Investigation protocols for onsite assessment of floor and wall components in historical school buildings

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Highlights

Main factors influencing the on-site investigation of historical buildings, in terms of investigation targets and conditions, are identified
Operation methods for acquisition, elaboration and interpretation of radar and thermographic data for traditional floor and wall components are discussed
Experimental results from onsite testing of iron/brick and concrete/brick slabs in school buildings of the early XX century are presented.

Abstract

The paper is going to describe a methodological framework for onsite non-destructive investigation of materials, construction components, residual performances and state of conservation of historical-architectural school buildings. In detail, some operation protocols are proposed and validated as decision-making support tools for radar scanning and thermography of floor and wall components in buildings of the early XX century, in order to achieve reliable and meaningful identification of the actual characteristics and anomalies and, thus, address compatible and low invasive maintenance measures.

Keywords

Historic school buildings, Investigation methods and techniques, Radar scanning, Thermography, Iron/brick and concrete/brick slabs

1. INTRODUCTION

The assessment and control of the school built heritage are crucial topics within the scientific and technical community, at national and international levels. Particularly, in Italy, as well as in most countries in the Mediterranean basin and in the Middle-east regions, school buildings are mainly historic with a great variety of traditional construction solutions. Thus, the on-going programs for structural, energetic and technological retrofitting require methodological guidelines and best practices, in order to address both improvement of performance levels and conservation of architectural values [1] [2] [3] [4] [5].

Within that scenario, onsite non-destructive diagnostic tests (NDTs) play a prominent role. They might enable the acquisition of meaningful and reliable data on the actual behaviour of the building system and sub-systems, without
interfering with the functionality of the places and the stability of the structures. Moreover, they might support the diagnosis of obsolescence and pathologies, particularly when available data on materials and construction techniques are limited. Consequently, they might address the selection and long-term assessment of durability and effectiveness for compatible maintenance and repair measures [6] [7] [8] [9] [10] [11] [12].

Nevertheless, NDTs should be carried out, according to specific operation protocols, based on preliminary data from historic research and direct survey, in order to identify the investigation targets and conditions and, thus, select representative components, suitable equipment parameters, acquisition layouts, elaboration and restitution routines, as well as correlation modes with complementary experimental and analytical data.

Taking into account the above-mentioned issues, the paper is going to describe a methodological framework for onsite non-destructive diagnostic investigation of materials, construction components, residual performances and state of conservation of historical-architectural school buildings. In detail, some operation protocols are proposed and validated as decision-making support tools for radar scanning and thermography of floor and wall components in buildings of the early XX century. The work is part of a comprehensive study, developed since 2013 under the research agreement between the Municipality of Bari and the Polytechnic of Bari for “Scientific and technical support on preliminary tests and analyses for the seismic protection of school buildings in Bari” (Coordinators: Prof. G. De Tommasi and Prof. F. Fatiguso).

2. METHODOLOGY

The proposed methodology (Figure 1) is based on the assumption that planning (P), application (A) and validation (V) of onsite diagnostic techniques should result from the preliminary qualification (Q) of the building, by integrated analysis of historic records, survey of geometry, materials and construction techniques, as well as thematic mapping of cracking, dampness and decay patterns. Particularly, those data should help identify the investigation targets (Q1) and surrounding conditions (Q2), in order to address compatible methods and tools toward accurate, meaningful and reliable results.

Specifically, the investigation targets (Q1) are related, at the planning level (P), with the selection of representative components (P1), technical input parameters of the equipment (P2) and measurement acquisition layouts (P3).

Similarly, the surrounding conditions (Q2) affect the acquisition modes, according to inner building characteristics (P4) and outer environmental and structural factors (P5).
Thus, the above-mentioned planning (P) key-aspects result in specific application (A) and validation (V) procedures, according to the particular diagnostic technique and investigation context.

Nevertheless, in all the cases, the selection of representative components (P1), in terms of typology, number and position (A1), is generally based on the validation goal, which might be the assessment of unknown building characteristics and anomalies by extensive investigation or elsewhere the confirmation of available data from preliminary historic research and direct survey (V1). Similarly, for all the diagnostic techniques, it can be stated that the onsite experimental data should lead to the final diagnosis (D) on the residual performances (D1) and state of conservation (D2) only by aware correlation with further destructive and non-destructive tests, analysis of similar case studies and historical-technical handbooks.

Based on the above-mentioned general framework, the methodology is developed below, at the application and validation levels, for specific techniques – thermography and radar scanning – and domains – stone cavity or solid walls and iron/brick or concrete/brick floors in buildings of the early XX century. Particularly, some results are presented and discussed, based on the experimental investigation on some representative school buildings in Bari (Figure 2 and Figure 3).
3. RESULTS

As far as the thermography is concerned (Figure 4):

- The technical input parameters of the equipment (P2) involve the direct measurement of infrared emissivity and reflected temperature of the surface under investigation (A2). The accurate assessment of those parameters enables the quantitative, rather than qualitative, detection of the infrared emitted radiation and apparent temperature (V2).

For the specific application, the qualitative thermography, which is simpler and faster, satisfactorily enabled the survey of morphology and decay of both floor and wall components, whereas the quantitative thermography would be more suitable for analysing the operation modes of HVAC systems.

