Geophysical and thermographic investigations addressed to the study of the church of "S. Maria del Rosario" in Sicily (Italy)

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Abstract: This paper is aimed at detecting the presence of crypts and/or buried structures within the church of S. Maria del Rosario, located in Motta S. Anastasia village (Catania, Sicily, Italy), by using the non-destructive Ground Penetrating Radar (G.P.R.) investigations.

Furthermore, infrared thermo-graphic analyses have also been carried out to individuate unhomogeneousities in the building structure and to collect information regarding the component elements, their shape, their physical characteristics and their state of decay.

The obtained results point to textural differences in the walls and some water infiltrations. Finally, in-situ drillings on the church's walls were performed to obtain information about the building material and their state of degradation. Thanks to these analyses an accurate repair work can be carried out on the building.

Key words: Ground Penetrating Radar, infrared thermo-graphic analysis, crypt, wall texture, Sicily

1. Introduction and historical account

The church of S. Maria del Rosario (Motta S. Anastasia village, southern slope of the Mt. Etna volcano, near the town of Catania), dated back to

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the XIIIth century, was originally built with a central plan, according with the typical Byzantine tradition.

Then, during the XVth-XVIth centuries, it was enlarged and turned into a Latin cross plan, similar to the planimetric scheme of a Roman basilica (Fig. 1a), whereas the present bell-tower was built in the XVIIIth century. Inside the church, a valuable altarpiece and a "Madonna del Rosario" picture, attributed to the Antonello da Messina's disciples, can be admired; furthermore, a picture of the Madonna del Carmelo of the same manufacture and a XVIth century crucifix are present.

Different and complementary methodologies were performed to carry out an accurate study of the building structure of the church. The importance of the church as cultural heritage requires the use of non-destructive scientific methodologies. Even in the case of a needed samplings, the results obtained are very useful to preserve the building from further damages.

Thus, the subsoil of the church has been detected in order to discover the presence of hidden crypts and/or anthropic structures by using the Ground Penetrating Radar (G.P.R.). That allowed us to obtain a sequence of images of the subsoil, thus permitting to individuate and delimit several areas with presence of anthropic structures and crypts and/or cavities, totally or partially filled. Then, the physical features and the state of preservation of the building structures of the church have been verified by using the infrared thermographic investigation.

Finally, the data acquired have been compared with those obtained from the execution of wall drillings, worrying to contain the damages to the investigated structure. All the methodologies used were chosen for their strong decisive power and because they are extremely non-invasive (Fig. 1b). All these pieces of information provided an adequate diagnosis about the state of conservation of the church.

2. Ground Penetrating Radar investigation

The G.P.R. investigation is based on the physical properties of the electromagnetic waves to be reflected by anomalies in their propagation path. The wave, produced by a radio-frequency aerial, detects the electromagnetic impedance variations in the propagation medium, such as different material

