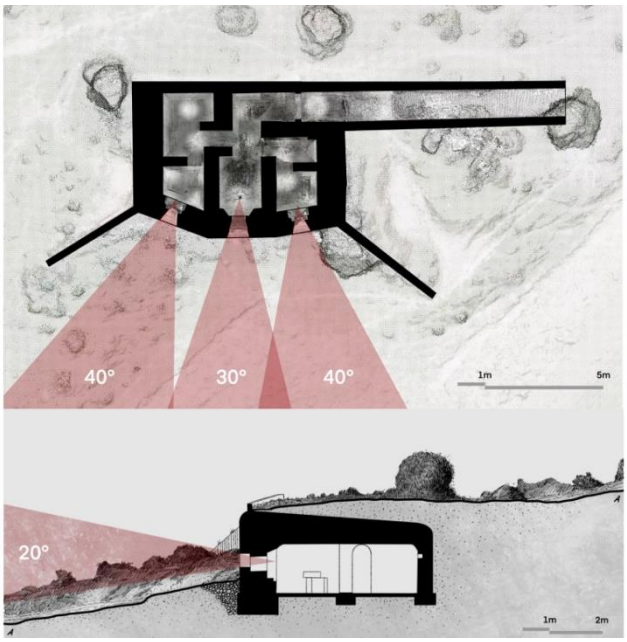

Fig. 8: Firing angle of the station 25 belonging to the stronghold14 (graphic elaboration by the authors)

Fig. 9: Stronghold C16, a fake church, on the hill of Pitz'e Serra (photo by the authors, 2017)

Fig. 10: Lookout in the locality of Is Mortorius (photo by the authors, 2024)

Fig. 11: West end of the containment arch of Quartu Sant'Elena. Bunker belonging to the stronghold "Carcangiolas" and positioned along the Poetto beach (photo by the authors, 2024)

3.2 Control of the Territory during World War II: The Case of Strongholds 13 and 14 near Simbirizzi Lake, Quartu Sant'Elena

The analysis of territorial control exercised by Italian strongholds during the Second World War provides significant insights into the firing angles and the effective coverage offered by the weapons installed within these defensive structures.

The firing slits, designed to enable defensive fire, exhibit varying opening angles depending on the type of weapon and the specific function of each position. Detailed analyses of Italian bunkers reveal that the horizontal firing angles of machine gun slits typically range between 20° and 40°, while those of artillery guns span from 30° to 60°. However, the actual operational firing angles were often narrower than the maximum permitted by the slit openings, due to mechanical constraints, precision requirements, and the structural design of the defensive positions. This limitation was due to mechanical constraints imposed by the gun mounts, the precision requirements of the weapon, and the structural configuration of the defensive position.

The vertical firing angle, which defines the elevation and depression range of the weapon, generally varies between 10° and 25° in Italian fortified positions.

This range partially limits the effectiveness of the bunkers against targets positioned at significantly different altitudes.

This configuration aligns with the primary function of Italian strongholds, which were predominantly designed for protection against land-based attacks and for controlling the terrain immediately in front of the position. By contrast, German bunkers, such as the Type 685, were characterized by significantly different design parameters.

Their horizontal firing angles could reach up to 120° (Rolf 1988), and their elevation range extended to 45°, enabling them to respond effectively to both aerial and armored threats.

These differences highlight a distinct defensive doctrine, with the German approach emphasizing a broader range of threats, while the Italian doctrine was more focused on ground-based defense.

Within the territorial scope of the containment arc of Quartu Sant'Elena, several key strongholds were selected for detailed analysis using a Geographic Information System (GIS).

Among these, the "Taormina" (C13) and "Licata" (C14) strongholds were chosen as primary case studies. Located between the hill of Pitz'e Serra and Simbirizzi Lake, these strongholds, together with "Corleone," "Caltanissetta," "Castroreale," and "Carcangiolas," played a critical role in controlling the coastline and the major routes connecting Cagliari to the surrounding territories. The stronghold "Taormina" (C13) consists of five bunkers, while "Licata" (C14) comprises four bunkers.

