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Interpretation and preservation of archeological sites from their building construction techniques. The case study of S. Maria in Portuno in Italy

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Archaeological sites are very complex systems, each having peculiar features, often characterized by local and characteristic construction technology and techniques. Their conservation and enhancement for cultural and tourist purposes have taken up a significant technical and economic role. The presence of archaeological sites is recognised as one of the essential components of the tourist supply and a strong incentive in promoting its development. Thus, an essential condition for the enjoyment of archaeological sites is their conservation. But any conservation project should consider a variety of factors (technical, cultural, relating to the landscape, economic, social and so on) the complexity of each of them is strictly related to a full understanding of the archaeological site. In this communication an interpretation for better understanding an archaeological site starting from the study of its building construction techniques is proposed. This approach is applied to the case study of S. Maria in Portuno's site (Italy). The obtained results will allow to guide the future conservation actions of the site and to increase the current knowledge of the ancient building practice.

Introduction

The S. Maria in Portuno's archaeological site (Corinaldo, Marche region, Italy) is located in the centre of Italy near the Adriatic sea (Fig. 1). It is positioned along a road axis that coincides with an ancient Roman road and it was investigated, since 2001, by a series of different archaeological investigations as shown in Giorgi and Lepore (2010) and Lenci et al. (2011). From these investigations an on-site continuity of human settlements seems to come out, allowing to identify five main building phases of the site from the Roman Age to the current period (Giorgi and Lepore, 2010): (1) the productive site in the Roman Age, confirmed by the well-preserved walls of the Roman kilns used to carry out bricks and tiles; (2) the construction of a little church and its cemetery area built between the 8th century A.D. and the 10th century A.D.; (3) a more complex church with one nave and two aisles, similar to those ones of the same period sited in Ravenna's area (Italy) and in the Byzantine Empire, and its cemetery areas in the High-Middle Age (10th-11th century A.D.) until the Middle Age (12th-14th century A.D.); (4) the collapse of the northern aisle and the rebuilding of the church with only one nave in the Renaissance Age (15th century A.D.); (5) the new façade and the bell tower dated 18th century.

The remains of the original medieval masonries (10th-11th century A.D.) of the northern aisle of the church and of its eastern area were found from these archaeological investigations (Fig. 2). They seem to represent an unusual, but surely smart, construction technique for building bearing masonries using cheap and really available materials, such as tile and brick fragments. In this way an interpretation for better understanding this archaeological site has started from the study of this building construction technique so as to obtain results that will allow to guide the future conservation actions of the site itself and to increase the current knowledge of the ancient building practice.

A technological-construction survey was firstly carried out. Then, chemical and physical analyses were carried out both on mortar samples and on ceramic ones. Furthermore, compression tests were performed on the ceramic specimens to characterize their mechanical behaviour.

Figure 1. Some views of the S. Maria in Portuno's site: the church (a) and the northern zone of archaeological excavations (b).

Materials and methods

In situ investigations were carried out on the medieval masonries of the church. A geometric and technological-construction survey was firstly carried out. The average dimensions of the tile and brick fragments were determined by the analysis of some "open" masonry transversal sections. The distinction between the fragments of tile and brick was reached by their dimensions. Successively, ceramic and mortar samples were taken from the investigated masonries following the procedure suggested by Italian UNI 11305 (2009). Samples were taken at the elevation level and at the foundations as reported in Table 1. Some ceramic samples were also taken from the few remains of Roman masonries sited under the medieval level of the site (Table 2), so as to investigate the possible reuse of tile and brick fragments coming from pre-existing Roman structures.