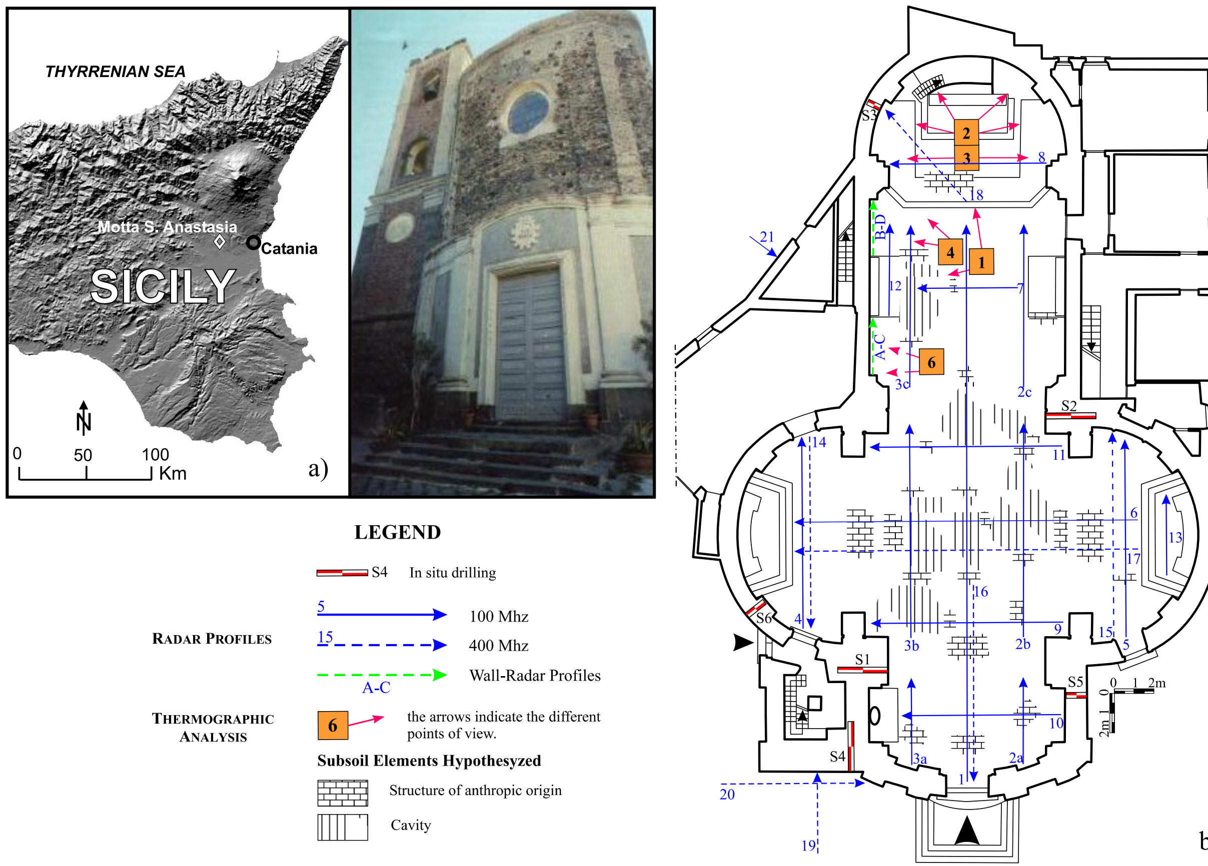

Fig. 1. a) Position of the site and an external view of the church of S. Maria del Rosario; b) Planimetry of the church and location of all the surveys performed and the detected crypts.

boundaries, empty cavities or water content variations. Measuring the time elapsed from the incoming of the incident wave to the detection of the reflected wave, the speed of propagation assumed to be known, it is possible to calculate the distance covered by the wave and the depth at which the discontinuity is present in the subsoil.

The G.P.R. technique addressed to archaeological prospecting gives very good results and allows to reveal historical findings of cultural and scientific importance (*Cammarano et al., 1997; Vaughan, 1986*). Detailed georadar survey (Fig. 1b) was carried out in order to verify the presence and location of natural or anthropic buried structures under the floor of the church.

Since the building structure underwent several adjustments, foundations or building rests can be supposed to be underground (*Tohge et al., 1998*).

2.1. Description of the radar instrument used

The technical instruments adopted in this study, represented by an acquisition unit and by an elaboration unit, are described here.

The field acquisition unit (RIS2K/MF), a multifrequency array finalized to the hidden structure research, is formed by: (1) monostatic and crosspolar MF 600 MHz aerial, (2) monostatic MF 200 MHz aerial, (3) monostatic MF 600 MHz and RX 200 MHz aerial, (4) monostatic MF 600 MHz and TX 200 MHz aerial and by a (5) four channel radar acquisition (PC Pentium III 266 MHz supplied with a 12 V battery, radar data check card, A/D conversion card and radar supplied and acquisition software by IDSGRAS). The survey was carried out by using only one aerial different array and by setting the bottom of the scale to 60 nsec.

The complete configuration has been obtained by using contemporarily the following radar channels for buried objects: two monostatic channels at 600 MHz (TX1-RX1; TX3-RX3) and two monostatic channels at 200 MHz (TX2-RX2; TX4-RX4).

