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Marco Giorgio BEVILACQUA, Denise ULIVIERI (Eds.)

DEFENSIVE ARCHITECTURE OF THE MEDITERRANEAN

Vol. XV

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Marco Giorgio Bevilacqua, Denise Ulivieri
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Mannu tower (Central-western Sardinia, Italy): from petrographic, geomorphological investigations and digital survey to intervention proposal

Stefano Columbu[a], Rita Teresa Melis[b], Paolo E. Orrù[c], Valentino Demurtas[d], Dario Fancello[e], Giorgio Verdiani[f], Giacomo Deiana[g]

[a] Department of chemical and geological sciences, University of Cagliari, Cittadella universitaria di Monserrato, Cagliari, Italy, columbus@unica.it, [b] Department of chemical and geological sciences, University of Cagliari, Cittadella universitaria di Monserrato, Cagliari, Italy, [c] Department of chemical and geological sciences, University of Cagliari, Cittadella universitaria di Monserrato, Cagliari, Italy, [d] Department of chemical and geological sciences, University of Cagliari, Cittadella universitaria di Monserrato, Cagliari, Italy, [e] Department of chemical and geological sciences, University of Cagliari, Cittadella universitaria di Monserrato, Cagliari, Italy, [f] Department of Architecture, University of Florence, Florence, Italy, giorgio.verdiani@unifi.it, [g] Department of chemical and geological sciences, University of Cagliari, Cittadella universitaria di Monserrato, Cagliari, Italy

Abstract

The Capo Mannu tower rests on a cliff edge in the central-western coast of Sardinia (Italy). It is placed on a 50-60 metres-thick aeolian sequence of Plio-Pleistocene age (Capo Mannu Fm.), that lies above Miocene to Lower Pliocene marine sediments (mainly limestones, sandstones, marly clays). Archival documents attested the decay state of the tower since 1620: "...les torres de Orfano Puddo, Scala Sal y Cabo Maño del Campidano de la ciutat de Oristany ha necessitat deser reparadas en moltes parts...". Repair interventions were carried out in 1784-1786, and in 1822 by the Towers Administration; the tower was garrisoned until 1846 and then abandoned. The decay of the building materials and of the tower structure is mainly due to the weathering and to the continuous gravitational collapses, triggered by the wave erosion that also produces the cliff retreat. The aim of research is to define: i) petrographic features and chemical-physical degradation of geomaterials; ii) building decay and geomorphological processes through the elaboration of a digital model of the tower and cliff. It will help to better understand the factors that affect the structure decay, and to refer the building materials to the original shape of the ruined tower. The digital survey will be mainly based on drone/UAV photogrammetry, with integration in 3D laser-scanner survey. In its final stage will try to propose possible interventions of consolidation and conservation in such a complex condition.

Keywords: degradation, chemical-physical processes, conservation, photogrammetry.

1. Introduction

1.1. Historical and architectural aspects

The tower rises 51 m. above sea level on the promontory of *Capu Mannu* (or *Capo Mannu*), in 1572 called *Capo las Salinas*, then later: Monte delle Saline di Oristano (in 1578), *Capitis Magni* (1590), *Cabo Maño* (1620), *Cabo Manno* (1639), *Cabu Mannu* (1729), *Cabidurimannu* (1740).

The tower history (recorded by archive documents) has been summarised and made available online by the Regional Agency of registry of the Sardinian Coasts (1).

In 1572 *Don Marcantonio Camos*, at the behest of Viceroy *Don Juan Coloma*, led an expedition of experts along the coastline of the island, to

Fig. 1- View of the Tower (photo byVerdiani, 2022)

identify the most strategic points for the erection of new coastal towers. He recommended to build the eighteenth tower at *Cabo del Las Salinas*, as an ordinary lookout tower manned by two men, with an internal cistern, which could be built at a total cost of *240 scudi*. The tower is then mentioned in the project for the construction of numerous coastal watchtowers and defence towers prepared by Viceroy *Michele De Moncada* (1578-83), being already under construction.

