On site and laboratory investigation on the 16th-17th century masonries: the Foxi defensive tower (Cagliari Gulf, Sardinia, Italy)

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Abstract

This study is part of an ongoing research aimed to examine a number of important defence towers situated along the Sardinian coast, Italy. In this paper we present the investigations of the Foxi coastal towers in the Cagliari Gulf. It has been studied through the analysis of masonries (ashlars, plasters and mortar) by an historical, architectural, technical and petrographical-chemical point of view, through a methodology based on a stratigraphical approach. The aim of this research is the understanding of the traditional building techniques used during the 16th-17th centuries, combining dating strategies, with four different principal objectives: i) put in evidence the peculiarities of the traditional building techniques used during this period; ii) increase the knowledge of the constructions and their degradation phenomena to warranty proper restoration; iii) identify different stones and component materials used for the mortar for the determination of binder/aggregate ratio and to determine the level of weathering of stones and mortars; iv) facilitate, on the basis of acquired data, the dating of other contemporary edifices, especially referring to the so-called *minor* buildings, which are very often object of inappropriate restoration.

Introduction

The Foxi defensive tower (Figure 1) is situated in Quartu Sant'Elena, Cagliari province, Italy. It is part of the tower system built between the beginning of the 16th and the end of the 17th century on the eastern side of the Cagliari Gulf, where there are also the following towers: Sant'Elia (13th century), Poetto (16th century), Mezzaspiaggia (16th century), Su Perdusemini (16th century), Carcangiolas (16th century), Cala Regina (16th century), Is Mortorius (16th century).

Unfortunately, some of them (Poetto, Carcangiolas and Is Mortorius towers) are in decay as a result of disuse and abandonment since the 19th century, after they had lost their original function. Also the Foxi tower suffered from deterioration through lack of care and attention and also as a result of inappropriate and misguided interventions.

With reference to the investigated buildings, the study carried out is based on the use of an archaeological method, consisting of the sampling and the classification of the masonries, through a photographical, architectural, metrical and material survey, concerning the structures, the stones and the mortars used for their construction. Specifically, stones and mortars were examined by a morphological, metrological, lithological and petrographical point of view. This path allowed to put in evidence the main characteristics of this architecture, referred to the 16th-17th centuries.

The sampling was supported by the use of a database, recording all the registered data about the typology of each tower and the traditional construction techniques. The drawing of each tower, with the annotation of their structural and material based conditions, was very useful for the understanding of their dimensional and technical characteristics.

Together with the examination of masonry techniques, the study included mineralogical characterisation of the masonry samples and mortars. Specifically, X-ray diffraction and optical polarised light microscopy (OM) on thin sections were carried out.

Historical references

As said before, the coast defense tower investigated dates back to the 16th-17th century, under the rule of Spain (Fois, 1981).

This period is very important for the development of the protection system, because Sardinia represented a strategic ambit at that time, by a commercial and political point of view.

During the second half of the 16th century Marco Antonio Camós was instructed by the viceroy Juan Coloma d'Elba to quantify the existing towers and to register their conditions. The viceroy's aim was to convince the authority to ameliorate the defense system, in order to protect Sardinia as well as Spain (Mele, 2000; Pillosu, 1957; Russo, 1992).

This process continued until 1587, when the dominator decided to institute an administration for the towers, starting up a concrete development process, the defense system of the Kingdom of Naples serving as example.

These towers had basically the role of a lookout point; therefore they were always located on rocky promontories. In other words, their position was imposed by the existence of obtaining a good visibility level towards the sea, as well as of the neighboring coastal area (Rassu, 2003, 2005).

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The architecture and the masonry technique

Prevalently these constructions show a circular plan, with a cylindrical or a cut-off conical façade, still in coherence with the past catalane culture. Usually a vaulted system covered the construction.

The dimensions of these towers are small, presenting a diameter included between 5 and 12 m, with a masonry section of 1 m and a height of 8-10 m.

