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Diagnosis for Architectural Conservation

A synthetic report of a campaign of non-destructive and minimally invasive diagnostic tests performed in the church of Santa Maria delle Stelle in Comiso (Ragusa, Sicily)

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***Abstract*—The paper presents the results of a campaign of non-destructive and minimally invasive tests that were conducted in the church of Santa Maria delle Stelle in Comiso (Ragusa, Sicily), which is the larger church in the Diocese of Ragusa. It includes a summary of the reflections that arose during the preliminary surveys and instrumental tests, and reasons that supported the choice of investigations to be performed and methods to be specifically applied for the consolidation of the architectural structures and plaster layers.**

***Keywords*—restoration, conservation, monument, diagnostics**

I. Introduction

Many kind of diagnostic instruments today employed in the field of conservation and maintenance of ancient architecture were born and developed in other sectors of the applied research and industry. In recent times, some diagnostic tools found interesting applications in the conservation of cultural heritage too. It's difficult to import methods and diagnostic techniques, already encoded for other work of research, in the field of conservation of the architectural and environmental heritage; the diagnostic instruments and methods to support a restoration worksite are to be specifically chosen and planned to reach the purpose of conservation.

This paper introduces a specific methodology for architectural diagnosis, conceived to introduce and permeate the results into the conservation project of the ancient Sicilian church. The diagnostic instrumental investigations can certainty localize every defect that architectural structures and finishes reveal and support the maintenance of the material document.

The investigations systems reached high sensibility nowadays and software can support data editing for every single survey to obtain scientific evaluations. But the value of the investigations is subsequently increased by the comparative analysis of all the diagnostic information and it's important for the different data to interact. The analytical methodology applied in Santa Maria delle Stelle church (fig. 1-4) is characterized by the consequent implementation of non-destructive diagnostic surveys and endoscopic observations (respecting a specific sequence) and pursues the finality to elaborate the conservation project of masonry and architectural finishes, in the full respect of the authenticity of monument and its historical stratification.

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Figures 1-4. Comiso (Ragusa, Sicily), Santa Maria delle Stelle Church, external ed internal views.

II. Radar investigation

The radar system that was used in the church consists of a device that emits high-frequency radio waves and receives electromagnetic reflections. The basic instrumentation includes the radar generator, a pair of antennas (combined into a single transceiver instrument) and a storage and data processing unit. The system has been configured to use an antenna with a frequency of 1600 MHz for the investigation of the walls and with a frequency of 600 MHz to investigate the volumes below the flooring.

When the electromagnetic waves just emitted by the transmitter encounter a discontinuity that reflects some of the energy, it returns to the receiving antenna. A pulse with a shape similar to that transmitted is generated and displayed in the laptop; it will then be processed to obtain the final radar sections. The result of the reflection is represented by a set of hyperbolic pulses of varying size. The electromagnetic waves show reflections whenever they interact with a cavity, a discontinuity or materials of different type inside the investigated section. The reflections of the electromagnetic waves, in particular, are generated every time the impulse passes through an interface formed by contact between materials with different dielectric constant.

The radar scans show some defects found through the investigation, as small cavity that generates simple and recognizable hyperbolic reflections, system of small cavity highlighted by irregular reflections and crossed hyperbole, compact section with the absence of electromagnetic reflections, discontinuity or lesion characterized by a system of reflections oriented towards specific directions, presence of humidity that involves the absorption of electromagnetic waves, and defects in adhesion between layers recognizable through the localization of layered reflections (fig. 5-6).

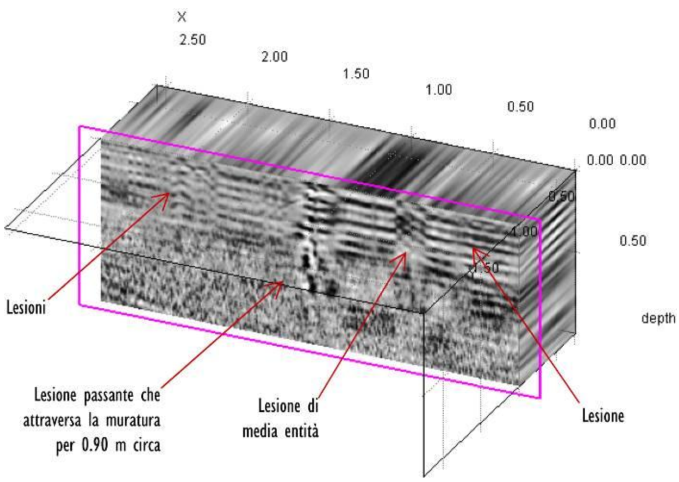

Figure 5. Volume of three-dimensional electromagnetic reflections in which the fractures within the masonry are made evident.