The characterization of the mortars was developed according to Candeias et al.(2006), Pecchioni et al.(2008) and following the protocols suggested by Italian UNI 11305 (2009) and UNI 11176 (2006). The determination of the samples particle size distribution was performed by sieve analysis on dried samples (UNI EN 1015-1, 2007). The mortar samples were fractionated and sieved through ISO 565 series sieves. Thin sections and polished surfaces were prepared by vacuum impregnation with low viscosity epoxy resin and they were observed with a petrographic microscope (NIKON OPTIPHOT2-POL) equipped with an automatic photographic system and a digital camera,enabling the identification of the morphology, dimension and type of aggregates, binder, and additives. Non-disintegrated mortar fragments were also included into acrylic resin, following the Italian recommendation Normal 14/83 (1983), in order to confirm the conclusion obtained by the petrographic analysis by using a scanning electron microscope (ESEM Quanta-200, FEI) with an EDS micro-probe (X-EDS Oxford INCA-350, FEI). The samples were polished and coated with a thin layer (10nm) of Au-Pd and examined.

On the binder fraction X-ray diffraction measurements (XRD) were carried out (X'Pert PRO MRD Panalytical diffractometer) with Ni-filtered CuKα radiation to determine the crystalline phases present on the samples. The patterns were recorded in the 3-90° 2θ range at room temperature, with a scanning rate of 0.001°/s and a step size of 0.02. Finally, thermogravimetric (TG) and differential thermal analyses (DTA) were recorded at 20°C/min up to 1000°C in flowing air (STA 429, Netzsch), in order to confirm the binder nature.

The characterization of the brick and tile fragments followed the protocols suggested by Italian UNI 11084 (2003). After a preliminary observation at stereo-microscopy, petrographic and electron scanning microscopies were used as reported before for the mortars. A GeoPyc 1360 Envelope and T.A.P. Density Analyzer (Micromeritics Inc.) was used to determine the bulk density (ρb). The true density (ρt) of the fired samples was determined using a gas displacement pycnometer instrument (AccuPyc 1330, Micromeritics Inc.) while the total porosity (TP) was calculated by using the following formula: TP = (1 – ρb/ρt)··.

XRD analysis was performed, in the same conditions used for mortars, on the fraction with grain size < 25μm in order to obtain information on the mineralogical composition and firing temperature of the ceramic fragments. Finally, thermogravimetric (TG) and differential thermal analyses (DTA) were performed,at the same conditions reported before for mortars, to confirm the firing temperature.

Six tile specimens of average dimensions 6×6×6cm^3, each consisted of two piled elements 6×6×3cm^3, and six brick specimens 6×6×5cm^3 were tested under compression, following the protocols suggested by UNI EN 772-1 (2002). The compression tests were carried out by displacement control and the displacement rate was equal to 0.02 mm/s.

Table 1. XRD results of the mortar fractions < 63 μm.

Sample code	Sampling area	XRD results (< 63 μm)
3	Masonryseptum	calcite (+++) quartz (++) muscovite (+) albite (t)
4	Masonryseptum	calcite (+++) quartz (++) muscovite (t)
12	Pillar	calcite (+++) quartz (+)
18	Apse	calcite (+++) quartz (+) illite (t)

Results and discussion

The tile fragments have two principal thicknesses: the first one, relative to the raised edges of the original tile, of dimension equal to about 6cm, and the second one, relative to the flat zone of the original tile, equal to about 3.5cm. The average thickness of the brick fragments is equal to 5cm. These average dimensions are consistent with those of the well-preserved U-shaped flat tiles and bricks found at the Roman level (Fig. 2).