All these examples, the Foxi tower included, show the use of the *cantieri* technique (Giannattasio and Grillo, 2010, 2011a, 2011b). This practice, deriving by the roman *opus incertum*, consisted in the preparation of two or three courses of rubbles, rough-hewed just in the external and support faces. The result was an irregular, coarse opus, with horizontal linings generally distanced 50-60 cm, distinguished by thick joints between one another, with mortar of poor quality, sometimes characterised by not slaked lime nodules. Very often the assembly of the rubble stony elements took place without paying attention to the stagger of vertical joints. This technique allows using all kinds and sizes of stones, well arranged thanks to the creation of horizontal level surfaces between *cantieri*.

Between two courses one can find tiny squaring materials, together with a double mortar layer, highlighting the passing from one another, i.e. the closing of a module of the masonry and the following restarting of the new one. Very often little pieces can be observed corresponding to manufacture discarding, applied to fill empty spaces, as well as for regularising the disposition of elements, with evident static aims. Sometimes planking holes can be found, prevalently distanced both horizontally and vertically about 1.70 m. Generally it can be observed that for practical reasons they are always aligned with the superior limit of the *cantiere*.

The stones composing the *cantiere* show different sizes, 15-20 cm high and 15-22 cm wide. In each *cantiere* the dimension of stony elements decreases from the bottom to the top of the tower, evidently for stability reasons.

This typology was the outcome of an ingenious device, conditioned by economical reasons, i.e. by the aim of making the most of the available stones of different size, accurately dressing external angles and using horizontal elements with stabilizing function thus warranting structural solidity. As we will specify, all the examples investigated used materials outcropping in the area. With reference to the Foxi tower, it recently has been the object of a reconstruction project, using masonry techniques not coherent with the primary ones (Figures 1 and 2).

The original parts compose of masonry with irregular ashlars of various materials. They are disposed in two or three courses, that define *cantieri* high 50-60 cm.

The structure is composed by regular blocks, ashlars and rubble stones, 9-40 cm in height and 8-45 cm in length. The joints, both horizontally and vertically, are of 1-2 cm. Here there are also planking holes, distanced about 1.15-1.96 m horizontally and 2.10-2.45 m vertically.

Materials and Discussion

The identification of stone and mortar present in the historical building is very challenging for the restoration of historic masonry structures. Modern guidelines for the conservation of historic buildings indicate that every attempt should be made to restore as much of the original building fabric as possible so that the resource continues to carry its original his-

Figure 1. East and west front of the Foxi tower. The pictures put in evidence the difference between the original masonry (c) and the parts recently restored (a and b).