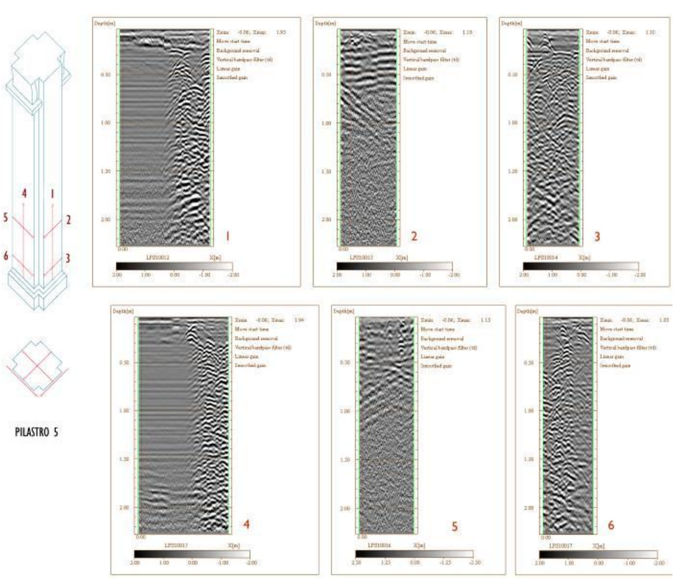

Figure 6. The base and the pillar show the reflections of the signal demonstrating different levels of compactness.

The radar survey does not solve all the problems related to the structural characterization of the architecture, but allow you to evaluate stratigraphic aspects, estimate the thickness of the wall texture, locate cavities and discontinuities, and assume the presence of objects hidden inside the walls. Moreover, the presence of moisture is clearly indicated by the attenuation of the electromagnetic signal, with the absence of reflected waves.

The maps filtering process took place in laboratory with the use of specific software; filtering improves the final graphs and highlights abnormalities and their location. The interpretation of the maps is then possible after the final filtering process; the development of three-dimensional graphics and tomography is also useful when the lesions inside the walls need to be localized. The radar survey was carried out by acquiring the electromagnetic scans both on the vertical surfaces (walls and pillars) and on the horizontal flooring, inside the church and outside, around the profile of the architecture. Prospecting is made with parallel scans at a constant distance, or along linear paths on the walls. Some very dense grids of acquisition have been drawn to study in greater depth and good resolution the walls of the tower facade.

III. Thermography

The emission of electromagnetic radiation in certain frequency bands of the mid and far infrared can be detected by an infrared camera, which scans the framed objects and instantly provides false colour images of opaque surfaces radiant intensity. Electromagnetic radiation is converted into electrical impulses and then into graphics with colour tones that vary in proportion to the intensity of the impulse. The temperature of the objects can be detected at a distance, without any contact with the surfaces and with extreme sensitivity, avoiding the assembly of scaffolding.

The thermography in “active method” was used to investigate the inner surfaces of the church (artificial marble on pillars, interior of the dome): it measures the temperature reached by the surfaces as a result of overheating due to a source of artificial heat (one or two fan heaters with hot air flow of 650 cubic meters per hour) and is optimal for the non-destructive monitoring of the degradation phenomena on finishing surfaces (fig. 7-10). The thermographic survey of the plaster and the exterior surfaces of the dome was carried out after the rise in temperature induced by sunshine during the day (fig. 11-12). The graphical representation of the spatial distribution of thermal levels and the control of its variation in time, allow detecting defects in the structure of the material, which cause locally alterations of thermo-physical properties. The thermographic method is then targeted to the location of defects in adhesion of the surface layers and humidity caused by phenomena of capillary ascension or infiltration.