The standard procedures performed during the acquisition processes were: the assembly and wiring of the acquisition unit, the setup of the system, the setting of the parameters and the check of the correct working. Several actions, focused to optimize the instrumental response, were performed before the phase of the data acquisition.

The calibrations performed permitted us to transform the time signal in depth. The transformation factors have been supposed to be constant in all the investigated area, although it is well known that the velocity of the electromagnetic waves changes due to the distance, to the depth and to the physical characteristics of the penetrated medium.

2.2. Unit of elaboration data

The results were analyzed by means of the RIS2K/MF system elaboration unit, consisting of **(a)** an elaboration station (Workstation Pentium IV; IDSGRED v.5.2 for recognizing the structures; IDSLAYERING for the stratigraphic reconstructions) and **(b)** a CAD station (PC Pentium IV; Autocad 2000; Data-Base Access 2000) for the graphic representation.

These two units work in interactive mode and in real time, with the first one dedicated to the radar data elaboration and the second unit devoted to all the CAD functions. The system is also supported by client with a relational data base, used for the management and the recording of the data.

The measurements were performed through a Subsurface Interface Radar System-3 (SIR-3) manufactured by Geophysical Survey Systems (GSSI) (*Imai et al., 1987*). The experimental set-up consists of 3 aerials of 1000, 400 and 100 MHz, in order to reach a depth of investigation ranging between 4 and 9 m.

The data were analyzed and filtered by using a commercial software "Radan 3", from GSSI (*Galinowsky and Levin, 1990*), which produces graphics filtered by an anomalous signal linked to the presence of eventual interferences. The results were visualized as coloured graphs framed within a depth vs. planar position diagram. A coverage of around 254 linear meters was acquired through 21 profiles in a grid of step of 2 m among subsequent scans. Furthermore, 4 profiles on some wall areas were acquired, for total 10 linear meters.

2.3. G.P.R. results and discussion

The non-destructive GPR system technique is particularly suitable to investigate sites of archaeological interest (*Malagodi et al., 1996; Sternberg and McGill, 1995*). The experimental results are reported in Figures 2a, b and c, where the x-axis stands for the linear dimension and the y-axis for the depth under the church's floor. The distances were calculated using a 2 m marker, from the propagation velocity study of the electromagnetic waves in the subsoil.

Areas with high wave absorbance values were revealed under the floor of the church. This occurrence can be explained by the presence of cavities empty or filled with crumbled materials. The graphs showed the presence of a series of anomalies in the emerging soils, probably due to the presence of both crypts and wall structures (Figs. 2a, b and c).

The radar section of the profile n. 1 (see Fig. 1b), parallel to the aisle axis and 28 m long, is reported in Fig. 2a. The depth of investigation has been of around 9 m and it is possible to see the course of the reflecting surfaces, that allows the identification of buried structures. In fact, the electromagnetic signal detected evidenced the presence of several buried walls, some of them as surrounding crypts in good state of conservation, while underneath there is thickened material constituent the substratum.

The Fig. 2b shows the profile n. 17 (see Fig. 1b), perpendicular to the aisle direction, and 17 m long, performed at around 10 m from the church's entrance, but with shallow investigation. The inclusive area between 1.5 and 4.0 shows some anomalies of propagation of the electromagnetic waves, probably tied up to the presence of wet substratum; in fact, it seems that the penetration of the waves and the consequent reflections are eliminated at an depth between 1.5 and 4.0 m around, especially in correspondence of the existence of the walls (between 2-3 m and between 14-15 m).

Finally, the Fig. 2c represents the result for the survey n. 6 (see Fig. 1b), located near the previous one (n. 17), so allowing to detect the same walls and, in addition, to reveal also the presence of two large crypts. This occurrence is mainly due to the different frequency of the aerials used by the two mentioned surveys; the higher is the frequency of the electromagnetic wave, in fact, the shorter is the penetration depth reached by the wave. The profile n. 17 was performed with a 100 MHz frequency aerial, while n. 6 with a 400 MHz frequency aerial, so the radar section related to profile n. 17 is less deep with respect to that of n. 6.