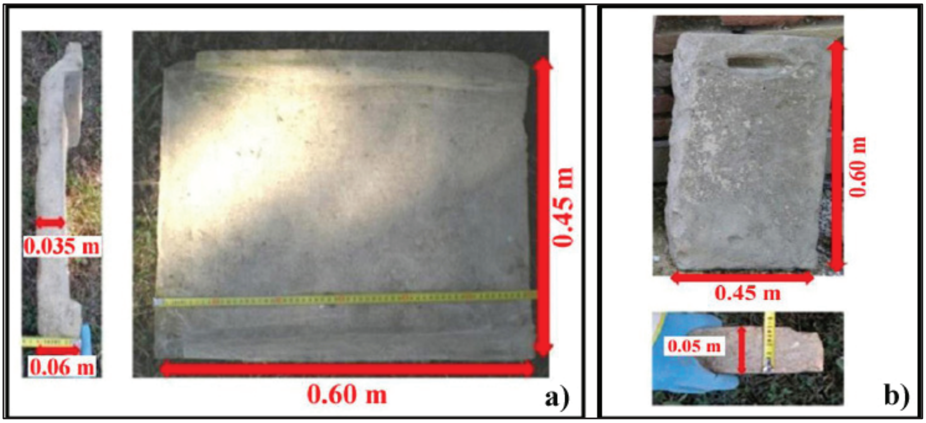

Figure 2. Well-preserved Roman tile (a) and brick (b), called manubriati, found at the Roman level lower than that of the medieval church.

The masonry lay-out at the elevation level is made by two types of horizontal layer, piled one above the other (Fig. 3). The first one (type 1) is made by brick and flat tile fragments so as to achieve an "U-shaped formwork" to be filled by the second layer. Tile fragments of the first type of layer were placed with the raised edges towards the outside and this construction technique permits to have a regular external leaf of the walls. The second one (type 2), confined within the first type of layer, is made by ceramic irregular fragments. This represent a smart local way of building bearing masonries to obtain regular external curtains from units with irregular shape, using cheap and really available materials such as tile and brick fragments.

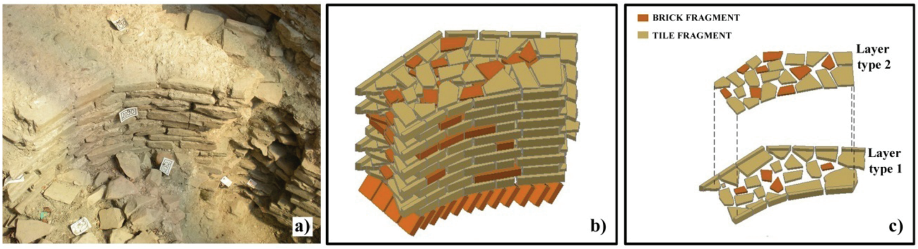

Figure 3. Some of the investigated Medieval masonries (a). An arrangement of the masonry lay-out (b) made by two types of horizontal layer piled one above the other (c).

The mortar joints have an average thickness equal to 1.5cm due to the granulometrical distribution of the mortar and to the irregular shape of the ceramic fragments. The same mortar appears to be rather coarse, crumbling by the simple effort of sampling, and it could be classified as a conglomerate by a first visual inspection, because there is the presence of aggregates larger than 2mm.

Considering the mortars taken from the foundations, the average percentage of gravel ($d > 2$mm), sand ($63\ \mu$m $< d <$ 2mm) and binder ($< 63\ \mu$m) was equal to 40.8, 55.4 and 3.8 wt%, respectively. On the other hand, the average values of the granulometrical distribution of the mortar used at the elevation of the investigated structures showed gravel, sand and binder content equal to 39.7, 54.5 and 5.9 wt%, respectively. The reported data showed that the average grain size distribution for the mortar samples at the elevation level was similar to that of the foundations. However, columns and pillars foundations and the elevations showed a quite different grain size distribution characterized by a gravel content lower than those of the other considered sampling areas.The binder content was very low for all the considered mortar samples with a small increment, in general, from the foundation to the elevation level.