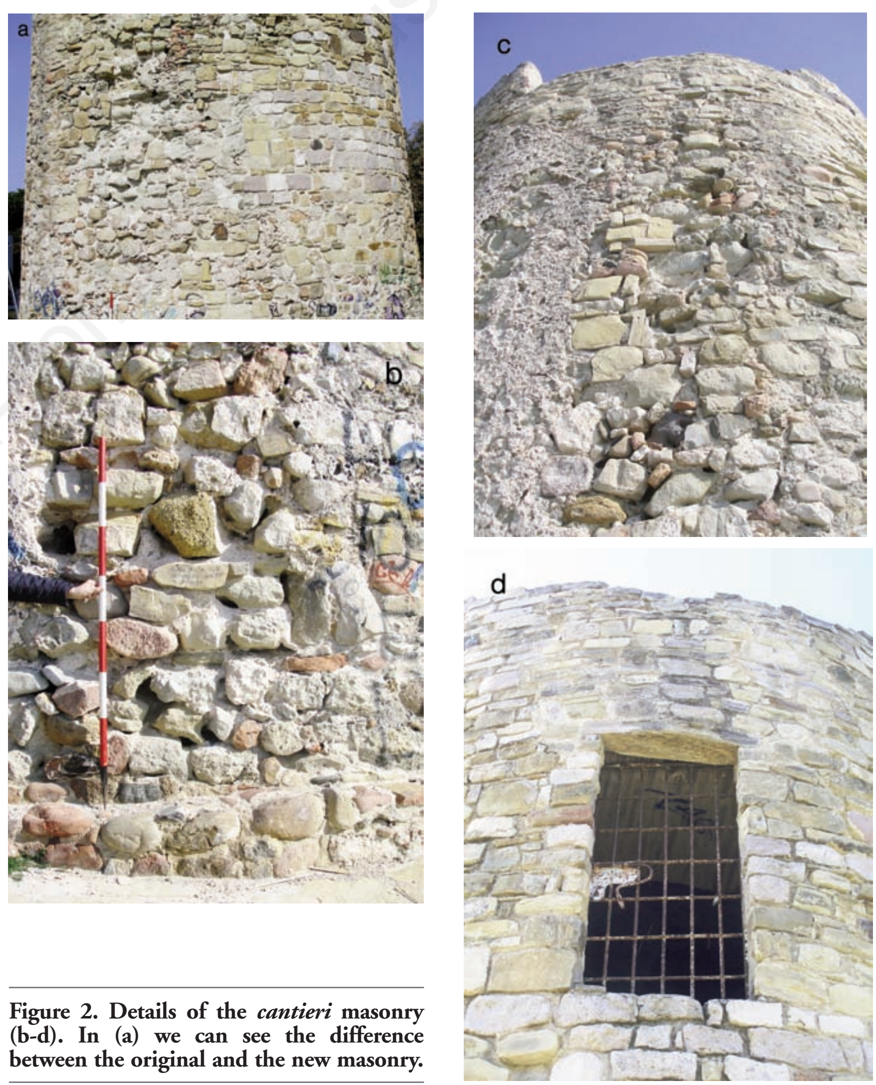

Figure 2. Details of the *cantieri* masonry (b-d). In (a) we can see the difference between the original and the new masonry.

tory. For this reason the identification and characterisation of the original stones, mortars and plasters used in these historical buildings is of appreciable importance in order to collect data that will be considered for the formulation of the restoration. Besides, it is very useful to define the characteristics of building elements (lithology of original stones, composition and quality of the mortar, plaster) used at a given time, in the specific case at the period between the beginning of the 16th and the end of the 17th century.

The geological formations of Oligocene-Miocene-Holocene volcanic-sedimentary sequences occurring in the area consist of marine deposit (littoral, carbonatic, lacustrine and continental). In the north western formations of Palaeozoic occur like metasandstones and quartzite, metaconglomerates, acids metavolcanites and granitoid rocks.

The original ashlars blocks used for the construction of the Foxi defence tower, generally originate from this formations cropping out in the south part of the island, consisting of sedimentary, volcanic, granitoid and metamorphic rocks (Figure 3).

The walls of the towers generally were all made of irregularly and partly regularly cut blocks of different kind of these stones (Herrmann *et al*., 2002). In the lower part of the tower they often show a classic rounded shape typical of river transport. In general stone as granite, acid metavolcanites, slate and sandstone used for the tower construction are highly resistant to weathering associated to aerosols due to diffusion and crystallisation of soluble salts of marine origin especially in combination with direct solar radiation. The replacement stones used for the rebuilding are mainly sedimentary rocks (sandstone), generally yellow, and subordinately volcanic rocks (Figures 1 and 2).

In contrast to the above described relatively stable features of the rocks used for the masonry, the historical plaster and mortar show very serious signs of weathering as disaggregation, exfoliation, etc., that are responsible of the sometimes serious damage of the towers. In fact, when the mortar weathers and is washed out from the interstices, the ashlars lose their stability and fallout from the walls. This phenomenon of weathering is very well developed on the walls exposed to the sea-side where wind and aerosols are heavily impairing the constructions (Figure 2). The main reason contributing to the erosion of mortar and plaster includes a presence of salt crystallisation, abrasive action of winds, disintegrating effects of plant growing on the walls and water penetration leading to the concentrations of moisture and dampness (Prokos, 2008).