Fig. 12: Stronghold "Licata" (photo by the authors, 2024)

Fig. 13: Stronghold "Licata", bunker no.26, not accessible because inside a private property (shot with drone, 2022)

Both were strategically positioned to cover the inland routes and coastal access points.

The firing apertures in both strongholds C13 and C14 exhibit angles ranging between 40° and 60°, with their armament consisting of machine guns, heavy machine guns, and anti-tank guns (Tab.1, Figs. 12–13).

This combination of firepower and positioning underscores the strategic importance of these strongholds in the broader defensive network of the area.

Tab. 1: Weapons in bunkers 13-14

Stronghold	Bunker	Weapon
Taormina C13	27	1 anti-tank gun
	28	3 heavy machine guns
	29	1 Machine gun open position (360-degree defensive coverage)
	30	2 heavy machine guns 1 light machine gun
	31	1 anti-tank gun 1 heavy machine guns
Licata C14	23	1 machine gun (shoot from two slits)
	24	2 machine guns
	25	1 anti-tank gun, 2 heavy machine guns
	26	1 anti-tank gun, 2 heavy machine guns, 1 light machine gun

3.3 A GIS Application for In-Depth Knowledge of the Defence Project

The interpretation of historical maps, field verification, and the survey of individual bunkers and their surrounding landscape form the foundation for the creation of a geodatabase.

This database is instrumental in evaluating information derived from both historical cartography and recent territorial imagery.

The development of a dedicated Geographic Information System (GIS) enables the overlay of maps, facilitating the analysis of diachronic landscape transformations.

For instance, within the surveyed area, Simbirizzi Lake has undergone significant changes in its extent over the course of the 20th century, resulting in the submersion of several historical routes.

The environment for scientific investigation was developed using the open-source QGIS desktop application, which allows for the visualization, organization, analysis, and representation of spatial data. The cartographic base includes:

- DBGT_10K_22_V04 (Geo-topographic database at a 1:10.000 scale provided by the Autonomous Region of Sardinia, Landscape and urban planning service), which includes geographic entities related to infrastructure, hydrography, topography, vegetation, utility networks, and administrative boundaries.
- Italian IGM cartography at scales of 1:25.000 (1990s) and 1:100.000 (1960).
- Historical orthophotos from 1954 and 1968 and recent orthophotos from 2022, made available by the Autonomous Region of Sardinia (RAS) through WMS services.
- A Digital Terrain Model (DTM) with surfaces, buildings, and vegetation (DSM) based on LIDAR data from 2008, with a 1-meter resolution.

The IGM cartography used by the Italian Military Engineers to represent the defense project is at a 1:25.000 scale.

This necessitates an interpretation phase to correlate the historical symbols drawn by military technicians with the digital cartography provided by the Autonomous Region of Sardinia.

Despite its lower level of detail compared to the RAS cartography (1:10.000 scale), the IGM map provides continuous descriptions of geographical data (e.g., contour lines and hydrographic networks) and human interventions (e.g., road networks and built environments), which are crucial for reconstructing the historical military landscape.

Overlaying the IGM map onto the recent 1:10.000 scale cartography allowed for precise identification and redrawing of the historical boundaries of Simbirizzi Lake, as well as the hydrographic network and historical roads, some of which have disappeared due to urban development (Fig. 14).

The subsequent phase involves determining the geographical location of each bunker, including its altitude, firing angles (azimuth coordinates), and the maximum range of the artillery.

These data are essential for assessing the defensive coverage provided by individual bunkers and, collectively, by one or more strongholds.

