Non destructive investigation for historic documentation and construction qualification of monumental buildings: the case of S. Gregory Church in Bari, South Italy

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Abstract

Although non destructive techniques are mainly used in the restoration of monumental buildings in order to assess the state of conservation and address suitable conservation measures without interfering with the structural integrity, they can be also useful for the identification of the historical and constructional evolution, whereas sources from libraries and archives and/or technical records are limited. The present contribution is going to discuss the application of an integrated system of non destructive techniques on S. Gregory Church in Bari, South Italy. The church, dating back to the XI century AC and located within the medieval fortified city walls, calls attention to some relevant aspects, particularly with reference to pre-existing structures, constructional transformations and previous restoration works. Specifically, based on historical research, mapping of materials/construction techniques and survey of cracking/moisture patterns, an investigation program was addressed, comprising sonic and ultrasonic testing, thermography and radar scanning. The analysis of experimental results, correlated with the historical and technical documentation, enabled a more detailed and reliable qualification of the evolution of the church, with specific attention towards structural components under the flooring, morphology and compactness of cavity walls, previous reinforcement techniques, as well as damage patterns on walls and columns and moisture patterns on a fresco. Furthermore, the importance of the results for the definition of future conservation and control strategies is discussed.
Keywords: architectural heritage, historic and construction qualification, NDT.

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1 Introduction

Monumental buildings should be studied according to the historical method, where sources play a prominent role. In fact, since they might be considered as the result of a distinctive process of development and transformation, the analysis of current aspects - spatial configuration, materials and construction techniques, architectural and artistic values, technical and functional characteristics, state of conservation - should involve a comprehensive research about their evolution throughout the time.

Sources can be certainly examined in libraries and archives, providing scientific and technical bibliography, as well as original manuscripts, records, accounts, drawings, sketches, models, maps and acts. Nevertheless, they can be supported by direct observation on the building, since onsite investigation and historical documentation are correlated aspects of the same preliminary knowledge, where all the relevant phases of the restoration process - analysis, diagnosis and intervention - come from.

Non destructive diagnostic methods and techniques can offer a valuable contribution to that knowledge. They have been thoroughly tested and applied on monumental buildings over the last decades, in order to support damage identification procedures and address suitable conservation measures, without interfering with the structural integrity [2, 3, 5–8]. However, they could be also very useful for historical and constructional qualification, particularly whenever sources from libraries and archives are limited and, thus, field survey methods are fundamental.

The present contribution is going to discuss the application of an integrated system of non destructive tests to an illustrative monumental building, S. Gregory Church in Bari, South Italy, where information on some relevant evolution phases was incomplete, but fundamental for the interpretation of occurring damage patterns. Thus, the investigation could address the improvement of the available sources, as well as the reliability of the diagnosis. Although aims, methods and results were targeted on the specific case study, it is worth mention that several representative situations were comprised, requiring different procedures and techniques, always selected according to some common well established criteria: feasibility, efficacy and correlation.

2 Background

Saint Gregory Church, located close to Saint Nicholas Basilica within the fortified walls of the historical centre of Bari, South Italy, is the most ancient church, entirely preserved and still operating, in the city (fig. 1). It is Byzantine styled with simple and massive walls, made out of local limestone squared blocks (fig. 2). The rectangular floor plan is east-west oriented, parted into three naves by eight monolithic marble columns and two limestone masonry pillars, and enclosed by three apses on the east side (fig. 3). The interior is not decorated, except from an oil painting on wood and a fresco on the north façade. The roof is composed by three fields of wooden trusses.

Figure 1: Aerial view of historical centre of Bari and S. Gregory Church.

Figure 2: South side of S. Gregory Church in S. Nicholas Square.

Figure 3: The three apses of S. Gregory Church.

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According to the sources in the Archive and Library of Saint Nicholas Basilica, the church was built in the XI century A.C., within the Katepano Court, where the Basilica was erected at the end of that century. From studies on the evolution of the historical centre in the Middle Ages, most scholars consider that the original spatial and architectural configuration of the church has not been changed over the time. Nevertheless, the possibility that the building was founded on previous structures is not ruled out, although not supported.