The petrographic analysis of the mortar samples presents a lithoclast with millimetric dimension and rounded smooth shape surrounded by the mortar. Analyzing the mortar, the image confirmed the very low binder quantity and the presence of micritic binder lumps where shrinkage fissures can be observed: this means that no particular care was devoted to the mortars curing, leaving the mortar dry throughout the setting reaction. The aggregates are made by sedimentary rock fragments with rounded smooth shape, crystals, mainly quartz, calcite and feldspars, and carbonate shell. No differences were observed in the mortar samples used at the elevation. The XRD patterns of the mortar binder fraction showed the predominant presence of calcium carbonate as calcite and quartz (Table 1), in agreement with petrographic and EDS results. The visible impurities are generally clay. TG analysis confirmed these results and enabled to confirm the typical lime nature of the mortars. In particular, it demonstrated the absence of any important weight loss before the calcite decomposition ranging between 820-840°C and releasing over 20% CO_2 (equivalent to over 45% $CaCO_3$). The mortars do not present any hygroscopic behaviour, since they contain adsorbed water more or less around 2% during heating up to 120°C, and the slight weight loss between 200-600°C is attributable to the characteristic dehydroxylation of the clay impurities. The obtained results allowed to define that the binder used in this site was lime with small amount of clay impurities that gave a slightly hydraulic nature to the mortar.

The mineralogical and physical properties of the ceramic samples taken from the medieval masonries of the church are consistent with those of the samples coming from the pre-existing local Roman structures (Quagliarini et al., 2014). In both cases, in fact, the samples are made by a homogeneous micritic matrix with crystals of quartz, calcite, biotite, microcline and iron oxides (Fig. 4). The XRD patterns of the samples ($< 25\ \mu$m) (Table 2) indicated that all the analyzed bricks and tiles were originated from a calcareous clay and were fired at around 900° C, but not for time needed to allow the complete transformation of the low-T phases. These results are in good agreement with the TG-DTA results that showed the characteristic decomposition of calcite at around 800°C. The porosity of the samples (around 40%) are quite similar, too.

The average compressive strength of the tile specimens was equal to 22.1MPa and that of the brick specimens was equal to 23MPa. They indicate good mechanical properties of the ceramic units if i.e. we consider that for Italian modern masonries the characteristic compressive strength of the brick unit has to be within 2-40MPa (Circolare Esplicativa 617, 2009). Furthermore, they are similar to those of some Medieval bricks shown in literature (Modena et al., 2002).

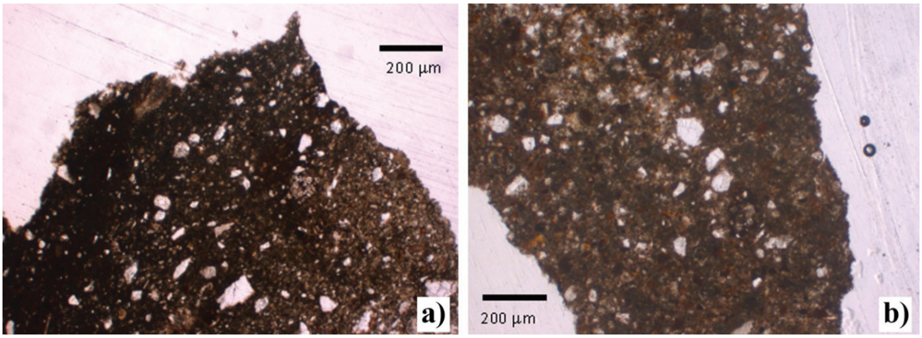

Figure 4. Petrografic micrographs of thin sections of brick samples: a) sample B22 (plane polars); b) sample B01 (plane polars).

Table 2. XRD results of the fraction < 25 µm for tile (T) and brick (B) samples and for the Roman ones.

	Sample code	Sampling area	XRD results (< 25µm)
TILE AND BRICK	T05	Masonryseptum	calcite (+++) microclino (++) quartz (+) muscovite (+)
	T08	Column	calcite (+++) quartz (+) diopside (+) anortite (t)
	B15	Pillar	quartz (+++) calcite (+) diopside (+) muscovite (+)
	B16	Pillar	calcite (+++) quartz (++) albite (+) muscovite (+)
	B22	Apse	calcite (+++) quartz (++) albite (+) ghelenite (+)
	B23	Crypt	calcite (+++) quartz (++) diopside (+)
	B24	Crypt	calcite (+++) quartz (++) diopside (+)
ROMAN TILE AND BRICK	T01	Roman masonry	calcite (+++) quartz (++) muscovite (+)
	T02	Roman masonry	calcite (+++) quartz (+) muscovite (+)
	B01	Roman masonry	calcite (+++) quartz (++) albite (+)
	B02	Roman masonry	calcite (+++) quartz (++) diopside (+)