The *Capo Mannu* tower was built between 1572 and 1580 to protect the salt pans, equipped with an internal cistern, but already in 1521, the Turkish geographer *Piri Reis* had noted in the *Capo Mannu* the presence of an unfortified guard post that arose to defend the Salina beach. The tower was also built to guard the cove of *Su Pallosu,* as certified in 1572 "... the Capo las Salinas can accommodate a good number of galleys, it possesses timber but no water...", and the tuna fishery that was already active in the 16th century. Together with the towers of 'Sa Mora' and 'Scala' e 'Sale', it guarded the whole coastal strip north of Sinis, up to the beach of Is Arenas and the cliffs of Santa Caterina. The tower was in visual contact with the towers of *Sa Mora*, *Scala Sale*, *Saline*, *Su Puttu*, *Pittinuri* and *Capo Nieddu*.

Architecturally, the tower is truncated cone-shaped, and it consisted of a single room with a domed vault (the tower keepers' quarters) accessed through a hatchway located about four metres from the floor. Originally, the tower must have had a diameter at the base of about nine metres, the diameter of the parade ground about eight metres, and a height of about 10 metres. Therefore, it was a "torre de armas" comparable in size to a "senzillas" already active since 1590. The guard service was initially carried out by two soldiers maintained by the city of Oristano, and two horsemen paid by the *corallari* (coral harvesters) of Bosa. In 1584 the tower was in activity (as reported in the map called *Descripcion dela Isla y Reyno de Sardeña* of the 17th century), although Francesco Vico in his Carta gave it in 1639. The first maintenance and restoration works are documented in 1620 and later in 1692 (Regia Amministrazione delle Torri, in ASC). As Sardinia passed under Piedmont rule, in fact, several military engineers were commissioned to carry out a new survey of the island's coastline to point out and better define the state of the existing towers, still in operation or discharged. Among these engineers, the figure of *De Vincenti* undoubtedly stands out, who delivered to the viceroy *Saint Remy* a detailed report on the state of the towers, as well as the expenses required for the maintenance of that defensive system.

Among the 67 towers enumerated by the engineer also appears the tower of *Capo Manno*. A person is put in charge of guarding the district comprised from the *Oristano Tower* to *Scala di Sale*. It is a watchtower between 1720 (so it appears from *Cagnoli's Report*, *De Vincenti's Report*, and Colombino's Map) and 1794, garrisoned by a garrison consisting of one commander and two soldiers, in which 1 artilleryman was included in 1801; it was equipped with two cannons, spingarda and rifles. In 1755 the factory required new maintenance work, at a total expense of five scudi (Royal Secretariat of State and War in ASC). In 1767 the tower was equipped with a cannon to defend the port of Paloso from attack by the Turks (Ripol Report). In 1822 the bricklaying contractors Salvatore Peddis and Antonio Contini received 1250 Sardinian liras from the Administration for their restoration work on the tower.

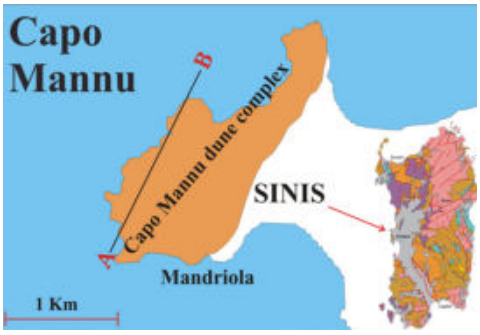

Fig. 2- Sketch map of Sinis sector (Abbazzi et al. 2005, modified). A-B: cross-section shown in detail in Fig. 7

In a Report by an unknown author kept in the Historical Archives of Turin, dated March 20, 1843, it is listed among the 63 towers still manned. In 1842 the tower was still operational in its functions with the presence of an alcalde and two soldiers, armed with two mortars and three rifles with bayonets. The tower was abandoned in 1846.

1.2. Aims of research

The research aims at studying the architectural morphological aspects, belongs to the "sanzillas" category, characterized by a central column in stone material (that supports the vault surmounted by the roof), a truncated conical wall structure.

The construction material features, and their decay processes also are the object of analysis, to know the petrographic and physical characteristics of stones that constitutes the base and the masonry of the tower, as well as all the internal structural elements.

