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Gjergji ISLAMI, Denada VEIZAJ (Eds.)

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Editors
Gjergji Islami, Denada Veizaj
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Virtual reconstruction of destroyed fortifications: the case study of Santa Caterina in Verona

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Abstract

Military fortifications have always played a key role in territorial defense. Their location and visibility often depended on strategic military choices, such as shape. The geometric development of the latter is the result of centuries of refinement of construction techniques concerning the evolution of warfare, the architectural consistency of the fortified area, and adaptation to the orography of the territory. A final common aspect is their history, often marked by transformations that have determined the architecture's level of preservation and use. These architectures can be perfectly preserved, destroyed, or fallen into disuse. Of the latter, many examples are scattered throughout the territories, a fascinating constellation of vestiges that have lost their visibility and importance. The instruments of surveying, drawing, and representation can support the virtual rediscovery of the ancient role of architecture. This research project focuses on the Fort of Santa Caterina in Verona. Originally called Werk Hess, it is a fortification located south of Verona and built between 1848 and 1856. Only a few small traces remain today, but the Fort of Santa Caterina was an architecture of remarkable beauty because of its naturalistic and environmental inclusion, an architectural and perspective cornerstone of the fortified city due to its dominant position. Through a comprehensive course of source analysis, the survey of the existing territory, and representation in plan and space, the research project aims to give a virtual shape to this military marvel, laying the groundwork for more complex multi-disciplinary analyses of the artifact and the surrounding area.

Keywords: 3D survey, virtual reconstructions, geometric analysis, destroyed fortifications.

1. Introduction

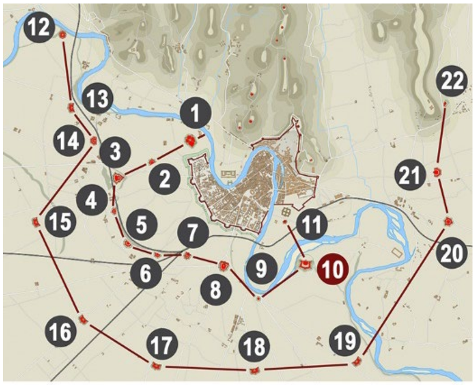
The study of fortifications that no longer exist is fascinating. The subject's attractiveness lies in understanding the logic behind the construction (geometric rules, materials, masonry techniques) and their relationship with the territory. Such knowledge is only sometimes easy to achieve due to lacking sources (Russo et al., 2023). Collecting reliable information can help read and interpret palimpsests, even if they have partially or entirely disappeared, losing any trace of pre-existence (Tytarenko et al., 2023). It is possible to regenerate a relation between the existing and the sources, investigating the divergences between the project and the built (Kowalski et al., 2023) and arriving at interpretative conclusions. The case study in this article concerns the Fort of Santa Caterina in Verona. The typology of the Fort, its historical role, and the traces on the territory defined the cultural research stimuli. The study aims to apply a multi-scale integrated survey technique (Guidi et al., 2009) to collect comparative data, opening critical analysis towards a virtual interpretation of its ancient form.

2. The fortified system of Verona

The area under study in the 19th century was under Habsburg rule. When the Italian State was created in 1861, the border between Italy and Austria excluded Trentino and Veneto, including Verona (Fig. 1).

Fig. 1- Map of Austrian territories as of 1835 (Hall, 1849) with quadrilateral fortresses

Within this framework, Verona was part of the Austrian Quadrilateral, a fundamental defense system built between 1815 and 1866 (Frasca, 1998). In 1833, the Austrian Empire decreed the restoration of the fortifications of Verona and the Mincio line. At that time, Franz von Scholl (1772-1838), an Austrian fortifications engineer, was already in Verona as director of the Imperial Royal Office of Fortifications. He was, therefore, entrusted with the construction of the works around Verona, working until he died in 1838. Upon von Scholl's death, the implementation of his defense plan was halted. It was later resumed between 1848 and 1859 when an entrenched camp was established, along with the construction of 12 new forts. These forts were strategically positioned approximately 1 km apart from each other and at a distance of 1 to 2.4 km from the bastion front (Fig. 2). The forts were initially named after commanders or to honor high-ranking personalities since 1866, when they adopted the name of the surrounding villages. The fortifications were generally trapezoidal, consisting of a perimeter rampart bordered by a moat and a 'Carnot-style' wall with rifle positions (Fig. 3). Inside them was a central masonry redoubt with bomb-proof rooms protected by embankments up to 2.5 meters thick. Today, Verona's urban wall is more than 9 kilometres long (Conforti Calcagni, 2008), and it was included in the UNESCO World Heritage List in 2000.