The limited historic records, dating back from the XIII till the XIX century, never provide a description of the church, in terms of constructional features and/or decay conditions. Only some references to pastoral visits of the XVII century were found that confirm the present arrangement and mention the presence of internal decors and ornaments in Baroque style.

Differently, the historic and construction evolution of the church in the XX century is clearer, particularly for the restoration programmes that were carried out from 1938 and from 1960. The available technical documentation on those phases is crucial for understanding the present characteristics and pathologies of the church, even though it is focused only on some specific aspects.

The first restoration phase from 1938 was needed because of the severe decay of the church. Specifically, the drift of the cross vaults on the north and south facades, the missing mutual connections of the masonries and the poor consistency of the inner part of all the cavity walls had caused a diffuse damage pattern: deformations of the facades toward the outside, vertical cracks in the corners, vertical cracks in the transversal section of the openings. In order to deal with the occurring rotation, some interventions were carried out: cross vaults were replaced by wooden trusses to eliminate the drift, most stone blocks at the corners were replaced to improve the connections and some metallic elements were used to tie the north and south facades. Those interventions are still visible in the church (fig. 4). Moreover, on that occasion, some complementary works concerned the realization of a drainage system under the flooring and the elimination of all Baroque decors and ornaments.

Figure 4: Interior of S. Gregory Church showing the wooden trusses and the metallic ties above the pillars and columns.

The second restoration phase from 1960 was needed because of the damages caused during the Second World War and worsened by the explosion of the ship Henderson in the harbor of Bari in 1945. Particularly, nine wooden trusses were collapsed and replaced. Moreover, the masonry pillars showed vertical cracks due to upper compression loads and, thus, consolidated by reinforcement bars and epoxy resin later in the 70s.

Nowadays, the church shows a fair state of conservation. However, based on the survey and mapping of damage patterns and decay tables, some critical situations might be pointed out: vertical cracks at the base of one pillar that is locally reinforced by metallic plates; vertical cracks in the transversal section of the openings; and diffuse moisture table in the upper part of a fresco on the north facade.

3 Investigation

3.1 Aims and methods

Based on the information from historical research, mapping of materials/ techniques and survey of damage patterns, a non destructive investigation programme was carried out in order to improve the historical and technical qualification of the monument.

Specifically, a system of diagnostic methods and technologies was applied to achieve a more comprehensive understanding about construction characteristics and previous restoration works that are not fully documented by historical and technical records, as well as current crack/moisture patterns of the church (fig. 5).

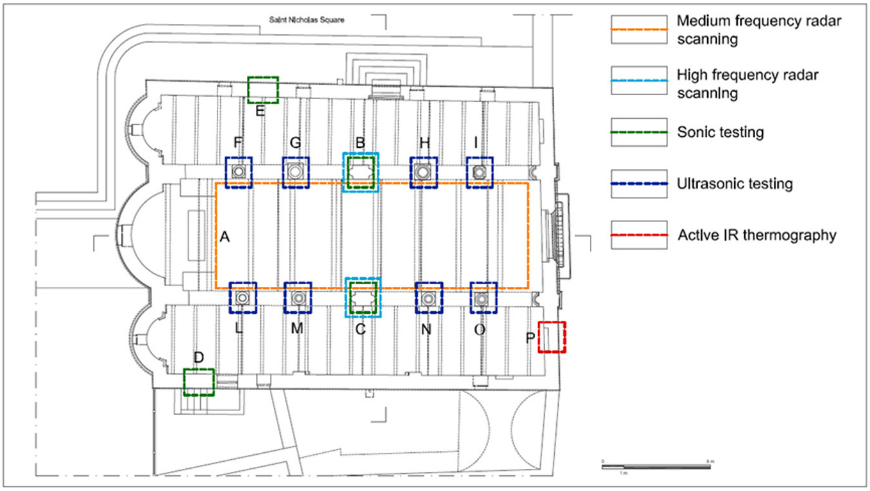

Figure 5: Plan of investigation tests.