Mineralogical characterisation of the16th-17th century masonry mortar was carried out both by X-ray diffraction and optical micro-

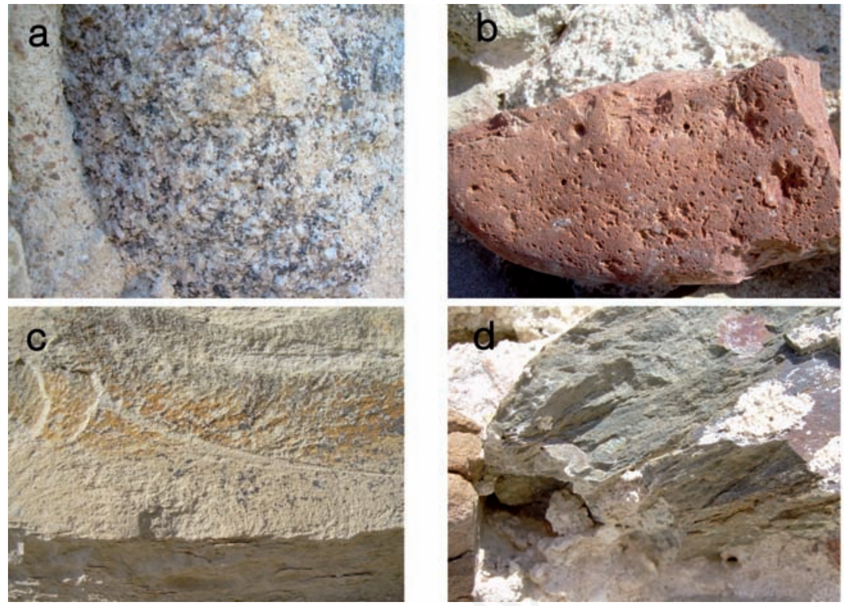

Figure 3. The original ashlars used for the construction of the Foxi defence tower, generally originated from formations cropping out in the south part of the island: granitoid (a), volcanic (b), sedimentary (c), metamorphic rocks (d).