Even the external finishing mortars that appear in several layers, due to different maintenance interventions over time, and the bedding mortars inside the wall, are the aims of this study. In detail the objects of research are: i) petrographic features and chemical-physical degradation of geomaterials; ii) building decay and geomorphological processes through the elaboration of a digital model of the tower and cliff. It will help to better understand the factors that affect the structure decay, and to refer the building materials to the original shape of the ruined tower. The digital survey is mainly based on drone/UAV photogrammetry, and 3D laser-scanner survey. ùIn its final stage there will be a proposal for possible interventions of consolidation and conservation in such a complex condition.

2. Geological setting of sector

The studied sector is located in the northern part of the Sinis Peninsula in west-central Sardinia. Geologically, Sinis is characterized by Cenozoic sedimentary sequences and volcanics of the Plio-Pleistocene magmatic cycle (Fig. 2). The sedimentary rocks are mainly limestones and marls of marine environment grading upward to evaporitic limestones (Messinian). Plio-Pleistocene volcanics are represented by small and elongated basaltic lava-flows. Rare Oligo-Miocene volcanics in the North-East of the region, and granitic rocks of Palaeozoic basement in the *Mal di Ventre* small island are also found. The Pliocene-Pleistocene sequence, where is the *Capo Mannu* Fm., overlies (probably with an erosional unconformity) a Middle Miocene-Messinian sequence resting on the Oligo-Miocene volcanic basement (Fig. 3). The sequence represents a shoreface unit followed by various dune units, locally overlain by Upper Pleistocene beach sandstones and conglomerates refered to the Tyrrhenyan transgression (Marine Isotopic Stage MIS 5e) and continental talus referred to the Marine Isotopic Stages MIS 4-2 (Carboni & Lecca, 1985; Carboni & Lecca, 1995; Lecca & Carboni, 2007). *Capo Mannu* Fm. consists of a calcareous and terrigenous 50m thick sand body, made up of four staked and laterally continuous dune units, overlain by three other dune units of lesser lateral continuity. On the whole, at least nineteen dune subunits can be identified in the aeolian complex (Carboni & Lecca, 1995; Abbazzi et al. 2008) (Fig. 3). Plio-Pleistocenic aeolian deposits diffusely observed along the western coastline of the region along the *Capo Mannu* cliff (Carboni & Lecca, 1995).

3. Methodological approach

The approach used in the study of construction materials and architectural aspects is based on different strategic intervention lines:

- evaluation of the formal and structural characteristics of the tower with dating the typological classification,
- analysis of the construction technique, description of construction phases,
- lithological mapping and analysis of main petrographic and mineralogical features of stones and ancient mortars.

The rocks and ancient mortars used in the construction of the tower were studied and analysed on a macroscopic basis.

The study was addressed in this first preliminary work, in characterizing only the materials recognizable outside the tower structure. The recognition of the lithologies and the characterization of textural and structural aspects were made using an portable optical microscope in reflected light, which made it possible in some cases to recognize also the mineralogical phases through the study of the crystalline habitus. The study of mortars was carried out subdividing them