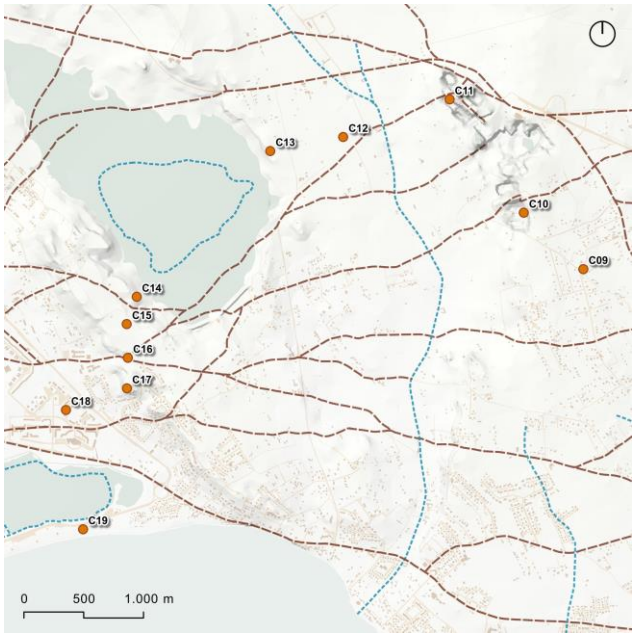

Fig. 14: Location of the historical strongholds on DBGT 2022 basis: the shading made from the DTM allows to highlight the morphological characteristics of the place (graphic elaboration by the authors)

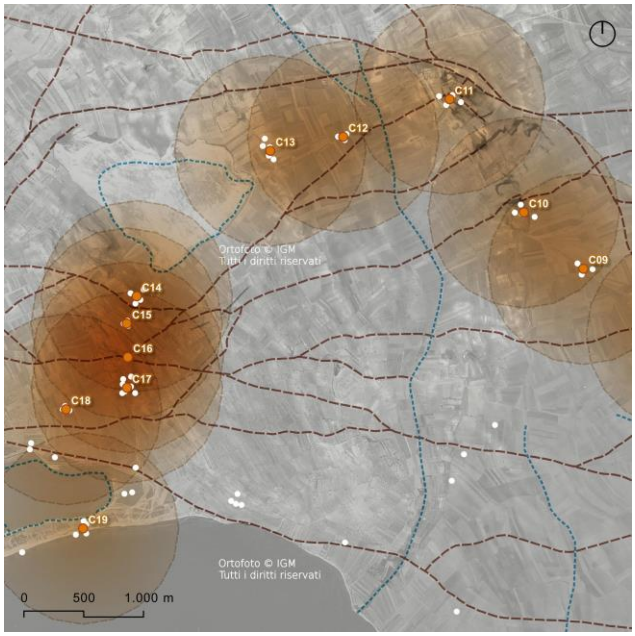

Fig. 15: Aerial based 800-metre buffer zones (light machine gun range) around the outposts showing overlapping of covered areas (graphic elaboration by the authors)

The maps produced, primarily in raster format, serve as the basis for further analysis and graphical synthesis. An initial result is shown in Figure 14, where the overlay of the 1942 IGM map onto a 1994 base map illustrates the expansion of Simbirizzi Lake and the resulting proximity of strongholds C13 and C14 to the lake's shore, as

well as the loss of three historical routes connecting the inland areas to Quartu Sant'Elena.

Figures 15, 16, and 17 provide two-dimensional representations that incorporate the site's morphology and the altitudinal positions of individual bunkers. These representations demonstrate the territorial control capacity of the defensive network and confirm the absence of significant natural or anthropogenic obstacles that would obstruct visibility.

Figure 15 specifically illustrates how the positioning of strongholds C13 and C14 was determined based on the effective range of the assigned weaponry. Heavy machine guns, with a useful range of 1.500 meters, were used for close-range defense, while anti-tank guns, capable of controlling sectors up to 7.000 meters, provided effective coverage against mobile targets within a range of 1.000 to 2.000 meters.

Within the QGIS workspace, it is possible to define visual basins from specific observation points, allowing for the calculation of the effective defensive coverage of individual weapons and their comparison with other armaments.