In order to support the analysis of moisture, the colder areas because of the evaporation process in progress can be highlighted and the extent of the phenomenon can be seen. Wet areas are visible because they clearly correspond to colder

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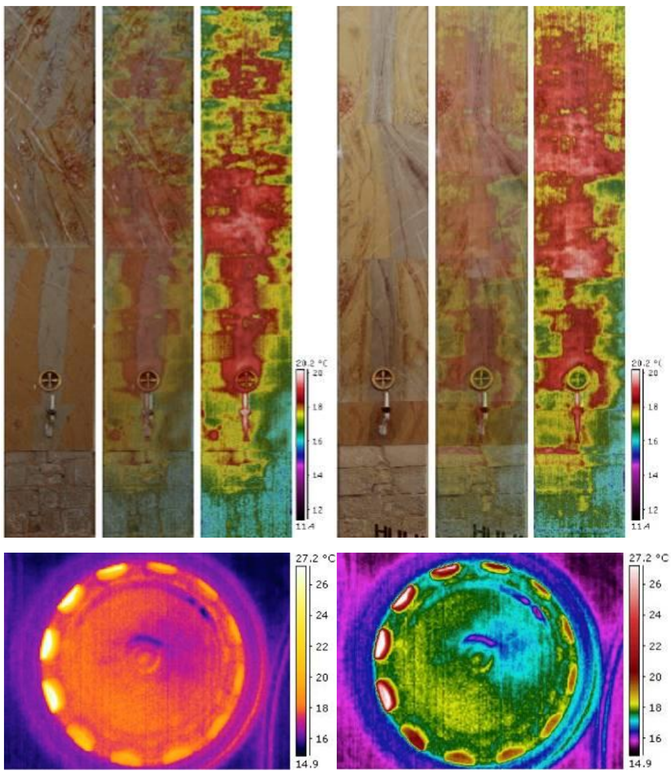
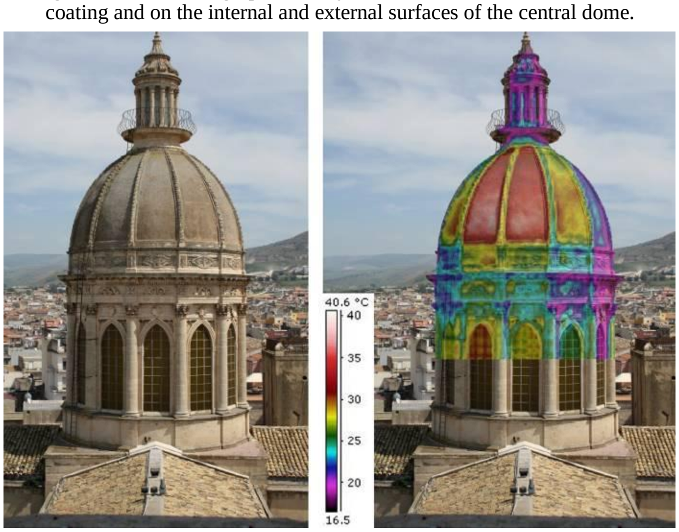
areas and the path of the water in materials is emphasized. The digital thermograms were then processed with the use of specific set of software: to make an accurate analysis of the infrared images, each thermogram was returned by mosaicking on the visible rectified image of the surface, without the perspective distortion. The final maps are therefore metric mapping of surface temperature distribution, which support useful and rigorous diagnostic assessments. The colour tone of the final graphics are obtained by combining the scale of the temperature measured at the surface to a scale of false colours, thus obtaining an interpretative model of the state of conservation that allows you to identify, with precision, the anomalies in the more superficial layers of coating.



Figures 7-12. Thermographic survey carried out on the artificial marble coating and on the internal and external surfaces of the central dome.