Results from mineralogical and physical characterisation of different ceramic samples are quite similar and this could corroborate the common Roman origin. The reuse of existing materials was a common practice during the High-Middle Age (Mannoni, 2000; Novara, 2000) and results seem to confirm that, even at S. Maria in Portuno's site, the ceramic fragments used for building bearing medieval masonries came from pre-existing Roman materials such as flat tiles and bricks. This totally agrees with what is reported in historical literature: the manufacturing of new bricks generally began on large scale from the 14th century A.D. (Mannoni, 2000) and this fact holds for the S. Maria in Portuno's church too, since the production of new bricks began with the building of the new defensive walls of Corinaldo after its destruction (1360 A.D.) as shown in literature (Giorgi and Lepore, 2010).

In this way, the considered construction technique allowed in the Middle Age (11th century A.D.) to build bearing masonries with regular sides starting from ceramic fragments characterized by irregular shapes. Moreover, this peculiar construction technique is very similar to a local Roman one, where the masonry lay-out at the elevation level is arranged in the same way by two types of horizontal layer, piled one above the other (Fig. 5). The only difference is that the first one is made up of a whole U-shape flat tile across the thickness with the raised edges towards the outside, so as to achieve an unbroken "U-shaped formwork" to be filled by the second layer. In this way, the results seem to demonstrate a continuity of the local building practice at least until the 11th century A.D. and the influence of the social and economic context on the building practice in the High-Middle Age, as shown in literature for other historical masonries (Tobriner, 2003).

The mortars used both at the foundation level and at the elevation level are similar in their compositions. They mostly contain big aggregates (> 2mm), mainly calcite and quartz, and the used binder was lime with small amount of clay impurities that gave a slightly hydraulic nature to it. Generally, the percentage of binder by weight (< 63 µm) results very low, also respect to the historical mortars described in literature (Calderoni et al., 2010; Corradi et al. 2008; Miriello et al., 2010). Some differences between the grain size distributions of the mortars of the considered sampling areas may be due to the historical building process characterized by poor economical conditions and by a lack of qualified workers.These mortars, from the actual engineering point of view, should be defined as "concrete" due to the gravel content in their compositions. In this way, they not only allowed the regularization of the horizontal layers of the masonry but also the filling of the large voids of the wall between the irregular ceramic fragments, a common role for historical masonries.

Figure 5. Well-preserved ruins of some local Roman masonries made by flat tiles near the S. Maria in Portuno's site (Suasa's archaeological site).

Conclusions

Archaeological sites represent an important heritage to be protected and preserved, but any conservation project should consider a variety of factors, such as technical, cultural, relating to the landscape, economic, social and so on, the complexity of each of them are strictly related to a full understanding of the archaeological site itself. In particular, each archaeological site is often characterized by local and peculiar construction technology and techniques which can represent a powerful interpretation mean of the archaeological site itself. In this way, in this communication an interpretation for better understanding the S. Maria in Portuno's archaeological site is provided starting from the study of its building construction techniques. The obtained results have pointed out that the medieval masonry construction technique is very simple, smart and does not require expert masons. It permitted to save money and time by re-using ceramic fragment coming from ancient Roman structures and by employing a mortar poor in binder and with big aggregates (> 2mm). Besides, it allowed to obtain regular external masonry leaves, by putting the raised edges of tile fragments toward the outside of the wall. In this way, these masonries at a first glance look like an ordinary masonry made by full bricks, and this can misguide engineers or architects. Moreover, a continuity of the local building practice at least until the 11th century A.D. and the influence of the social and economic context on the building practice in this period seem to be demonstrated.The obtained results will also allow to guide the future compatible restoration of the investigated masonries.

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