The following excavation steps, performed along all the radar profiles, with results showing walls and crypts presence, have confirmed the existence of the same structures, with location coincident with the ones of the interpretation except in a few cases, where the sharp location displayed error of about 50-100 cm.

3. Infrared thermo-graphic analysis

The IR thermo-graphic analysis, based on the property that every body spontaneously emits infrared electromagnetic radiation when it reaches a particular temperature over the zero absolute (*Burney et al., 1988*), allows to detect the different inertial thermal behaviour of the materials.

The measurements were carried out by heating the study object and, subsequently, by recording the radiation emitted during the cooling (*Ludwig and Milazzo, 1996*).

Furthermore, this methodology also analyzes the very important thermo-hygrometrical anomalies affecting the wall structures as the presence of water and its changes of physical state (vapour-liquid), responsible for damages of the materials (*Cruciani et al., 1998*).

Inside the church, a thermo IR investigation was performed on the wall structures of the building, in order to detect possible thermal anomalies due to an inhomogeneous building texture or to water capillary rising (*Milazzo and Ludwig, 1998*).

The plan of the inspected areas and the map of the temperature distribution are shown in Fig. 1b. The used instrumentation is a scanner unit, equipped with a Stirling cycle cooling, working in long range (wavelength $= 8 \div 12$ nm), with a 12° focal cone and a control unit for running and registering of the images. For visible analysis, a photographic camera Pentax P50, with a 50 mm optic, was used. To make the thermal discontinuities recording under the plaster layer easier, a heating by thermo-convector with a power of 23.500 Kcal was guaranteed. Contemporary, a thermo-hygrometric measurement was performed (*Balaras and Argiriou, 2002*). To calibrate the instrument response, some known structures were tested, in order to individuate a correspondence between the thermal characteristic of different materials and their spatial distribution. In particular, *Grinzato et al. (2002)* evidenced that compact materials, such as basaltic ashlars, result to be cold, whereas heterogeneous materials, such as mortars, appear uniformly warm and, consequently, it is impossible to distinguish the different components. Furthermore, also compact materials can be detected a little warm because they can absorb heat from neighbouring materials.