IV. Ultrasonic and sonic tests

The study of the propagation of ultrasonic and sonic vibrations in the walls of the church has been applied. The propagation speed of mechanical pulses is a function of the elastic characteristics of the Comiso stone masonry (modulus of elasticity, Poisson coefficient) and its density. Each inhomogeneities (cracks, degraded areas) changes the speed and the direction of propagation, reflecting and refracting the wave of vibration, partially mitigating it according to certain directions; analyzing these processes it is possible to assume that specific inhomogeneities are causing them.

The survey was performed by the indirect method (damaged piers of the central portal), with coplanar probes, and by the direct method (or transparency mode) on the interior pillars. In both cases, the wave packet has completed a course within the investigated material, returning a signal with different transit times or propagation speed when crossing layers with different characteristics or density.

The sonic/ultrasonic test instrumentation consists of the central unit for data acquisition and processing, the transmitter probe for the ultrasonic survey (masonry near the portal), the instrumented hammer for the sonic investigation (thick section of pillars), the receiving wideband probe and the palmtop computer with cable and bluetooth connection to the central unit; the computer screen enables you to see the graph of the pulse between the probes. The transmitter probe (or the instrumented hammer) produces ultrasonic pulses (or sonic pulses) with predefined frequency. The receiving probe auscultates the pulses after they have crossed the masonry interposed. The counter measures the transit time of mechanical waves and a peak-trough graph appears on the display. The crossing time is put in relation to the thickness of the material and crossing velocity is obtained by applying appropriate mathematical method.

The types of probes used during the investigation were selected according to the thickness of the walls to be investigated. Recording the speed of propagation along a square mesh grid, the ultrasonic tomography has been developed. The measurements are shown in the graphs and the areas with defects have lower speeds of micro-seismic waves and increased transit times (fig. 13).

V. Endoscopic inspection

The evaluation of static instability in the structures required the inspection of the internal parts of the walls. The inspections were carried out by inserting the endoscope head in lesions but, sometimes, it was it necessary to make holes in the walls with a drill. The endoscope is a bundle of optical fibres inside a sheath: a part of the fibres carries the light energy at its end (except a small part which is absorbed), the remaining part carries the image to the storage device. To record images and video clips of the internal parts, a digital camera was coupled to the endoscope with a specific connection element. The endoscopic system applied to the case of Santa Maria delle

Stelle church is composed of a fiberoptic endoscope and a digital camera; the camera has been properly set to display and store the images transmitted by the optical fibbers in the best resolution.

To improve the graphics performance of images, characterized by high radiometric contrast areas, the camera was set to a nominal sensitivity of ISO 800 with very low contrast values. The assessment of exposure was estimated through the camera's internal exposure meter (TTL) using a sensitivity of -0.5 EV on an evaluation matrix system. The sharpness is improved by placing the camera to focus on the macro setting and using the appropriate ring of light scope. Some limitations are however perceived during the test: the first is the inspection of limited portions of the inner surface, the second is the background noise caused by the optical fibbers. Despite the limitations of endoscopy, inspection of internal parts has provided important information to refine the analysis of the crack (fig. 14).

Figure 13. A lesion in the wall near the entrance central portal. Ultrasonic tomography processed with the measurements of pulse propagation time between the probes.

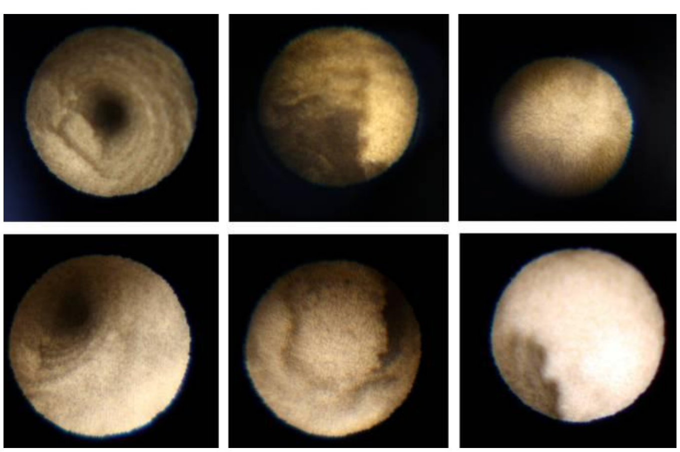


Figure 14. Observations inside the masonry (squared blocks of Comiso stone linked with lime mortar) made with a optical fiber endoscope.