This analysis reveals that each weapon is designed with a distinct range, enabling comprehensive territorial control through an assessment comparable to the scenic perception of the contemporary landscape, including foreground, middle ground, and background views (Cassatella et al., 2013).

Further graphical elaborations, such as environmental sections, axonometric views and bird's-eye view derived from the DTM (Fig. 18), enhance the description of the defense project.

The GIS environment also supports a three-dimensional interpretation of the site by overlaying the geodatabase onto the Digital Terrain Model (DTM) and the Digital Surface Model (DSM), incorporating buildings and vegetation with 1-meter resolution LIDAR data from 2008.

The QGIS plugin Qgis2threejs (3D visualization powered by WebGL technology and the Three.js JavaScript library, developed by Minoru Akagi) facilitates the 3D visualization of the DSM-DTM, which can be enhanced with orthophotos, cartography, and geodatabase layers, creating an immersive scenario for site analysis.

This GIS environment also enables the verification of the effective range of the weapons, which, until now, had only been theoretically assessed.

The plugin Visibility Analysis (developed by Zoran Čučković) calculates visibility surfaces based on digital elevation models, providing a precise evaluation of the visible area from designated observation points.

The data regarding firing angles and ranges for the weapons housed within the C14 stronghold are integrated into the information system, generating a raster image that visualizes the actual visual cones of the defensive positions.

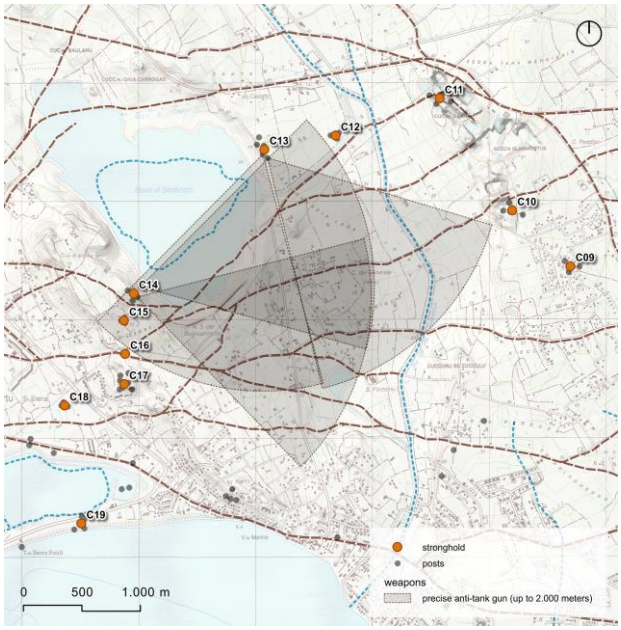

Fig. 16: Base 1994 defensive coverage by precise anti-tunk guns of C13 and C14 weapons

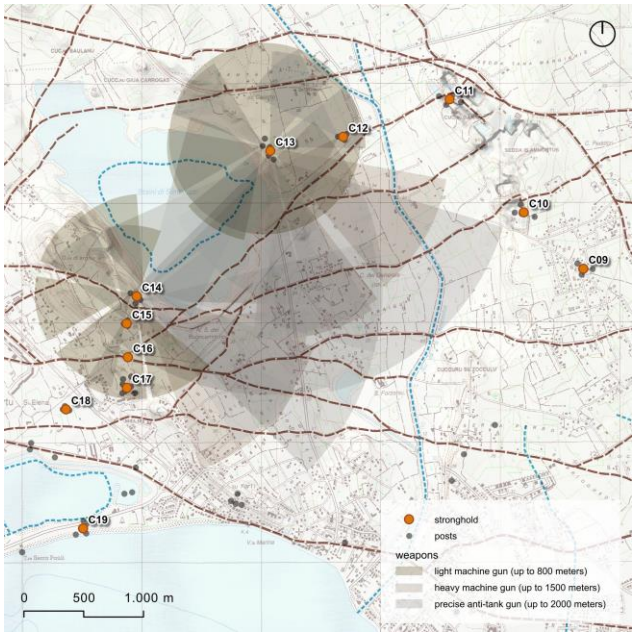

Fig. 17: Base 1994, total defensive coverage of C13 and C14 stronghold (graphic elaboration by the authors)