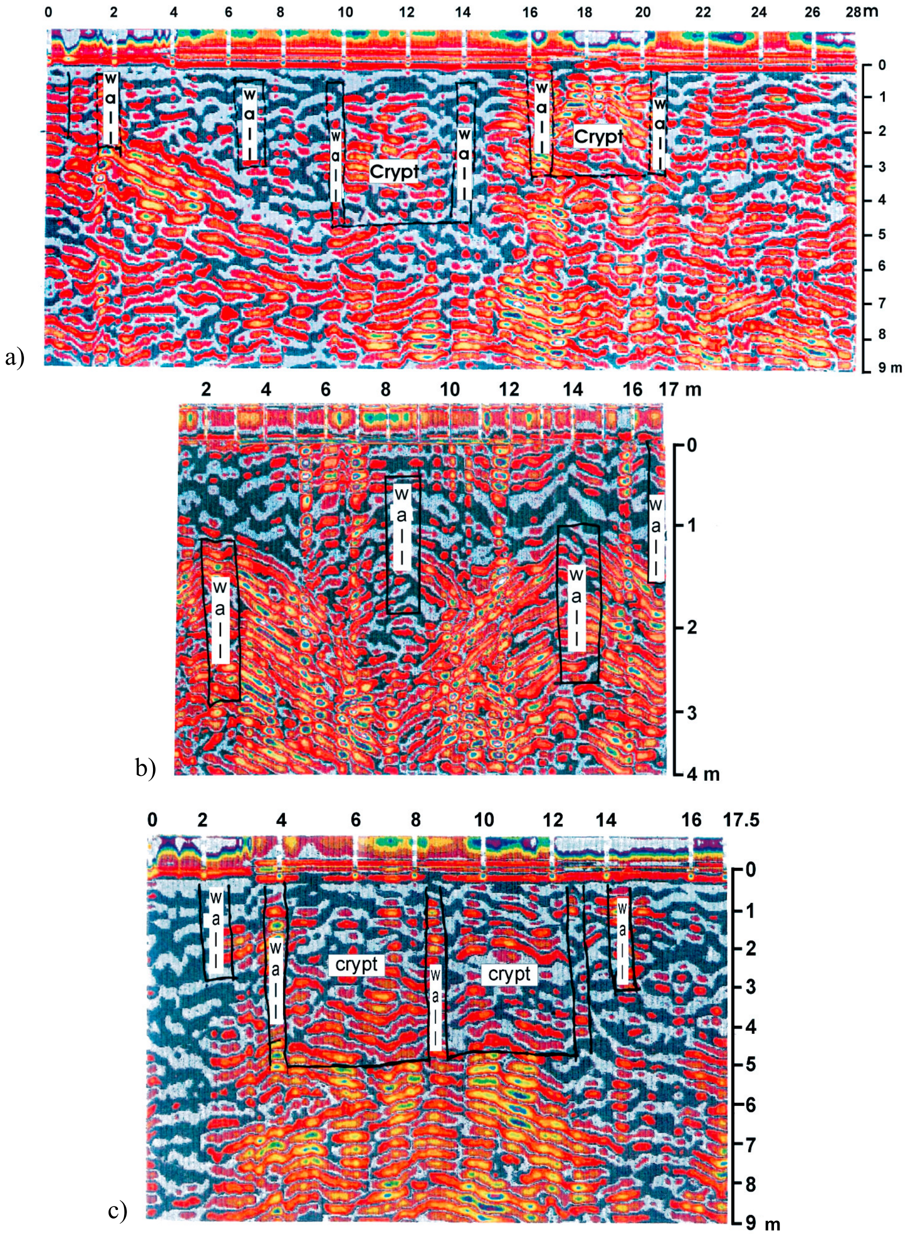

Fig. 2. a), b), c) Images of the georadar profiles. Georadar sections relative to Fig. 2a and 2c were obtained by means of the 400 MHz aerial whereas Fig. 2b shows a georadar section acquired with a 100 MHz aerial.

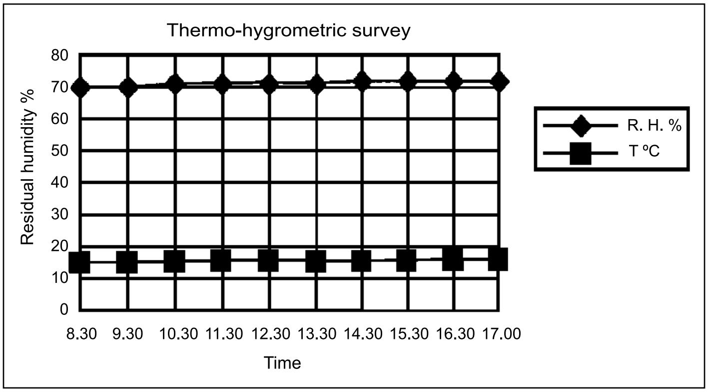

Fig. 3. Thermo-hygrometric surveys diagram. The X-axis represents the time interval of the measurements, the Y-axis shows the Relative Humidity in percentage.

3.1. Thermo-IR results and discussion

During the thermo-graphic survey, temperature and relative humidity were ranging between 15.1-16.2° C and 70-72%, respectively. The parameter values are shown in Fig. 3. Analysing the obtained data, a sensible differentiation among some building texture was evidenced. The images were recorded in emission stage, about 20 minutes from the heating stop.

Figure 4a, shows the thermo-graphic survey on the northern wall of the aisle. The regular shape of the darker parts, images of the cold materials, is indicative for the presence of basaltic ashlars, localized near the altar and with dimension of about 30×10 cm.