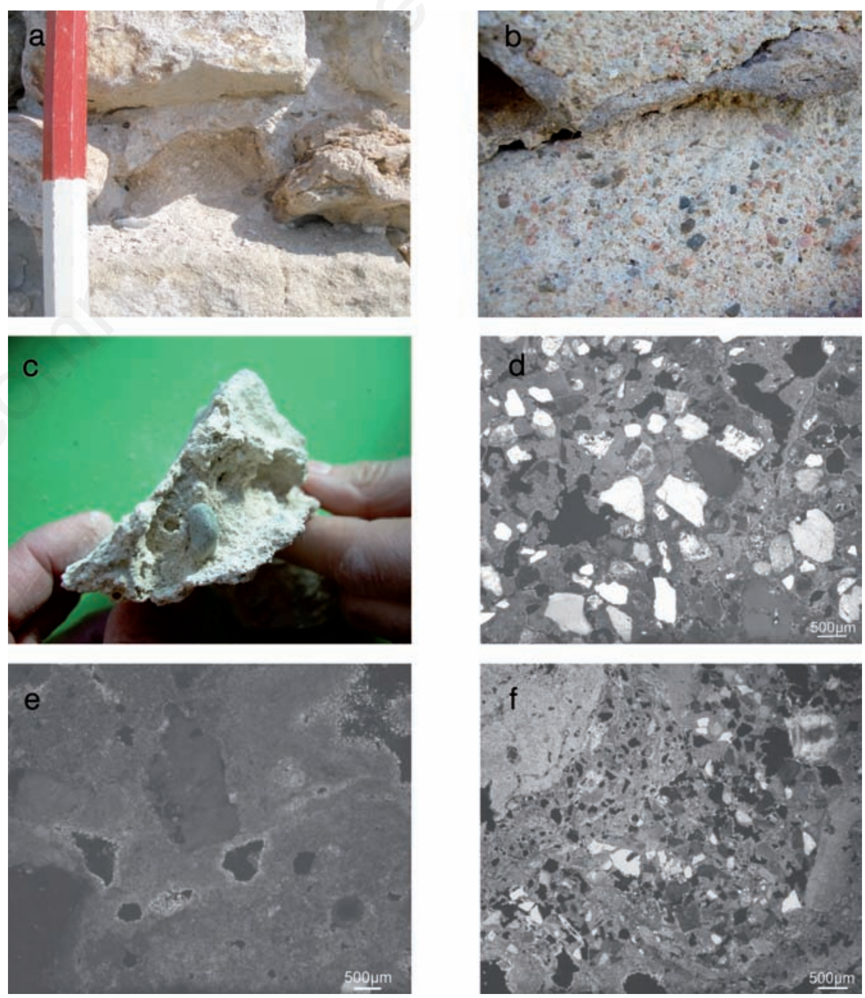

Figure 4. a-c) Macroscopic examination of mortar and plaster; d-f) thin-section photomicrographs (crossed polariser) of plaster mortar: coarse grained quartz-feldspar and few metamorphic aggregates (d), micrite binder with lumps and cryptocrystalline reaction rims (e), and micrite and microsparite binder and coarse grained quartz-feldspar aggregates (f).