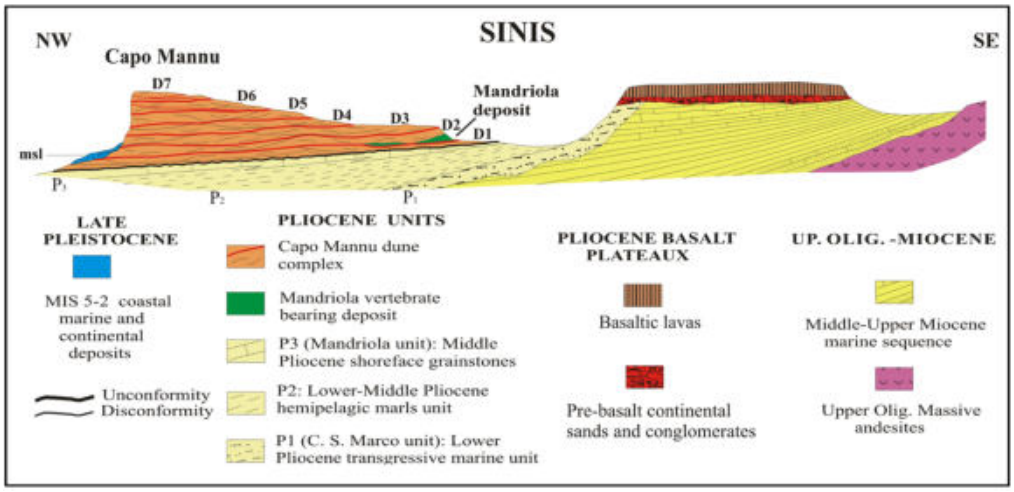

Fig. 3 - Synthetic cross-section from the Capo Mannu to Capo San Marco of Sinis stratigraphic units (Abbazzi et al. 2005)

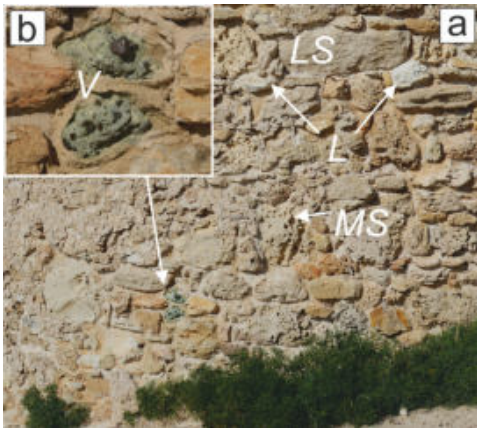

Fig. 4 - a) external masonry showing the main rock types; b) detail of pyroclastic fragments; V= pyroclastite; LS= laminated sandstone; MS= massive sandstone; L= limestone (graphic elaboration by Fancello, 2022)

into: bedding mortar of stone ashlars (not clearly observable in situ), render mortars of wall and plasters. The render mortars are used to close the centimetre space between the stone ashlars and to prepare the substrate for the next finishing layer of plaster. From the macroscopic examination it was not possible to understand whether they themselves also function as bedding mortars for the stone ashlars. An adequate and statistically significant sampling and study of materials (currently not yet executed) could certainly resolve these constructive and stone-compositional aspects. The plaster mortars represent the external finish that in the past was completely covering the irregular truncated-conical wall of the tower. The macroscopic analysis of the entire external wall of the tower has also allowed the mapping and definition of the forms of degradation (e.g., exfoliation, flaking, alveolation, salt crystallization, etc.) and to understand how the alteration processes of material evolve.

4. Results

4.1. Petrographic features and decay of construction materials

The tower is mainly built using local stones belonging to the Plio-Pleistocene sedimentary sequences, with subordinate Messinian limestone and rare volcanics (Fig. 4 a-b). The ashlars have different dimensions (from 10 to 60 cm) and irregular shapes, except for some well squared blocks commonly aligned to set the horizontal plane during the building and/or the restoration phases. The ashlars were bound with a bedding mortar and a render plaster used to fill the voids.

Interestingly, the finishing plaster is still preserved only on the north-west side, where the dominant wind blows from (see the left side of the tower in Fig. 1); this suggests a plastering intervention in more recent times, rather than being the original plaster. All mortars seem to be lime-based and their conservation state is not good, tending to

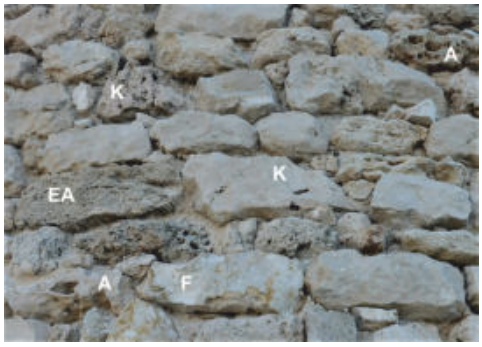

Fig. 5 - Decay forms on the tower masonry. A= alveolation; EA= elongated alveolation (fissure); F= fracturing and flaking; K= karstification, (graphic elaboration by Fancello, 2022)