1. Forte San Procolo
2. Forte Spianata
3. Forte San Zeno
4. Forte San Massimo
5. Forte Fenilone
6. Forte Santa Lucia
7. Forte Palio
8. Forte Porta Nuova
9. Torre Tombetta
10. Forte Santa Caterina
11. Forte Gazometro
12. Forte Parona
13. Forte Chievo
14. Forte Croce Bianca
15. Forte Lugagnano
16. Forte Dossobuono
17. Forte Azzano
18. Forte Tomba
19. Forte Cà Vecchia
20. Forte San Michele
21. Forte Cà Bellina
22. Forte Preara

Fig. 2- Verona's fortified system in 1866

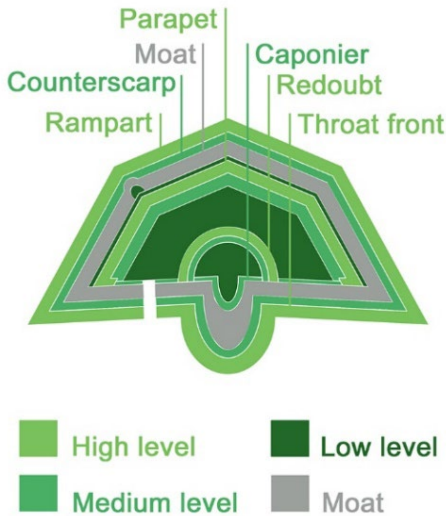


Fig. 3- Typical polygonal fortification scheme used by the Austrians

The remains of the Fort of St. Caterina represent the barely visible trace in the territory of one of the most critical fortifications belonging to the first line of the Austrian Quadrilateral system (Fig. 1).

3. Santa Caterina case study

The Santa Caterina Fort was the most complex and magnificent of many buildings in the famous Habsburg Quadrilateral. Located near the riverbank of the Adige, it concluded the first entrenched camp to the east (Fig. 4). It formed a system on the right, with Fort Porta Nuova and the Tombetta Tower, on the left bank with Fort San Michele. However, it was predominantly conceived as a self-sufficient stronghold in a dominant position on the edge (Rideau) of Santa Caterina (Jacobacci, 1980).

From Franz von Scholl's complex plan, drawn up in the years 1834-1838, Johann von Hlavaty derived the more economical one, summarizing in a single large fort all the functional tasks (Fig. 4). Hlavaty's design was then realized in the years 1850-1852, under the direction of Conrad Petrasch (Fig. 5). The primary function of the Fort was the indirect defense of the Santa Lucia-San Massimo ridge. Its architecture epitomizes von Scholl's fortification technique and art. In the parts still preserved, the quality of the stone cutting stands out, with opus polygonal tufa facings. Its initial name derives from the chapel dedicated to the Sienese saint. The Fort was later officially named after Baron Heinrich von Hess (1788-1870), artillery general and Chief of Staff in Radetzky's army. It was armed with 33 artillery pieces in wartime, stocked with 58,000 kg of gunpowder reserves, and could accommodate 660 soldiers.

Fort Santa Caterina was a complex machine, carefully studied in its tactical aspect, built with majestic architectural forms. Overall, the Fort's layout responded to the criterion of compartmentalization of the work in isolable sectors for security and progressive defense. The Fort was divided internally into four parts, separated by dry security ditches (diamond ditches). The Fort was accessed through four rusticated, arched portals with a drawbridge framed in the northern *ridotto* (Fig. 6).