In detail:

- The flooring of the central nave (A) was inspected by radar scanning, in order to detect the reflection of medium frequency (600 MHz) electromagnetic waves and, thus, identify some underground structural anomalies and/or peculiarities, eventually connected with the historical evolution of the church. Measurements were acquired by DAD 1ch Fastwave IDS reading unit and IDS TR/600 antenna. A 35cm spaced grid was used, covering all the investigated area, in order to elaborate the radar tomography.
- Masonry pillars (B and C) were inspected by radar scanning at higher frequency mode (2GHz), using TRHF 2000 antenna, in order to get accurate information about their morphology, as well as the arrangement and effectiveness of the reinforcement works carried out in the second restoration phase. The measurements were acquired by a 6 x10 grid, 10 cm spaced, corresponding to the bottom of the pillars, in order to elaborate the radar tomography. The investigation was supported by the visual inspection of the holes filled out by resin and by magnetometer detection of the bars on the surface.
- Two areas on the pillars (B and C) and two areas on the north and south walls (D and E) were investigated by direct mode sonic testing in order to detect the travel time of low frequency mechanical waves though the structures and, thus, assess their compactness and homogeneity. Particularly, the measurements were evaluated by comparison to understand whether the first restoration phase somehow concerned the inner parts of the cavity walls that were found poorly consistent then and are still cracked in the openings nowadays. A CMS-V3H equipment was used, consisting of a reading unit, one piezoelectric hammer as emitter and one piezoelectric transducer as receiver. The measurements were acquired on 5 x 5 points, 25cm spaced, for the walls and 3 x 3 points, 25 cm spaced, for the pillars, in the same areas where the radar investigation was carried out. The receiver was coupled by modeling clay with the surfaces.
- All the eight monolithic marble columns (F, G, H, I, L, M, N and O) were investigated by direct mode ultrasonic testing, in order to measure the travel time of high frequency mechanical waves though the structures and, thus, detect some discontinuities, as they are visible in one of them (L). The same CMS-V3H equipment was used, with one piezoelectric transducer at high frequency (55 kHz) and power (> 1,6kV) as emitter. For each column, the measurements were acquired for five paths, namely across one diameter at five levels (0.4m, 0.7m, 1m, 1.3m and 1.6m from the flooring). Moreover, for the cracked column (L), thirty-four paths were measured at one level (1.2m), corresponding to the upper part of the cracks, in order to elaborate a tomography of the structure.
- The moist fresco (P) was analyzed by active thermography, by Neothermo TVS-700 (Avio), in order to identify the extent and origin of humidity. The surface was heated by IR Term 2000 lamps, in order to enhance the emission and reduce the influence of surrounding conditions.

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3.2 Results

The radar tomography on the flooring steadily showed the intersection of the rhombus tiles under the surface, while some areas at different response could be clearly detected from 15cm till 65cm in depth, at the west side of the altar and at the south border of the central part of the nave (fig. 6). Those areas, whose reflection is higher than the average, might eventually correspond to underground cavities, with quite regular shape. The church site was certainly used in the past as graveyard, as testified by the eleven inscriptions on the south façade. Even though the burial of members of noble families generally took place outside the place of worship, it is plausible that small charnel houses were located inside. On the contrary, the presence of underground walls, belonging to previous construction phases, seems to be more doubtful, because the depth of those areas is quite limited and the expected response would have been a lower reflection, thus a higher attenuation, compared to the surroundings. However, the investigation provided valuable information to guide some local destructive tests.

As far as the radar investigation on the pillars is concerned, the 2D radargrams showed the morphology of the structures, composed of stone blocks, 20cm thick, all along the perimeter and an inner cavity (fig. 7). Moreover, the 3D elaboration enabled the identification of the reinforcement work. Specifically, the presence of slightly inclined bars was detected by tomography that goes through half the depth of the pillar (fig. 8). Based on the arrangement of the holes, as detected by visual inspection and magnetometer testing on the four sides (fig. 9), it was assumed that those bars create a tridimensional grid within the pillar, whose tensile strength has been eventually improved.