VI. Evaluation of dampness

The positioning on the wall surfaces of the electrodes allows measuring the amount of water in percentages. The measure is effective when the water rises up by capillary action in the pores of the stone and tends to evaporate on surfaces. The measures of weight or volumetric content of damp were discarded because it would be necessary to collect many samples of material, at different heights and depths, damaging stone surfaces.

The most effective and direct method to measure the values of moisture is via the control units with electrodes. In damp walls, the water has spurred the passage of current between the electrodes, closing the electrical circuit. The intensity of the current is proportional to the amount of water in the material and activates the detector with a digital display where you can read the humidity level, expressed as a percentage. The instrument also has some additional devices to make measurements in the elements that have an irregular shape (like the heads of the deteriorated wooden beams).

The measurement of the amount of water on the walls has been made along a grid of acquisition traced on walls and pillars. The psychrometric charts of the wet front have been represented by combining the percentage of moisture to a graphic scale. The final charts can than be imported in cad software as raster images and further processed.

VII. Conclusions

The restoration of Santa Maria delle Stelle church in Comiso has been designed by the Superintendence for Cultural and Environmental Heritage of Ragusa, which sought the advice of the research laboratory LIRBA (University of Palermo, UniNetLab). The synergy between these valuable cultural and scientific resources allowed the achievement of high quality standards in the preliminary diagnosis and restoration planning, in view of the worksite opening. The sharing and exchange of knowledge make it possible to achieve original results in applied research, with positive effects also in the professional sphere of conservation of cultural heritage.

The Italian sectorial rules confirm and underline the importance of the diagnostic tests, to be carried from the stage of preliminary project. The local authorities responsible for protection of cultural heritage allocate large sums upon performance of diagnostic tests, preferring non-destructive or minimally invasive tests. But one of the important aspects for Architectural Conservation is the improvement in the training of architects-engineers and technicians who work in the field of restoration and maintenance, still lacking in many aspects.

The case of Santa Maria delle Stelle church is exemplary for its ability to support scientific conservation through the fusion of the diagnosis with the project. The restoration project is in fact a particular kind of architectural project that has the goal to maintain ancient monuments as more as possible. To get this purpose, diagnostic surveys are to be really considered as well as conservation tools. A wrong employment of the diagnostic resources can compromise the quality of the investigation and a negligent iconographic elaboration doesn't allow you to reach the diagnosis that is proper for the intervention yard. No measures are in fact requested if they cannot be processed in order to obtain a preoperative diagnosis: every analytical gesture made in the church became a gesture of operative effectiveness. A correct diagnosis marks the beginning of the curative treatment.

The case study demonstrates that the application of preliminary testing by non-destructive investigation, in combination with the visual observation, generated some very interesting and utilizable results in the determination of the status of architectural structures and finishing. It must be underlined that the results given by diagnostic tests can get a basis for the future procedures of maintenance. The non-destructiveness, in particular, represents a great advantage in the preservation of monuments. We also have to critically consider the significant amount of effort like the technical tools, cost and time as well as the efficiency of the diagnostic findings.

Thermography, radar and ultrasonic survey, in synergy with other tests, offered many essential information that once was possible to reach only through direct investigation, altering the integrity of layers: a clear vision of the degradation entity in those structures to be consolidated has been obtained. The future experience in the field of architectural conservation will surely emphasize the relationship between architectural surveys, instrumental analysis and elaboration of the project. The most interesting developments are the ones characterized by the synergic use of non-destructive testing technologies and laser scanner: this integration produces the metric precision that is requested for the restoration and the sustainable management of our architectural monuments.

Some are developing original research in the fields of computer science and robotics too, in synergy with diagnostics and conservation disciplines. Small helicopters, tracked vehicles, or other types of remote-controlled machine can fly over or observe from the lower level buildings also at risk of collapse. The first drones that move in architectural contexts may inspect the structures and detect the presence of thermal phenomenon, defects or lesions, even when natural events (earthquakes, landslides, mudslides, floods, hurricanes) damaged the monuments and environment.

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