Other basaltic elements, but with irregular shape and with dimension of about 10×5 cm were noticed near the column. Moreover, a vertical warm area, located at about 40 cm from the altar, attested the presence of heterogeneous materials, probably brick fragments and mortar. On the apse, some cold but not very sharp zones were revealed, so an irregular arrangement of the basalt ashlars can be hypothesized. Wide warm areas (mortar and various materials) are delocalised all over the wall (*Gaussorgues and Chomet, 1994*).

As concerns the infiltration of water, several areas on the coverage of the apse are affected by active percolation, in particular near the cornice and the columns. Furthermore, a thermal investigation of the roof was carried out. As can be seen by the images, some false vault is supported with a centering. The Fig. 4b shows the photo that represents the real image of the vault.

The inset of the figure is a thermo-IR-image sampling of the same area. In particular, the internal structure of the vault is represented and is very clear the water infiltration in the lower part of the image determining a wide damp area in the lower part of the inset.

4. Drilling surveys

Six drilling surveys, performed with a continuous drilling technique with core conservation, were carried out on the church's walls in order to reconstruct the stratigraphy of the building materials. The samples collected (up to 6.63 linear meters) were successively characterized by physical-mechanical analysis.

4.1. Data analysis and results

Location and stratigraphic sections of the six performed drillings are shown in Figs. 1b and 5, respectively.

The analyses reveal a discrete homogeneity regarding core borings labelled as S_1, S_4 and S_6, which are mainly formed by volcanic squared blocks linked with mortars. The core boring S_2 is different because enriched in a large amount of mortar. The core boring S_3 is very different for the absolute lack of volcanic block as main constituent of the wall; a very hard mortar mixture is present. Finally, the core boring S_5 shows a heterogeneous wall texture, with volcanic blocks and bricks mixed with mortar; nevertheless the investigated depth is lower than the other core borings.

5. Physical characterization of mortars

The stratigraphic scheme of the core borings performed on the walls is reported in Fig. 5. Among them, four samples of mortar, labelled S_1, S_2,