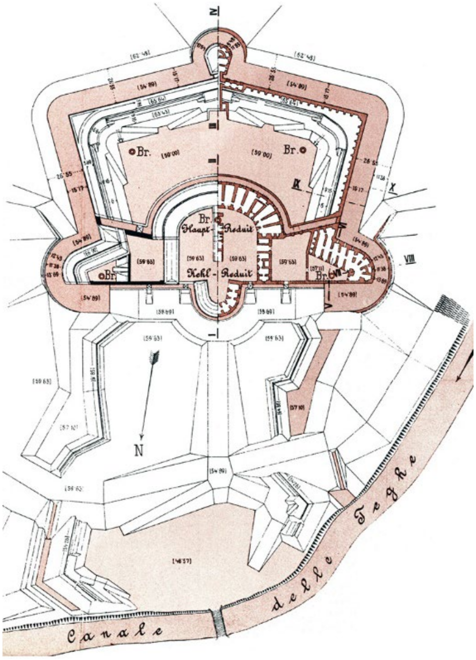


Fig. 4- Drawing of the Fort of Santa Caterina (Jacobacci, 1980)

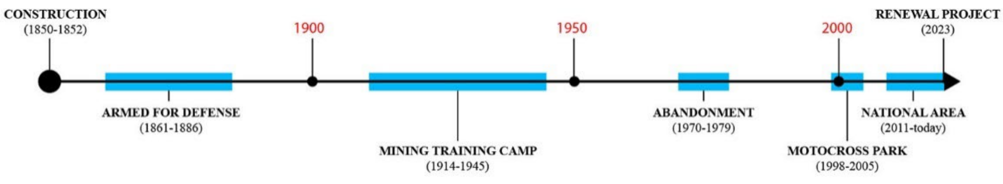


Fig. 5- Historical pipeline of the Fort main transformations

Fig. 6- Historical photo by Moritz Lotze (Lotze et al., 1996)

In the inter-war period, still used by the army, the Fort was used as a training camp for miners. Thus, with repeated mine operations, the Fort was partially dismantled. It also suffered severe damage from the explosion of an ammunition depot at the end of World War II. When the military use of the fortified structure ceased, after a period of abandonment, in the 1970s, the Fort was used as a motocross track. It resulted in further damage and tampering. The Fort was then wholly abandoned, becoming prey to vandalism, damage, and spontaneous vegetation encroachment. Since 2011, it has been under the concession of the *Cooperativa Sociale* "I Forti," which initiated renovation work to return the Fort and its appurtenances to public use for cultural and leisure activities.

4. The actual building

Very little of the Fort's original architecture is preserved. Part of the southern *ridotto* (1/3), its wings connecting to the northern *ridotto*, part of the artillery rampart, part of the *poterna,* and the *caponiera* have been demolished.

Fig. 7- Drone photos of the northern *ridotto*

The outer entrenchment was also completely levelled following the rectification of the course of the Adige River (late 19th century). The rest of the area is in a semi-abandonment state. Only the northern *ridotto* is now occasionally used as an exhibition space (Fig. 7). A master plan for the area's redevelopment, financed by the EU was presented in 2023. In this context, the site survey was developed to define the basis for a better investigation of the Fort's shape and relationship with the surrounding area, leading to the hypothesis of a virtual reconstruction.

5 Methodology

For the study of the area, the integrated methodology between active and passive sensors was applied, employing a GNSS system, ground-based and drone photogrammetric techniques, and terrestrial 3D laser scanners (Ramos & Remondino, 2015; Bercigli & Bertocci, 2017). Hence, we moved to 2D and 3D representations, considering interpretative tolerances in developing drawings and the model. Finally, these products served for the critical analysis of the system (Caroti et al., 2021), enriching the current knowledge on the Fort (Valenti & Paternò, 2021).

5.1. Data acquisition

The surveyed area is approximately 230000 m^2, consisting of the former Barracks buildings, the infrastructure, the monumental complex of Fort St. Caterina, and wooded areas.

The first step was to frame the survey in the technical cartography of the Veneto Region. The planimetric coordinates of the control points were determined in the UTM ETRF 2000 national cartographic system, while the elevations referred to the National Altimetric Datum. This survey approach aimed to produce a 1:500 scale map, considering that the maximum linear expansion in the Verona city area by the UTM map representation is about 0.3 per 1000. A total of 22 GNSS vertices were permanently materialised and surveyed with high precision (Topcon GR5 receiver in static mode), defining the framing network with a total error (RMSE) of 0.034 m. It was followed by defining a secondary system of vertices, surveyed in GNSS NRTK mode, and defining a GCPs reference for the active and passive data acquisition phases.