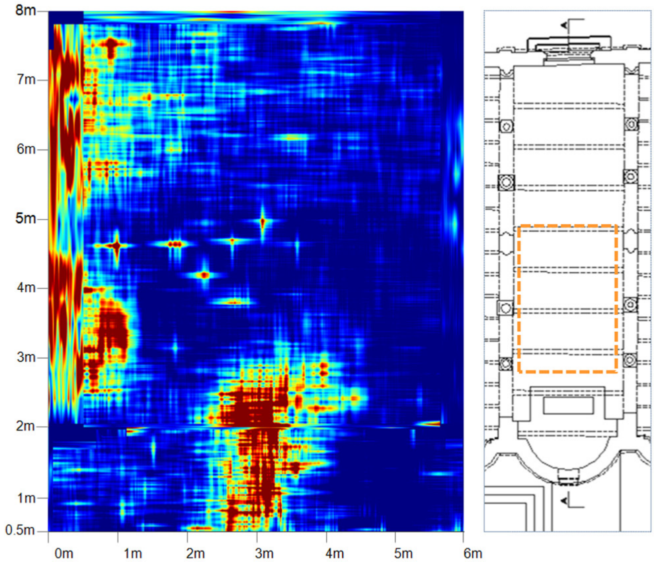

Figure 6: Flooring tomography (30cm depth), showing a structural anomalies.

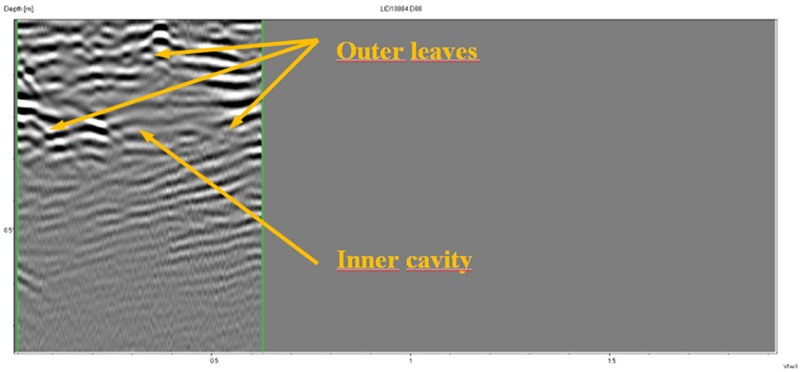

Figure 7: Radargram of pillar C showing the construction morphology.

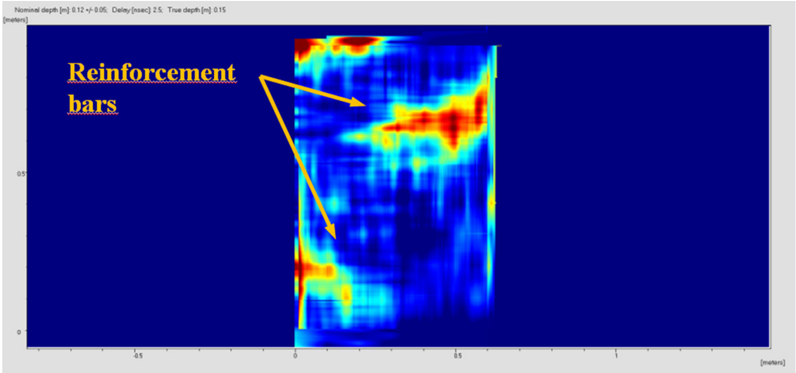

Figure 8: Radar tomography of pillar C showing the reinforcement bars.

Figure 9: Surface position of reinforcement bars on pillar C.

Sonic testing confirmed the previous results. Specifically, measurements showed quite different values: on the pillars, the average velocity was 2112.3 m/s for B and 2470.4 m/s for C (fig. 10), whereas, on the walls, it was 1105.8 m/s for D and 1437 m/s for E (fig. 11). All the data was acquired and elaborated, according to a procedure developed by the authors within a previous work [4]. Thus, it was speculated that all the investigated structures, both pillars and walls, have similar thickness, about 70cm, and similar morphology, comprising two outer leaves and an inner nucleus. As a consequence, the higher velocity response of the pillars was only due to the reinforcement, where the lower velocity response of the walls was connected with the diffuse poor consistency of the cavities, which were reasonably not reinforced when the pillars were. Some local destructive tests could confirm the assumption.