Fig. 6 - Aerial view of Capo Mannu cliff. Red line: plan position of cliff along the coastline and within the sea (graphic elaboration by Fancello, 2022)

ground into flour to the touch. The observation of sandstone ashlars reveals the presence of different sedimentary textures. Some of them exhibit a developed stratification, with evident cross-cut laminations. Some other are more massive and lack a clear stratification. Also, grain size, colour, and compactness change from one ashlar to another, suggesting the materials supply from different stratigraphic levels. Miocene limestone can be recognized by the lighter colour, the more compact texture, and the lower number of terrigenous clasts. Rare fragments of greenish volcanics, likely pyroclastites with cystal- and litho-clasts and juvenile fragments, rarely are scattered along the external walls, apparently used to fill the voids between the irregularly shaped ashlars. The different nature of the stones results in different forms of decay (Fig. 5). The most common is the alveolation, evident in the poorly stratified to massive, and in the less compact sandstones. The stratified ones are also affected by alveolation, but voids are concentrated along bedding planes and their coalescence often results in fissures, thus the typical aspect of the alveolation decay is lost.

Limestone ashlars are variably affected by the decay; many of them are perfectly sound, other are affected by surficial alteration (reddish oxidation patinas), other again are affected by fracturing, flaking and/or karstification. No significant differences are observed between ashlars at different heights of the masonry.

4.2. Geomorphological features of the cliff

The tower is located near the *Capo Mannu* cliff, which is set on the *Capo Mannu* Fm. about 50 metres thick (Fig. 6). The stratigraphic sequence consists of the superposition of several dune units (Fig. 7), represented by sandstones with terrigenous and bioclastic lithic components with different degrees of cementation. The dune units are also separated by paleosols and colluvium (Carboni & Lecca, 1995). The whole cliff is affected by

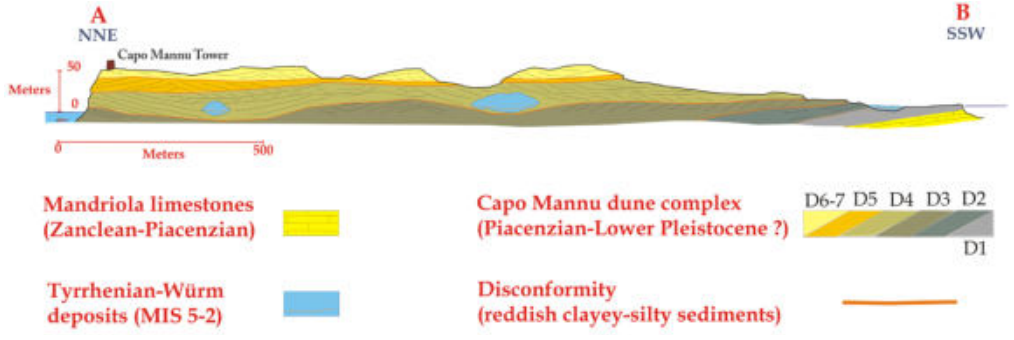

Fig. 7 - Cross-section of Capo Mannu upper dune complex (Abbazzi et al. 2005)

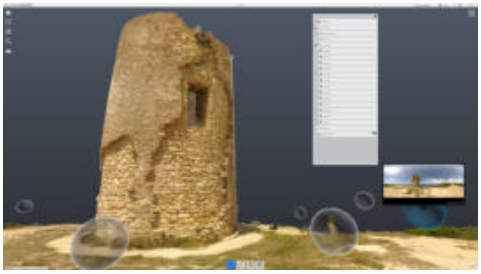

Fig. 8- View of the aligned 3D laser scanner point cloud of the Sa Mora Tower (graphic elaboration by Verdiani, 2022)

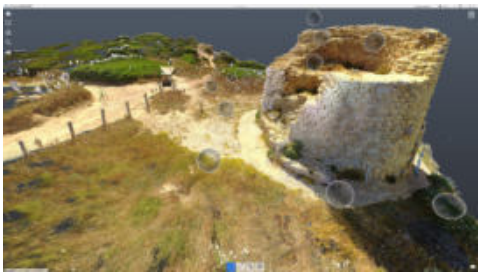

Fig. 9- View of the aligned 3D laser scanner point cloud of the Capo Mannu Tower (graphic elaboration by Verdiani, 2022)

landslide processes of collapse and overturning of sandstone blocks. These phenomena are most present in the sectors where sandstones with a weak or very weak degree of cementation and pronounced erosion by disintegration are exposed in the wall.

