



## The role of non-invasive diagnostic techniques in assessing the resilience of the Cultural Heritage

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Cultural heritage assets are increasingly exposed to aging processes, environmental and anthropogenic actions, that threaten both their material integrity and cultural value. In this context, resilience and therefore the ability of heritage systems to withstand, adapt to, and recover from damage—has become a central objective of conservation-oriented engineering.

From a resilience perspective, among the various diagnostic approaches currently in use, non-invasive geomatic and geophysical techniques represent decision-enabling tools. They provide essential data for identifying vulnerabilities, supporting preventive conservation strategies, and informing risk-aware engineering decisions.

Furthermore, the integrated use of geomatic and geophysical techniques enables highly accurate time-based monitoring, supporting resilience-oriented assessments of cultural heritage assets.

This approach allows for the early detection of degradation and damage mechanisms caused by climate-related stressors, urban pollution and seismic activity. It gives a contribution in implementing conservation strategies in line with UNESCO frameworks.

In this context, the authors present a concise review of the application of non-invasive diagnostic methodologies for the preventive conservation of historic architectural elements they have analyzed within the field of the Cultural Heritage. The cases were investigated using non-invasive geomatic and geophysical techniques, complemented by analyses of the petrographic characteristics of historic building stone materials. Indeed, a comprehensive understanding of stone decay processes and associated alteration mechanisms primarily relies on detailed knowledge of the intrinsic properties of the materials constituting historical building artifacts.

Geomatic techniques, including close-range static digital photogrammetry and terrestrial laser scanning, were employed to obtain high-resolution three-dimensional models for metric documentation, material surface characterization, and detection of morphological alterations. These datasets were integrated with geophysical investigations, specifically 2D and 3D acoustic

tomography and indirect ultrasonic measurements, aimed at assessing internal material conditions, elastic properties, and the spatial distribution of fractures, voids, and material heterogeneities. Petrographic analyses were used to characterize building stone materials, texture, and microstructural features, supporting the calibration and interpretation of geomatic and geophysical results. The choice and combined use of the above techniques were based on decay typology and the petrographic and physical properties of the stone materials, with specific attention to diagnostic reliability, resolution, and methodological limitations, in order to support early detection of damage and informed preventive conservation and maintenance strategies.

The above methodologies were applied to selected case studies focusing on architectural elements from some of the oldest historic monuments in Cagliari (Italy). These monuments represent a wide range of construction techniques and stone materials, making them particularly suitable for investigating the relationships between intrinsic material properties, environmental exposure, and observed decay patterns.

This integrated and multidisciplinary approach aims to assess the state of conservation of cultural heritage and to promote the adoption of preventive strategies for restoration and preservation.