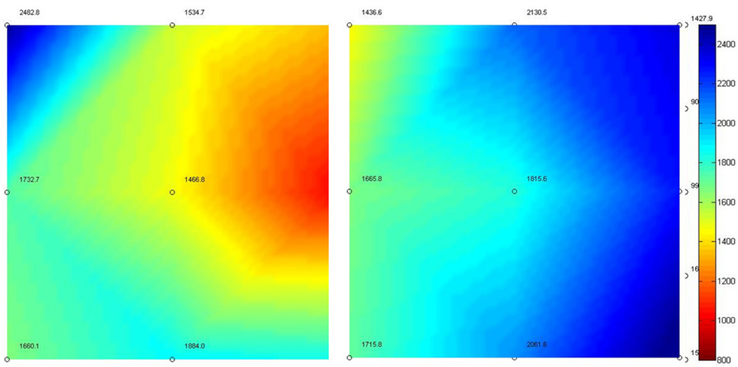

Figure 10: Sonic velocities on pillars B and C.

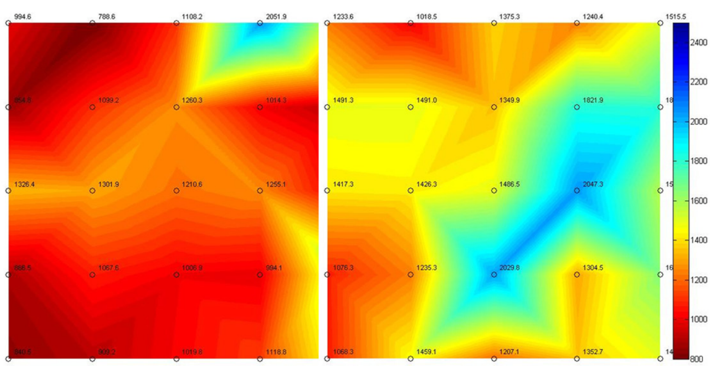

Figure 11: Sonic velocities on walls D and E.

Differently, concerning the ultrasonic testing of all the marble columns, no critical situations were detected. All the velocities were found quite consistent and varied only due to different monolithic materials (fig. 12). As a consequence, the presence of inner discontinuities was ruled out. However, the measurements confirmed the damage of column L, whose tomography (fig. 13), showed that the visible cracks, corresponding to points 7 and 16, cross the whole section, creating a fracture surface, marked by white line. Moreover, it should be underlined that the cracking development has exceeded the area tied up by chains. As a consequence, a damage progression compared to the past could be speculated, requiring further assessment by monitoring.

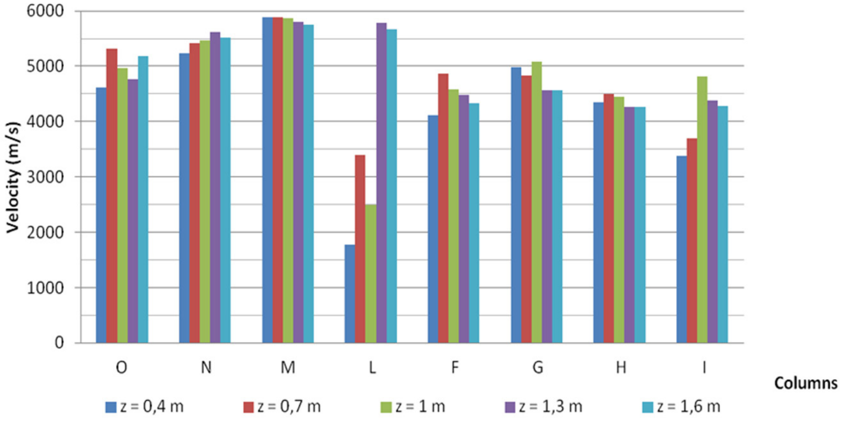

Figure 12: Ultrasonic velocities on all the marble columns.