The sandstones, due to their high porosity, are subject to intense and easy absorption of meteoric water, continuous input of marine spray, as well as storm surge, resulting in a deterioration of the already poor geomechanical characters of the rock outcrop. In addition, the presence of paleosols and colluvium, which are even less competent than sandstones, make isolated sandstone blocks less stable by cracking and vertical joints on the cliff.Gravitational phenomena are also favoured by other factors such as the angle of layering, compositional and textural characters, and meteorological factors.

4.3. Digital survey of the tower

Even if the object of the main intervention on material analysis it was the *Capo Mannu* Tower, the digital survey was immediately extended to both the towers in *Capo Mannu*, this choice was planned to define a base on which later organize all the information about materials, state of decay, specific aspect of the towers and of their territory. Documenting with a clear and fast procedure the conditions of these particular buildings was then a mandatory aspect. The procedure adopted for both was based on the integration of terrestrial 3D laser scanner survey, terrestrial photogrammetry and aerial photogrammetry using a UAV/Drone unit. The scanner in use was a Cam/2 Faro Focus 3D 70s, a unit with phase shift measuring technology that mix very good features with light weight of the instrument and rapid operations. It has an operative range of 70 metres and an accuracy of about one millimetres at ten metres of distance on matte surfaces, the full panoramic field of 360x320 degree allow to easily cover any architecture and gathering a large part of the natural environment around the towers.

The high accuracy of the dataset is also a valuable factor in front of the readability of the masonry. While the possibility of scanning at extreme close range made this scanner versatile for all the narrow passages that characterize the position of these towers on their cliffs. The approach to both towers was then similar, a simple sequence of scan stations around the main body of the tower, with some more scans dedicated to the top part of the one named “Capo Mannu”, which is crack open and easy to climb; and some extra scan from the distance for the one named “Sa Mora”, to add more information about the environment and having a better coverage of the top parts.

The resulting coverage was completed in the turn of one day, with 13 scans done for the “Sa Mora” and 15 for the “Capo Mannu”. All the scans were done using the photographic feature from the scanner, so to obtain also realistic RGB colours for the resulting point cloud model. The following alignment and optimization of the point clouds were done in Autodesk Recap Pro, so to have a resulting dataset easy to share and fully compliant with CAD procedures. To extend the quality of the details and the documentation of the top parts, an aerial and terrestrial SfM/IM (Guidi et al. 2015) photogrammetry survey was operated.

The aerial shooting was done using a UAV/drone DJI FC330, using its 12 Megapixel camera and producing 383 shots according to a grid with the camera pointing to the ground and with a series of shots taken in circle around the tower.

The ground photogrammetry was operated using a Nikon D800e, 36.3 Megapixel camera with a Nikkor 24-120mm F4 lens taking 274 shots. The overall set of pictures was then processed in Agisoft Metashape, using the classic procedure of alignment/sparse cloud generation, dense cloud creation, production of mesh and texturing (Rodriguez-Navarro, 2012). The resulting model shows a large part of the cliffs and of the ground around the tower, giving place for reference the samples and allowing the extraction of sections and other drawings which are useful for the analysis of the area and for creating proper bases for restoration, intervention and enhancement of the access to these two significant fortifications.

5. Discussion and conclusions

The study of the tower of *Capo Mannu* has made it possible to define its structural and architectural aspects and the characteristics of the geomaterials used in its construction. The tower has had several historical decay vicissitudes, followed by various restoration interventions since the early 1600s, highlighting clear processes of degradation both in terms of structure and materials, to which the artefact has undergone over the centuries.