Fig. 18: "Hybrid" representation obtained through a re-drawing of the 3d model for the visualization of the historical military landscape of the containment arch of Quartu Sant'Elena (images by the authors 2024)

This methodology confirms and refines the assessments made by military engineers during the design phase, ensuring that the strongholds provided effective territorial control and optimized visibility across the landscape.

4. Conclusions

The application of digital technologies and spatial information systems has significantly enhanced our understanding of the containment arc of Quartu Sant'Elena, a critical component of the defense network designed by the Italian Military Engineers during the Second World War.

This study highlights that the spatial arrangement and orientation of each individual bunker were not random, but rather the result of a carefully planned strategy aimed at maximizing territorial control (Fig. 19) and optimizing the allocation of resources.

The research demonstrates that these sites were strategically designed to provide 360-degree coverage, with a clear distinction in the deployment of weaponry (Fig. 20):

- Heavy artillery was concentrated along the southern coastal sector, anticipating the primary threat of an Allied landing. Cannons and heavy machine guns were oriented towards the sea and the main communication routes to safeguard these critical access points.
- In contrast, the inland areas, considered less vulnerable, were defended by light machine guns, sufficient to protect the rear and prevent infiltration from the hinterland.

This precise organization underscores the fact that the orientation and positioning of each bunker were fundamentally determined by the perceived level of threat and the strategic value of the terrain.

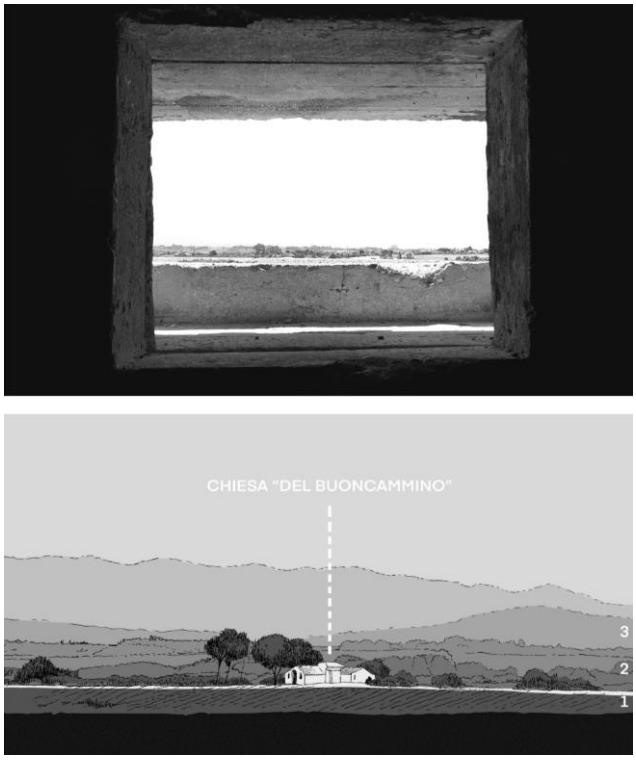

Fig. 19: Photo and drawing synthesis of the view plans from the anti-tank loophole from bunker 25 towards the Buoncammino church (images by the authors 2024)