The passive and active techniques were applied in a shared locale reference system. The RPAS survey method used a DJI Mavic mini 2 drone equipped with an FC7303 camera (4000 x 3000 pixels, 4.49 focal length, 1.62-micron pixel size). Numerous additional targets were temporarily positioned and surveyed for each flight. The 4 flight plans were designed to ensure adequate longitudinal and transverse coverage of the images, dividing the area into four parts and acquiring approximately 1180 images at an altitude of 57 meters, with a GSD of 2 cm (Fig. 8). In this phase, only those artefacts that were not covered by vegetation were acquired, while for the wooded areas only the perimeter was determined.

Fig. 8- Photogrammetric acquisition schema of the whole area

The architectural survey focused on the northern part of the *ridotto*, integrating a 3D laser scanner (RTC360, Leica) and UAV photogrammetry to acquire the Fort's exterior and interior correctly. Given the complex geometry of the monument, 67 scans were taken from the ground along the perimeter and inside the rooms to cover all surfaces except the roof (Fig. 9).

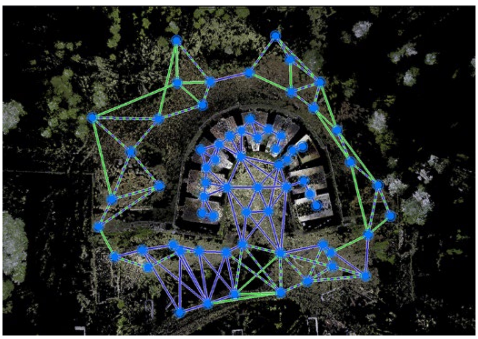


Fig. 9- Ground scanning network

The roof was acquired by integrating RPAS flight in manual mode at low altitude (Mean Dist. 20 mt, GSD 6 mm). Finally, a photogrammetric campaign was completed from the ground with a DSC-HX60 camera (Sony), a focal length of 4.3 mm, 5184 x 3888 pixels. The high data density produced acquired information helpful for documenting the state of deterioration of the building. During the active and passive architectural survey, several common GCPs were recorded, allowing all data to be framed in the same local reference system.

5.2. Data integration and analysis

At a territorial scale, the extraction of the point cloud made it possible, first of all, to construct the DTM (Fig. 12) and the orthoimage of the area (Fig. 10). The morphology of the terrain is substantially flat, except for some slight undulations and the embankment and ditch to the south of the Fortress, evident traces of the barrier of the fortification. The orthophoto map shows the altimetry of the terrain with contour lines with a variation of 1 meter, indispensable for producing the 1:500 scale representation of the area.

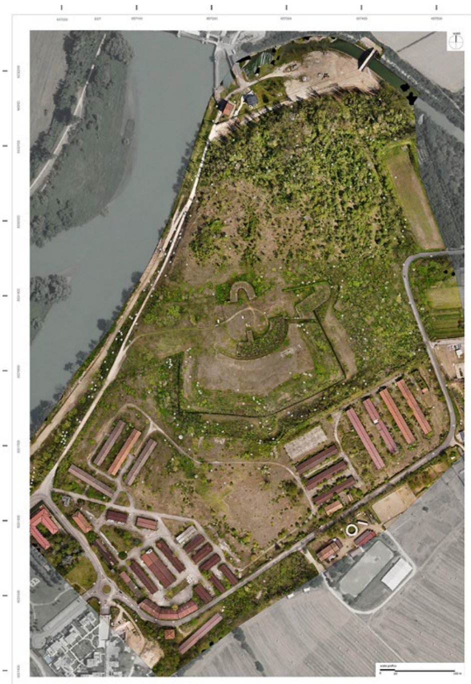


Fig. 10- Orthophotos of the area with contour lines

At the architectural scale, the point clouds were pre-aligned automatically using the VIS system and then roto-translated in the common reference system, with an overall error of 7 mm in the orientation of the point clouds.

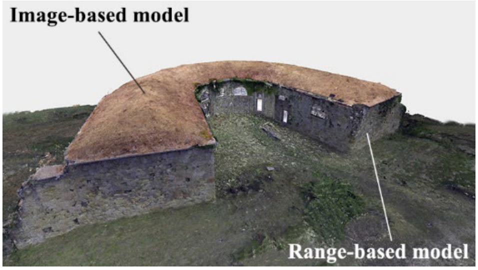


Fig. 11- Integrated 3D point cloud

From the photogrammetric flight, a dense point cloud of the northern ridotto was obtained in the same TLS reference system to get an integrated and complete model (Fig. 11). The photographs from the ground, combined with those from a drone, were used to draw up ortho-images of the fronts and the development of the two north and south fronts of the ridotto (Fig. 13). The maximum errors on check points and control points did not exceed 5 cm.