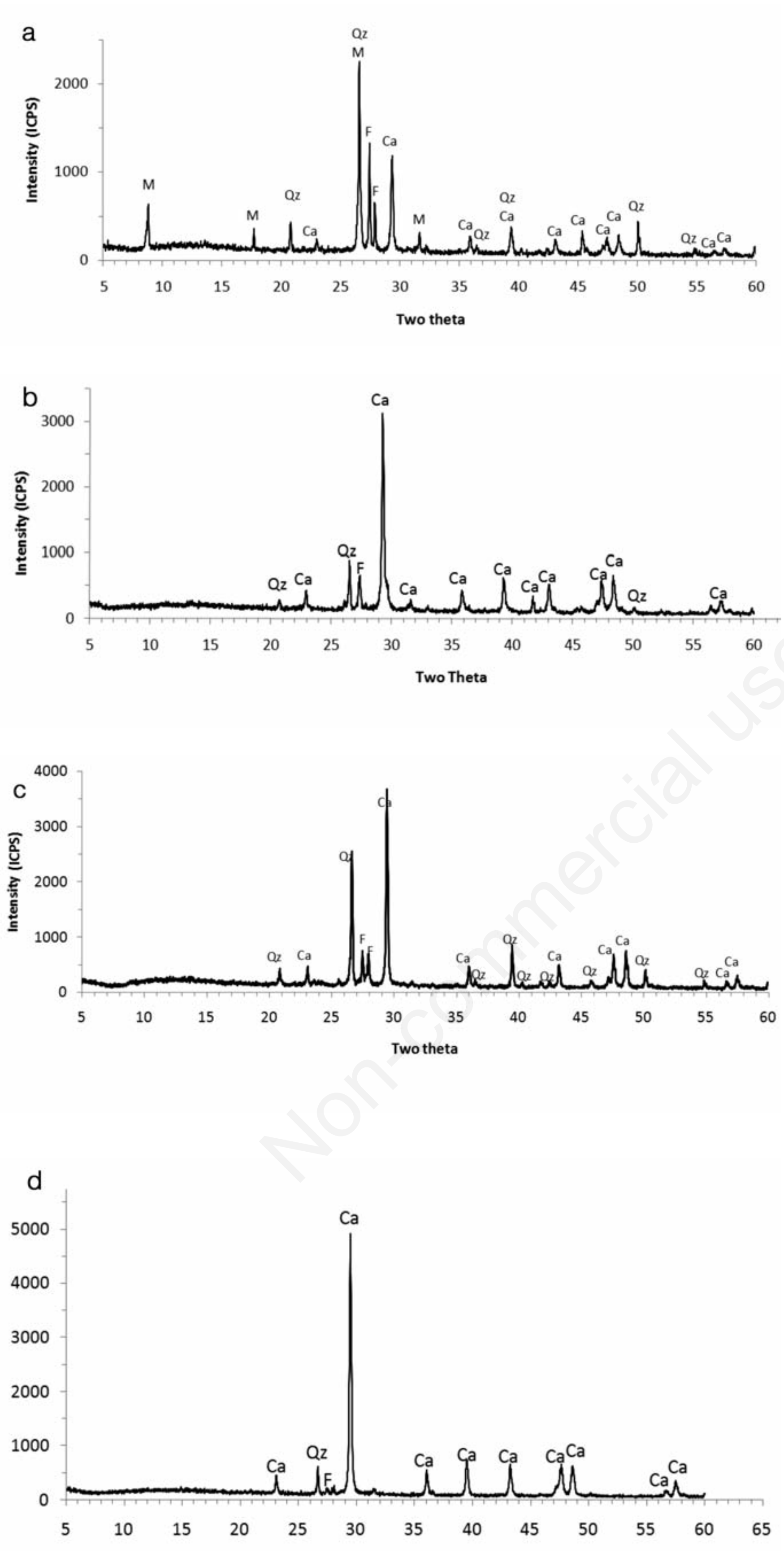

Figure 5. X-ray diffraction powder pattern of mortar: aggregates (a-c); binder (d). Q, quartz; F, feldspar; M, muscovite; Ca, calcite.

scope with polarised light on the thin section (Casadio *et al*., 2005; Elsen *et al*., 2004). The sampling of the mortars was carried out using a hammer and a small chisel. The size of each sample was the minimum that could guarantee the success of the analyses. Mortar and plaster were examined by naked eye to determine the different type, dimension, color, hardness and coherence. They have always white/cream binder, while the aggregates have some difference mainly in the binder/aggregate ratios and in the particles size coarser for the plaster (Figure 4a,b,c).

The optical study of thin section of mortars shows that they consist of sandy aggregate coarse size, well graded, sub angular shapes composed mainly of single crystal quartz grains, feldspar (grey/white), very few fossils, lithic calcareous and metamorphic fragments (light brown) (Figure 4d and 4f).

The lime binder consists of micro to cryptocrystalline carbonates and sometimes it shows a non-homogeneous texture due to the presence of lumps. A rim of reaction with formation of cryptocrystalline carbonate is often present around aggregate grains (Figure 4e).

The two mortars differ especially in the binder/aggregate ratios and in a higher content of the aggregates in the mortar used as plaster.

The mineralogical composition of the mortars has been confirmed by the investigation with X-ray diffraction (Figure 5).

The X-ray diffraction analysis shows that the binder of the investigated mortars essentially consists of calcite and only in few cases it is possible to see very week indications of the presence of lumps, observed also under the optical microscope. Finally the X-ray does not evidence the presence of any phase of calcium silicate hydrates as belite, celite, halite, *i.e.* of minerals typical of hydraulic mortar (Figure 5d).

The investigation of new mortar used for the recent tower's restoration show the presence of concrete (usually Portland cement-based). Portland cement is extremely hard, withstands the movement of water, shrinks upon setting, and undergoes relatively large thermal movements: Besides it suffers from deterioration caused by weathering, as witting and drying, and salt crystallisation.

Conclusions

This study, based on an interdisciplinary approach using the knowledge of the construction techniques together with the physical-chemical analysis of the materials, aims to individuate the characteristics of this already dated architecture, i.e. to provide a chronological *datum* that can be applied to identify and date other previously anonymous constructions, which mostly consist of vernacular building without formal architectural features. It allows to revaluate our architectural heritage and to recognise the wider sense of the word *monument*, that may now also include traditional historic urban fabric. In other words, even if the study is not exhaustive, it offers a sampling that can represent a useful point of reference for recognizing historical construction built during the 16th-17th centuries.

Besides the knowledge of the constructive characteristics (from a structural, lithological, petrographical and mineralogical point of view) is groundwork to plan a conservation project, with respect to material and aesthetical consistence of architectural heritage. The decay conditions of similar historical structures highlight the need for a restoration strategy that will ensure their preservation and management.

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