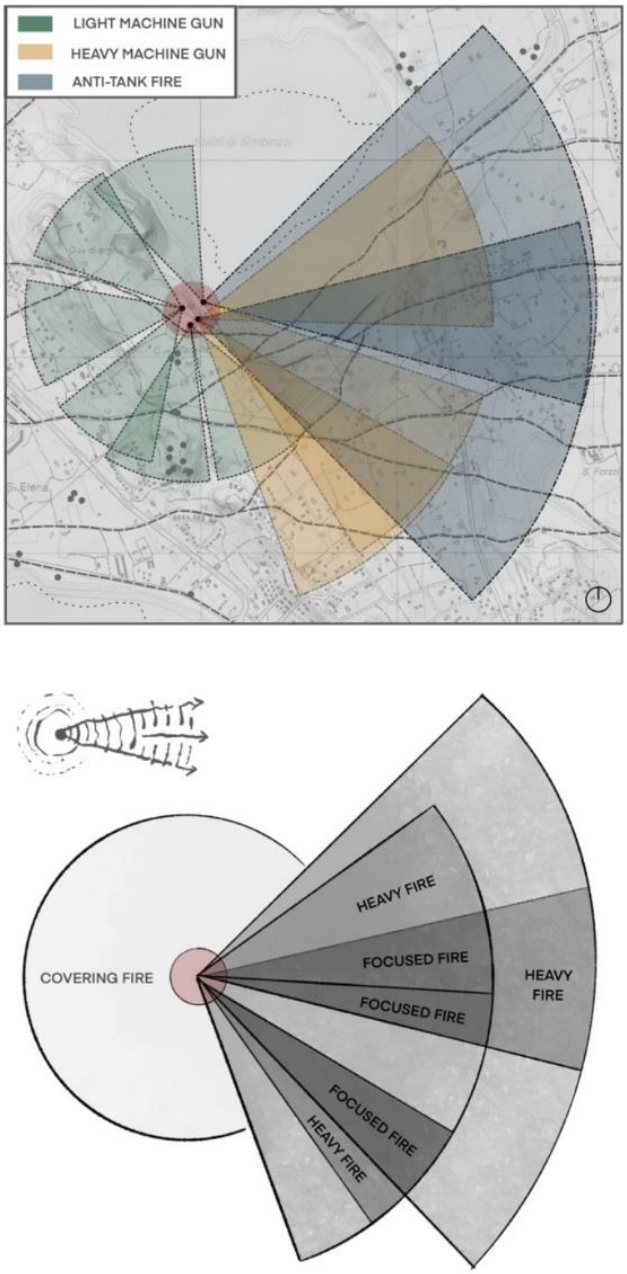

Fig. 20: Images showing the angles of fire of Checkpoint 14 with three types of fire coverage

The Taormina and Licata strongholds exemplify this defensive logic, demonstrating a complementary synergy. By overlapping their fields of fire, these positions provided redundant coverage in specific critical sectors, reinforcing the overall defense system and minimizing potential vulnerabilities. The analysis of the 800-meter buffer zone around each stronghold revealed a continuous defensive coverage across the entire study area, effectively preventing unauthorized crossings of the defensive perimeter.

This configuration is particularly evident in the segment of the containment arc between strongholds 13 and 14, which represents the widest distance between two consecutive positions within the network (Figs. 21, 22).

Despite this distance, the overlapping fields of fire ensured continuous territorial control.

Additionally, the Licata stronghold, located along the ridge of Pitz'e Serra Hill, was specifically positioned to reinforce protection in a sector considered particularly exposed (Figs. 23,24).

While this configuration rendered the area highly secure against infantry infiltration and light vehicular access, it remained potentially vulnerable to heavy armored vehicles or aerial bombardments, reflecting the inherent limitations of the fortifications.