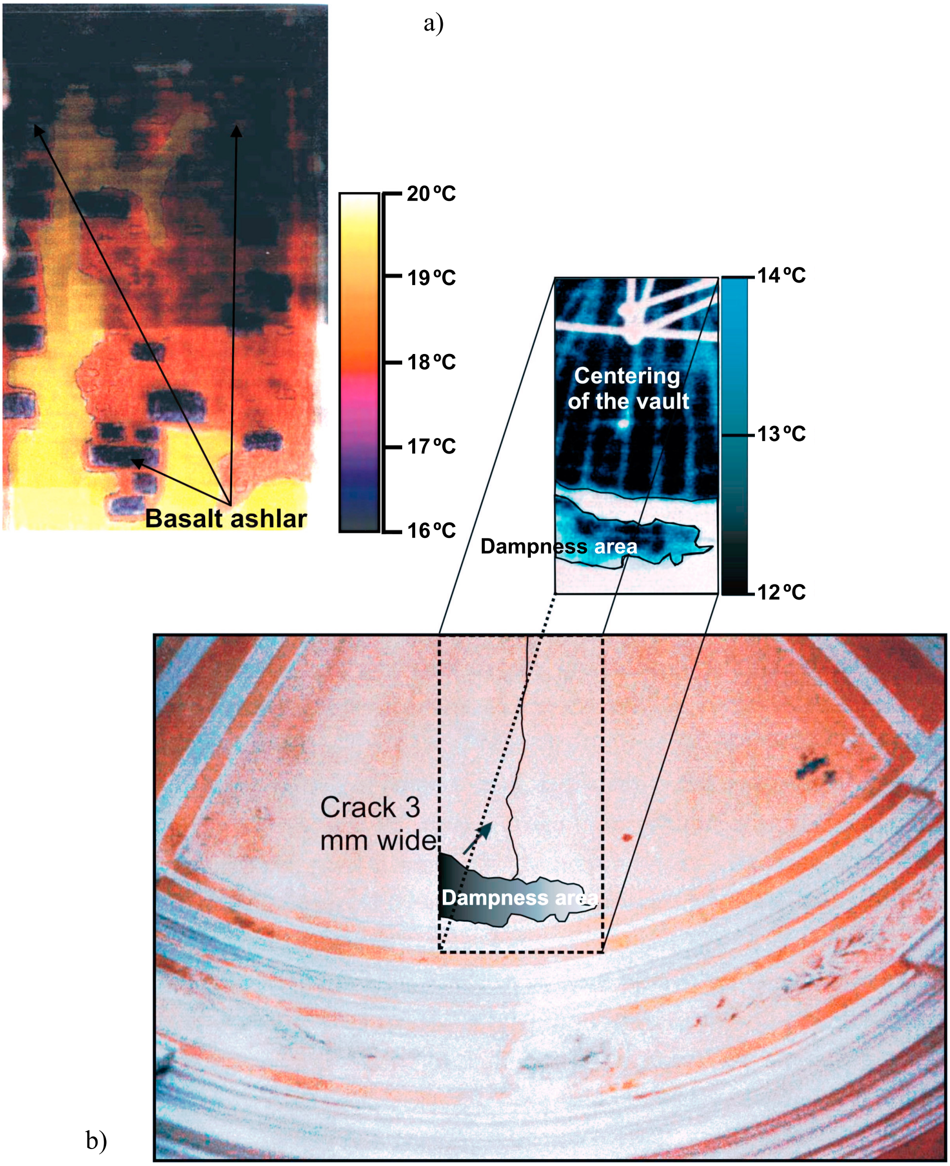

Fig. 4. Thermo-IR images a) texture of the northern wall of the aisle; b) Photo of the vault. The arrow indicate a water infiltration, the same revealed by IR measurement reported in inset. In the lower part of the inset, is clearly evident the large dampness area caused by the water percolation in the vault crack.

S_3 and S_4, were chosen to be analysed.

The measurement of volume weight, dry weight and specific weight on the above mentioned samples was determined by the arithmetic average on three measurements for each sample. The location of the four samples and the corresponding calculated values are reported in Table 1.

Table 1. Physical characterization of mortar samples. Each value is the average on three measurements on the same sample

Sample	**Location**	**Volume weight g/cm**	**Dry weight g/cm**	**Specific weight g/cm**
S_1	column on the left of the entrance	1.660	1.049	2.342
S_2	central column on the right of the aisle	1.864	1.772	2.570
S_3	northern wall of the apse	1.902	1.784	2.737
S_4	external wall of the bell-tower	1.964	1.712	2.588

The results for samples S_2 ,S_3 and S_4 show a dry weight (corresponding to the weight of a sample of unit volume, without water) value similar to those of the typical local mortars. The value of dry weight for sample S_3 is slightly higher, probably related to a mixture of mortar and cement.

Although the sample S_1 shows a specific weight similar to that of the other samples, the volume weight and dry weight values are rather lower and very different from the value typical for carbonate mortars, probably due to a very high porosity of the materials.

6. Conclusion

The results of the G.P.R. investigation performed in the church of S. Maria del Rosario in Motta S. Anastasia (Catania, Italy) bear witness to some anomalies in the flooring, related to the presence of crypts and wall structure in the interior of central parts of the aisle and near the altar.

In particular, it has been noted that the use of different aerials has allowed to have high resolution images along the performed radar profiles, even if sometimes the underneath sediments show zones where a high percentage of humidity was present.