The measurement acquisition layout (P3) concerns the relative position between thermocamera and surface (A3) and, thus, the frame angle and extent (V3).

For the case studies, wide-angle images supported the detection of morphology of slabs – number and direction of bearing iron or reinforced concrete beams – and walls – arrangement of stone blocks and mortars and presence of reinforced concrete pillars and beams. Differently, zenital images enabled to survey the dimensions of all the construction elements, knowing the distance between sensor and surface and the view factor of the thermocamera.

The acquisition mode according to the inner building characteristics (P4) refers to two conditions, which make the detection of thermal gradients feasible. The first is the presence of a significant heat flow crossing the component due to the temperature difference between its border surfaces – intrados/extrados for slabs and inner/outer facades for walls. The second is
the presence of materials under the investigated surface showing different thermal properties.

The former factor might lead to the employment of infrared lamps in order to increase low thermal exchanges (A5.1) by active thermography, rather than passive thermography (V5.1). In the case studies, the worst conditions occurred in internal walls and floors, where the temperature was almost steady on both the border surfaces, thus requiring artificial heating.

The latter factor might require ruling out some areas where similar materials are expected (V5.2). In the case studies, that happened for continuous concrete slabs or for walls with tuff blocks and cement-based mortar joints that show similar thermal capacity and conductivity.

The acquisition mode according to the outer environmental and structural factors (P5) concerns the need to avoid visible obstacles (A5.3), such as scaffoldings, furniture, false ceilings and thermal obstacles (A5.4), such as heat sources, direct solar radiation, high infrared reflectivity surrounding elements that might interfere with the measurement feasibility either/or reliability. The above-mentioned obstacles were always avoided in the experimental campaign. The following Figure 5 shows some illustrative thermograms with some of floor components, which were detected in the investigated school buildings.
As far as the radar scanning is concerned (Figure 6):

- The technical input parameters of the equipment (P2) involve the selection of suitable antennas (A2.1), since high-medium frequencies (1GHz – 2 GHz) enable shorter investigation depth and higher geometrical resolution (V2.1) compared with medium-low frequencies (600 MHz – 400 MHz).

In the case studies, all the slabs, about 25cm – 30 cm thick, were thoroughly investigated by high frequency antennas (2 GHz) with satisfactory accuracy in detecting even small inclusions, such as the lower transversal metallic bars in concrete beams. The same experimental set up was appropriate for solid walls with comparable thickness. On the contrary, solid and cavity walls, up to 80 cm – 100 cm thick, required medium frequency antennas (600 MHz), which guaranteed good signal propagation along the component, reduced multiple small reflections due to the numerous interfaces between stone blocks and mortar joints and, thus, emphasized the detection of relevant anomalies and discontinuities.

- The measurement acquisition layout (P3) concerns number, direction, length and spacing of the radar profiles (A3.1) that, in turn, affect the investigation output. Particularly, single profiles might be displayed as 2D radargrams, whereas a grid of profiles might enable 3D tomography (V3.1). In the case studies, the slabs were investigated by two perpendicular profiles, which clearly showed the stratigraphy. Differently, the walls required a set of longitudinal and transversal profiles, in order to achieve redundant data, elaborate a three-dimensional model by interpolation and, thus, visualize
some planes parallel to the investigation surface. Consequently, in the latter application, the activities, although more complex, in terms of time and resources, resulted in a clearer detection of the inner stratigraphy, especially for cavity walls.

- The acquisition mode according to the inner building characteristics (P4) refers to the interface solutions between surface and antenna, equipped by an odometry wheel (A4.1). The above-mentioned issue is particularly relevant for the walls, whenever their surfaces are rough and irregular. Differently, the slabs can be easily investigated on the extrados, where the floor tiles are generally flat. Thus, the walls should require rigid/flexible boards/mats to make smoother the connection of the antenna. Moreover, on mats/boards, the layout of the profiles could be preliminarily marked, in order to speed up the acquisition process.

- The acquisition mode according to the outer environmental and structural factors (P5) concerns some critical conditions that should be avoided. That is the case of areas with high moisture that might cause great signal attenuation either/or metallic elements that might induce high signal reflection (A5.2). In the case studies, those issues were found in the roof slabs showing meteoric infiltration and in the walls at the ground floors with evidence of rising dampness.

Figure 6. Methodological framework for radar scanning.
The following Figure 7 shows some illustrative radargrams with some of the floor components, which were detected in the investigated school buildings.

Figure 7. Radargrams of bidirectional reinforced concrete slab with hollow brick clocks and iron slab with curved hollow bricks.
4. CONCLUSIONS

The case studies allowed developing the planning, application and validation of radar scanning and thermography for buildings of the early XX century, in terms of assessment and control of methods and tools that might influence the accuracy, meaningfulness and reliability of the investigation results. Nevertheless, the proposed procedures are flexible, in order to enable further improvement, in terms of technologies and experimental fields. The final goal is to set a comprehensive decision-making support tool for all the stakeholders who will be asked to implement the ongoing retrofitting programs for the architectural-historical school buildings.

5. REFERENCES