Mainly local stones, basically of sedimentary origin (limestones, terrigenous sandstones, aeolian deposits, etc.) were used for its construction. Due to the prevalent carbonate composition of such lithologies and high porosity (which places meteoric water in communication with the rock matrix), they show poor chemical and physical resistance in response to the action of atmosphere agents. Indeed, in this coastal area, there is the constant presence of wind (often very strong) and marine aerosol with constant contribution of easily soluble salts (i.e., halite). The degradation is due, in the physical aspect, to the continuous cycles of solubilisation and crystallization of salts and, in the chemical aspect, to a dissolution of the carbonate component by rainwater both on the sandstones and on the binder of the bedding mortars and plasters (today no longer observable).

The degradation of the stone leads at the microstructural level to a decohesion and disintegration of the matrix (especially the sandstones and aeolian deposits) and a consequent retreat of the vertical profile of the tower wall in the advanced stage of alteration. The decay processes that affect the construction materials also occur on the cliff outcrop representing the substrate of tower,

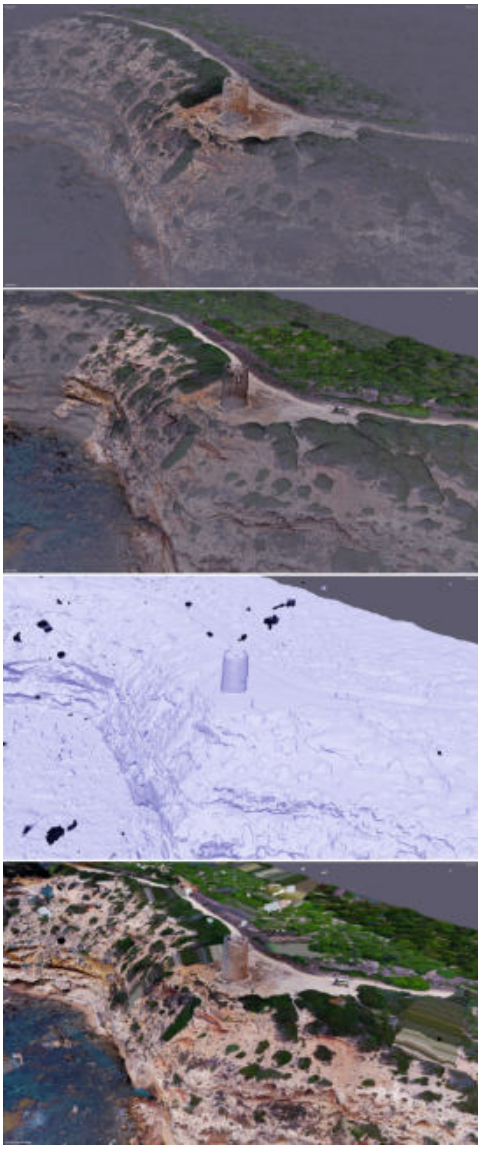

Fig. 10 - Sequence of the photogrammetry processing for the Sa Mora tower, from the sparse cloud to the textured model (graphic elaboration by Verdiani, 2022)

which is subject to continuous geomorphology readjustment processes in continuous changing. Thus, the position of the tower near the cliff and a substrate that is not stable in terms of mechanical strength of the rock mass, lead to further factors of degradation, with numerous collapses of the tower, as highlighted by the 3D digital survey

that showed the absence of a large upper part of the structure. Developing proper project of knowledge and documentation allows an effective and efficient enhancement of the possibility of future intervention, at the same time it increase the knowledge about the relationship between nature, territory and human settlement, especially in situations where the territory is showing rapid changes like it is for *Capo Mannu*, where almost all the past buildings and road structures are gradually going in ruins. The monitoring of the built heritage and of its environment is then fundamental, the use of digital technologies allows an efficient state of knowledge that when connected to interdisciplinary skills may bring to significant results in terms of safeguard of the Patrimony and dissemination. Previous projects focused on fortifications have indicated how these procedures may be efficiently applied (Rodriguez-Navarro et al. 2015), would be proper to see this same solution, fortified by years of experience, applied for a rich patrimony like the one of the Sardinia Coasts offers.

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Notes

(1) https://torricostiere.squarespace.com/torre-di-capo-mannu

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