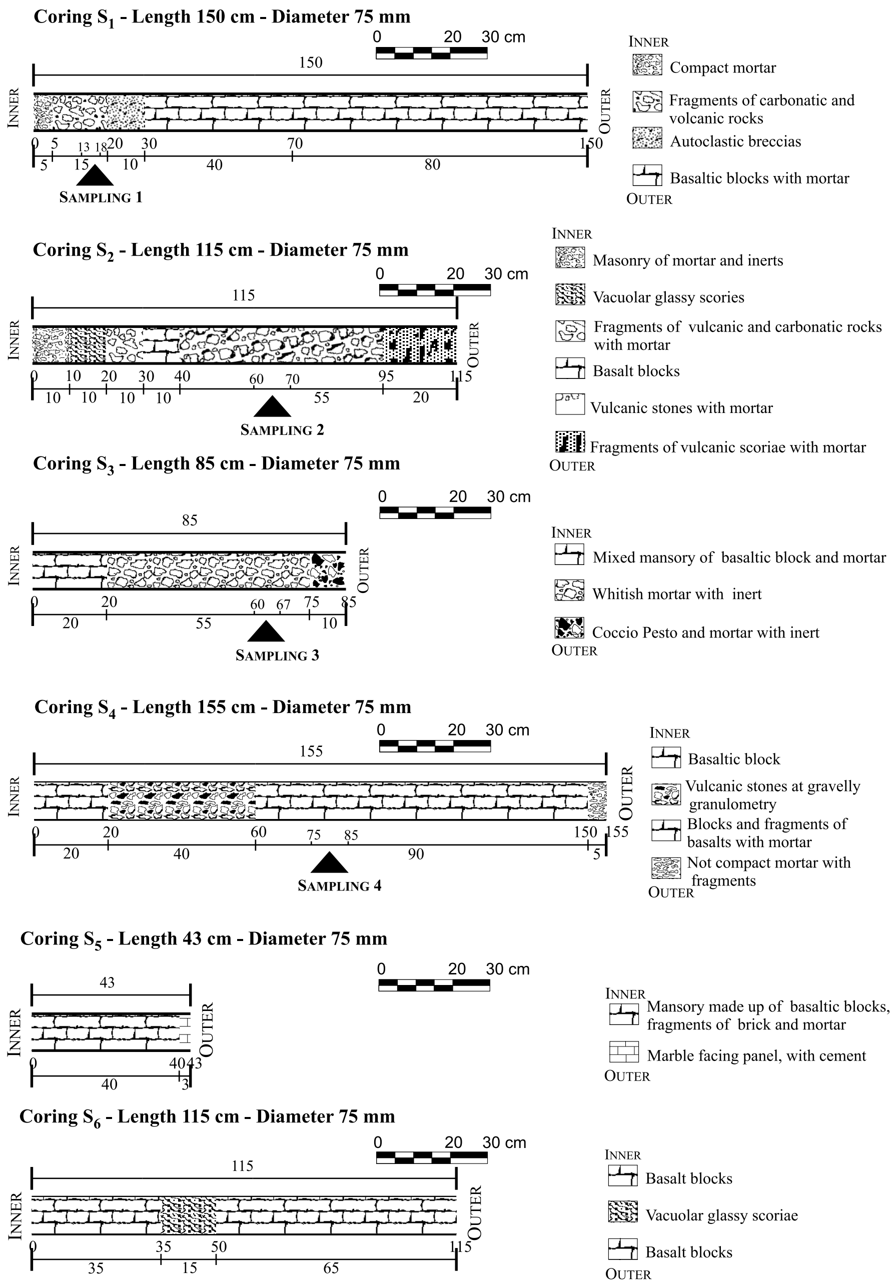

Fig. 5. Stratigraphical sections related to the drilling surveys.

In some georadar profile (Fig. 2a, 2b) the reflecting surfaces seem to be till 1–3 m deepness, but this just a wrong interpretation due to a water presence.

The thermo–IR analysis allowed to reveal a wide inhomogeneousity in the wall structure, thus testifying a differentiated texture in the building structure.

Furthermore, thermal anomalies probably due to water capillary rising in the walls were detected. Damp is a strong damaging cause, second in importance only to the structural deterioration, for ancient building; moisture investigation in walls is one of the most reliable application of IR thermography in Cultural Heritage preservation.

Regarding the six drilling surveys performed at the church's walls, the stratigraphic sections show a similar structural composition, with the exception of a local abundance of mortars coupled with a lack of volcanic blocks.

Finally, some physical parameters performed on four samples of mortar, drawn by the core borings, result to be similar to those of the typical local mortar and of a mortar and cement mixture, and they are also characterized by a very high porosity.

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