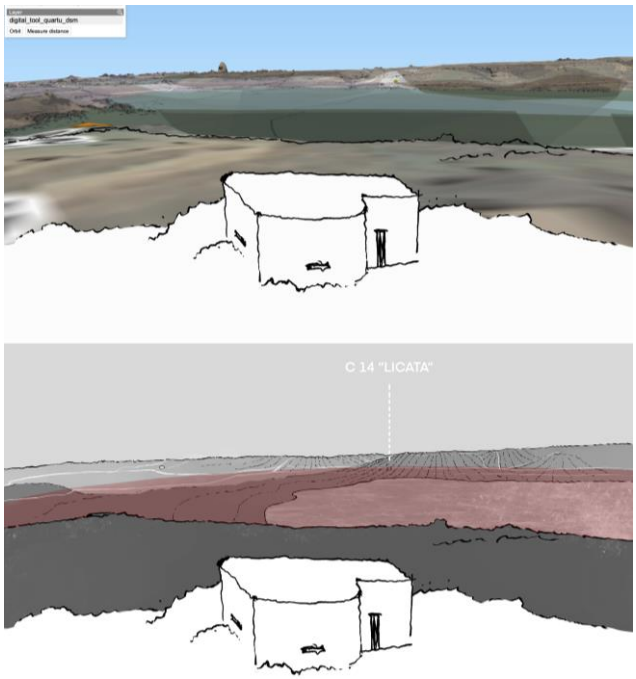

Fig. 21: Graphic elaboration based on DTM showing the coverage offered by the stronghold C13 towards the stronghold C14 (drawings by the authors)

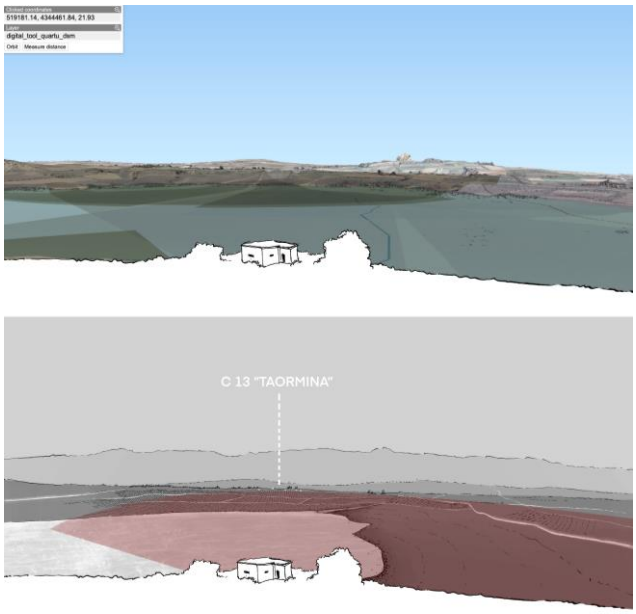

Fig. 22: Reworking based on DTM showing the coverage offered by the stronghold C14 Licata towards the stronghold C13 Taormina (drawings by the authors)

This type of investigation is essential for understanding the design logic of these fortifications.

The spatial and functional configuration of each bunker, including its orientation and interaction with adjacent positions, is a direct result of the strategic considerations analyzed in this study.

Without such an analysis, the defensive rationale behind the positioning of these structures would remain incomplete.

	ID	observ_hgt	radius	azim_1	azim_2
1	30a	2,0000	800,00	1,00000	41,00000
2	23a	2,0000	800,00	130,00000	170,00000
3	29a	2,0000	800,00	0	360,00000
4	28a	2,0000	800,00	191,00000	231,00000
5	24b	2,0000	800,00	243,00000	283,00000
6	32a	2,0000	800,00	204,00000	244,00000
7	28b	2,0000	800,00	240,00000	280,00000
8	28c	2,0000	800,00	290,00000	330,00000
9	30b	2,0000	800,00	51,00000	91,00000
10	23b	2,0000	800,00	173,00000	213,00000
11	24a	2,0000	800,00	187,00000	227,00000
12	24c	2,0000	800,00	299,00000	339,00000
13	26a	2,0000	800,00	316,00000	356,00000
14	21	2,0000	800,00	306,00000	346,00000
15	21b	2,0000	800,00	340,00000	20,00000

Fig. 23: Viewpoints configuration in GIS attribute table. These results were written with standardised field names and to reprojected match the elevation model used

The methodology employed combining historical cartography, field surveys, and GIS-based visibility analyses provides a comprehensive framework for evaluating military architecture in its spatial and strategic context. This interdisciplinary approach not only enhances our understanding of the defensive systems in the territory of Sardinia but also offers a replicable model for studying similar fortifications in other regions.