Some initial analyses were conducted starting from the survey data, comparing the existing shape with the sources. The wire perimeter of the historical plan (Fig. 4) was superimposed on the orthoimage, highlighting discrepancies between the existing plan and the designed one. The plan of the Fort's shape was interpreted, preserving the geometry of the traces found in the area (Fig. 12).

The superimposition of the two plans shows some minor differences in proportions and symmetries. This step was validated by superimposing the interpreted shape on the DTM to verify the correlations between the terrain conformation and the hypothesized shape (Fig. 12).

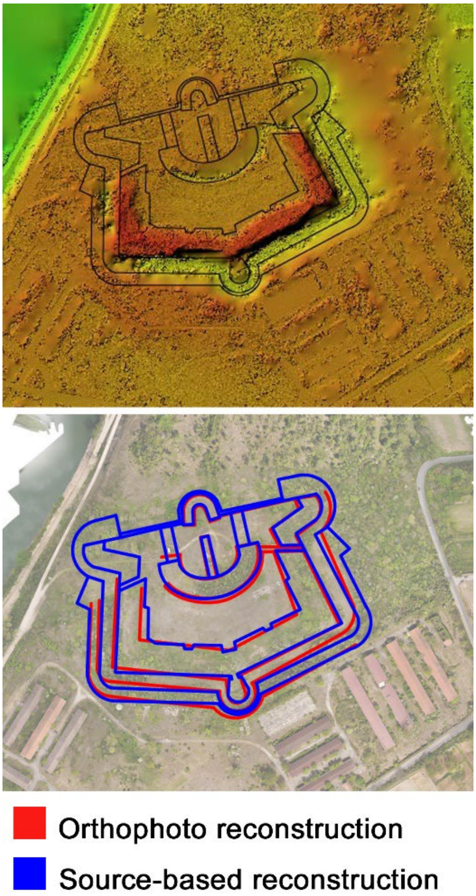


Fig. 12- Above the interpreted geometry on the DTM, below the superimposition of the theoretical and actual geometry on the orthoimage.

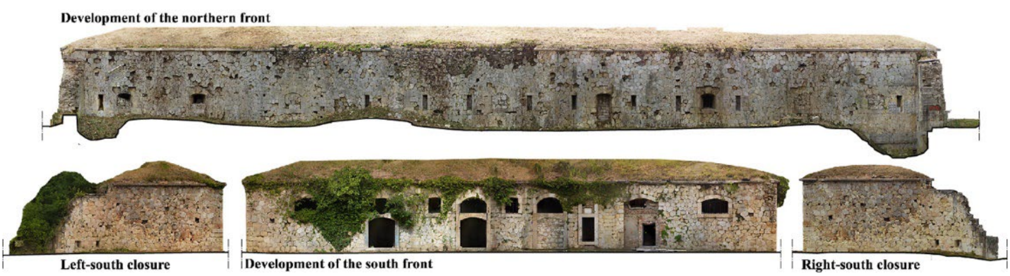


Fig. 13- Orthoimages of the main facades of the Fort

5.3. Data modeling and communication

Extracting vertical and horizontal sections from the integrated 3D point cloud made it possible to reconstruct the 2D plan and elevation. The 3D geometry is aimed at identifying the original shape of the building through a regularization process that preserves a centimeter tolerance with the reality-based model. The principal vertical planes were identified by employing fitting operations on portions of the point cloud. The center of the bundle of planes, defining the radial distribution of the masonry, was geometrically determined (Fig. 14). Based on these constraints, the model was reconstructed. This approach confirmed the construction of a dodecagon, with a constant angular opening of 30.5 degrees, which defines the structural pitch.