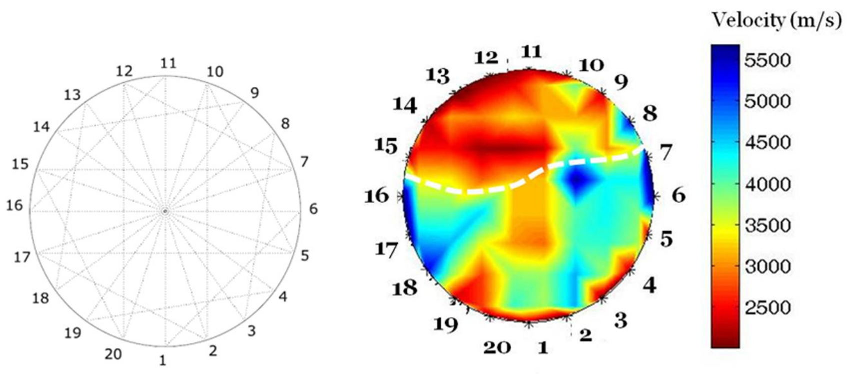

Figure 13: Ultrasonic tomography of column L.

Finally, the active IR thermography helped understand the mechanism causing the diffuse moisture pattern on the fresco. Specifically, the surface was heated for four hours and thermograms were acquired every fifty minutes. Initially, the indoor temperature was 13°C and the outdoor temperature 8°C. IR lamps at 500 W were placed symmetrically at 1m distance and 45° from the surface, according to a procedure, developed by the authors within a previous work, in order to control the temperature increase and distribution throughout the process [1]. The infrared response of the surface showed pretty different behavior between the upper and the lower part of the fresco, as defined by a straight line (fig. 14). In fact, while the upper part quickly dissipated the heat, enhancing the presence of moist areas, the lower part maintained higher temperatures. Thus, it was speculated that the fresco was placed on different supports, showing different thermal properties. Particularly, the upper part was supposed to be less insulating. As a consequence, it might be often cold, causing the air to condensate, especially in winter. The investigation also enabled the identification of an underlying arch and of all the detached parts where the temperature is slightly higher due to air gaps.

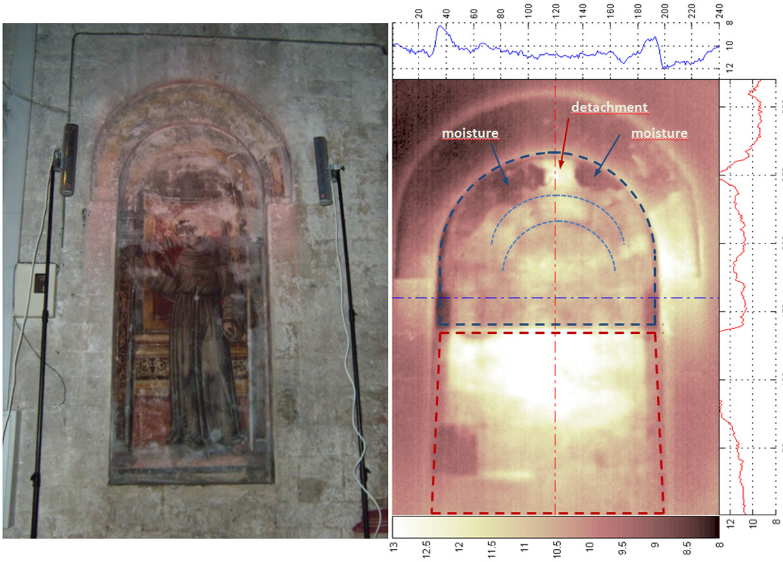

Figure 14: Visible and infrared image of the fresco.

4 Conclusions

Non destructive investigation on S. Gregory Church enabled the identification of some relevant characteristics: presence of underground anomalies, eventually corresponding to charnel houses; configuration of pillars, composed of an inner cavity and previously reinforced by tridimensional grids of metallic bars; poor consistency of unreinforced masonry walls; good compactness of the columns, except from the cracked one, whose damage concerns the whole transversal section; low heat insulation of the fresco, causing condensation.

Within the diagnosis process, all that information might support the interpretation of some mechanisms occurring within the building and, thus, guide the following different phases of the restoration process: local destructive tests,

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e.g. for the flooring and the cavity walls; monitoring cycles, e.g. for the cracked column; conservation measures, e.g. for thermal protection of the fresco.

Nevertheless, first and foremost, the acquired data has implemented the historic documentation and construction qualification of the monument, by improving the available resources about the past, providing a comprehensive picture of the present and establishing a reference scenario for the future, within a long lasting process of development and transformation, which features the distinctive identity of the monument itself.

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