The insights gained from this study can inform conservation strategies and heritage management plans, contributing to the preservation and potential musealization of these defensive structures.

This, in turn, would enhance their cultural and historical value, making them accessible to future generations as a testament to Sardinia's military history.

Ultimately, this study not only sheds light on the strategic coherence and territorial efficiency of Sardinia's military defenses but also establishes a robust framework for future interdisciplinary research aimed at preserving and interpreting the island's rich military heritage (Fig.25) in a international context.

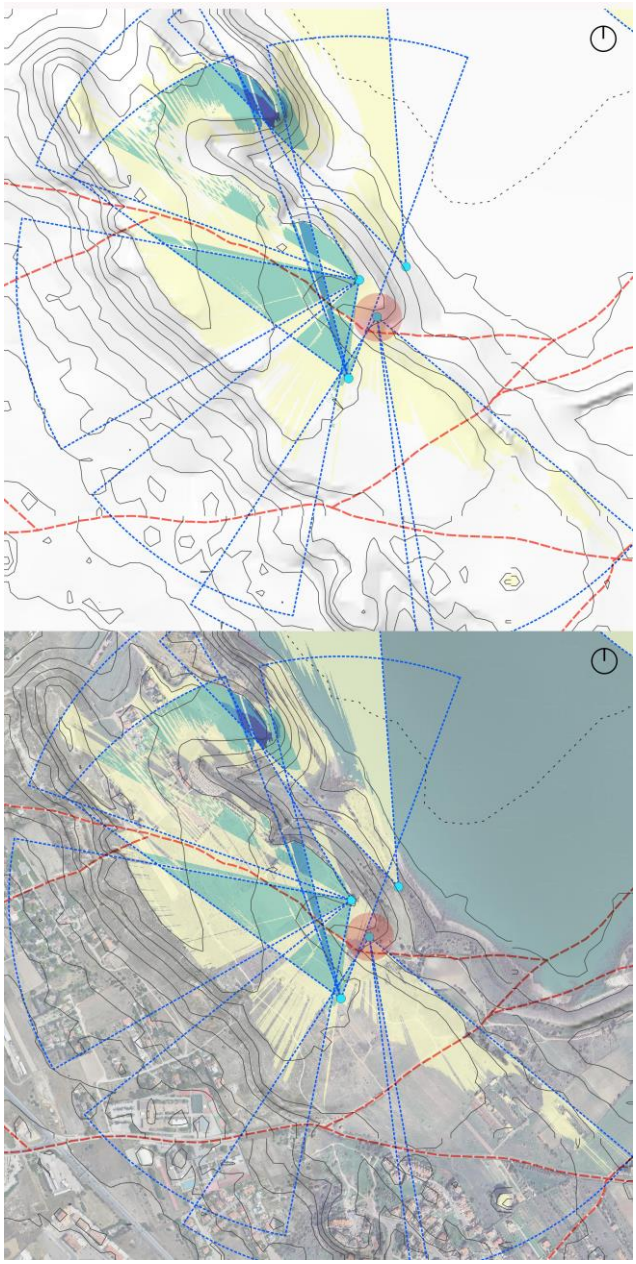

Fig. 24: Visibility defensive cover analysis offered by the Licata base's machine-guns; yellow parts represent the territory covered by a weapon, the green by two weapons, the blue by three weapons (two different representation)

Fig. 25: Collage of photographs documenting Bunker No. 25, part of the Licata stronghold. From top to bottom, the images show: a panoramic view of the Simbirizzi Lake landscape from the roof of position No. 25; the three embrasures, respectively for a heavy machine gun, an anti-tank gun, and a heavy machine gun; and finally, an external view of the fortified position highlighting its location on the hill adjacent to the lagoon (photos by the authors 2024)

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