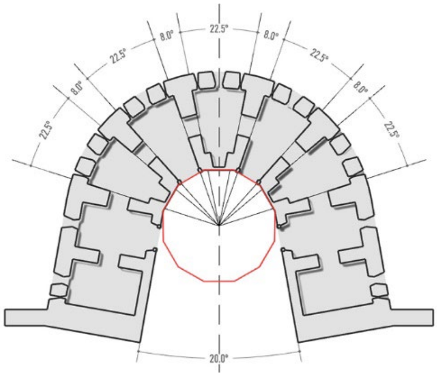


Fig. 14- Geometrical analysis of the plan

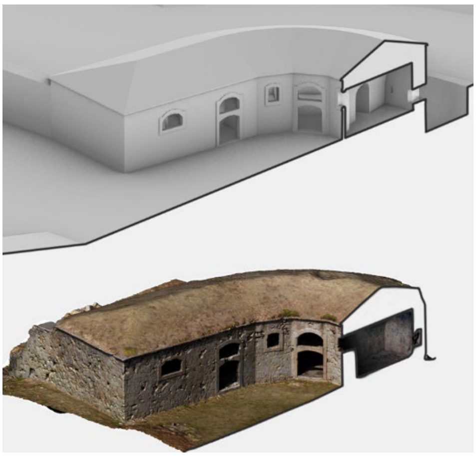


Fig. 15- Vertical axonometric section of the virtual and reality-based model

In reconstructing the interior spaces, this methodology has also led to accurate results in the restitution of the internal barrel vaults, which have a horizontal ridge line, a set plane inclined 11 degrees to the ground, and a variable radius (Fig. 15). Following this approach, an initial volumetric model of the Fortress was defined based on the additional portions surveyed and the information extracted from the sources. In the reconstruction process adopted so far, the virtual model's reliability level was verified by comparing the reconstructed model with the surveyed model. It resulted in a reconstructive tolerance of a few centimeters (Fig. 16).

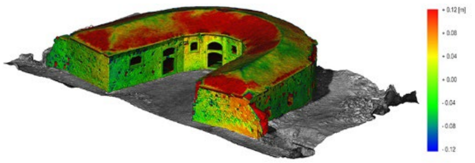


Fig. 16- Metrical comparison between the reality-based model and the virtual reconstruction

6. Conclusions

The research proposed here illustrates a survey and representation of one of the most important Austrian forts in the Austrian quadrangle. Its trace in the territory has now been lost. The redesigning of the area has provided new stimuli for the in-depth survey and the analysis of the territory. The aim was to collect heterogeneous data, which can lead to rediscovering the historical shape and the relationship with its environment. The methodology is based on the critical comparison between different sources and the re-proposition of some original geometries and volumes. This research defines a functional basis for communicating the site and supporting a subsequent investigation and design phase. The ongoing research is focused on refining the virtual model of the Fortress (Fig. 17), analyzing the wall facings and the details of the construction techniques.

Notes

(1) The authors' research results from joint and integrated work. In writing the article, M.R. was responsible for paragraphs 1, 3, and 4, G.F. edited paragraphs 2 and 5.2, A.B. paragraphs 5.3, and V.R. paragraphs 5 and 5.1.

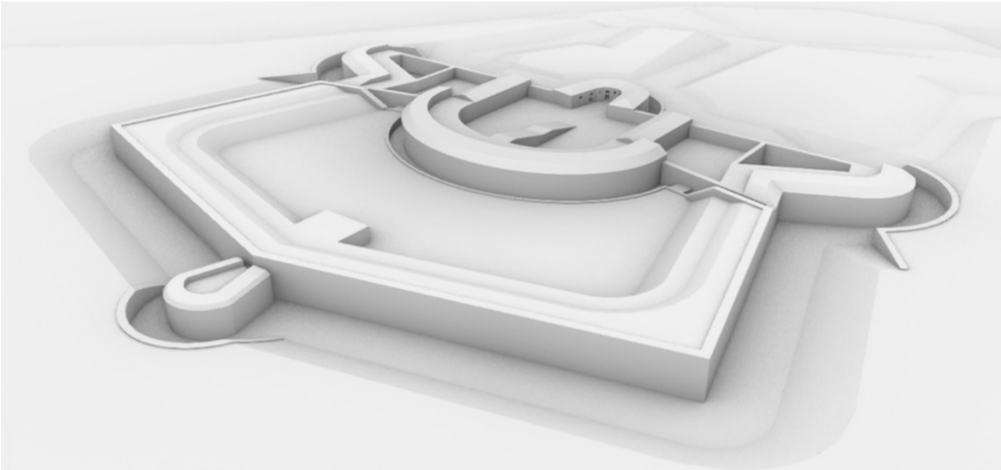


Fig. 17- Volumetric 3D model of Fort of Santa Caterina

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