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Non-invasive methods for in-situ analysis of historic structures

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ABSTRACT: Non-destructive techniques (NDT) for on-site analysis of various structures such as historic buildings and monuments are gaining traction due to inherent limitations of conventional invasive methods requiring sample collection for often off-site assessment. This work will investigate current trends in non-invasive assessment of built structures of historic and/or cultural significance, which include methods such as infrared thermography (IRT), ultrasonic pulse tomography (UPT), ground (surface) penetrating radar (GPR), and others. It will also explore whether NDTs available today can replace traditional destructive analysis methods in physical assessment.

1 INTRODUCTION

Preservation of cultural and historic heritage, which includes physical structures such as monuments and buildings as well as construction methods among other things, is essential to society's identity and sense of belonging. Preservation activities may involve exploration, health monitoring, and, if necessary, restoration processes, all of which require appropriate tools for the assessment of the structure's physical conditions (Goncalves, Rodrigues & Gaspar 2018).

The conventional procedure for an assessment of structures with historic and/or cultural significance (often referred to as heritage) consists of several stages. It starts with determining objectives of the investigation, i.e. clarifying if the final goal is conservation of the structure, scientific exploration or some other objective. It is usually followed by preliminary investigation of the structure including steps such as analyzing available information on the structure's building materials and previously performed construction and restoration works (Hughes & Callebaut n.d., Wong 2019). Then, based on the scope of the investigation and the preliminary inspection results, the methods for a further detailed analysis can be selected. Common analytical techniques are invasive in their nature and require sampling for off-site laboratory analyses (Goncalves, Rodrigues & Gaspar 2018).

However, this poses significant challenges in terms of both heritage conservation and validity of the obtained results, as the stakeholders involved in the structure's assessment try to minimize interventions while striving for greater accuracy. The significance of the studied objects accompanied by difficult physical and political circumstances impose restraints on the

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assessment process enforcing additional caution during sample extraction and handling stages. Moreover, conservation philosophy encourages minimal alterations to the original form of the structure leading to small or non-representative sample quantities, which can possibly cause doubts in the validity of assessment results (Hughes & Callebaut n.d.).

This work will investigate current trends in non-invasive assessment of built structures of historic and/or cultural significance, which include methods such as infrared thermography (IRT), ultrasonic pulse tomography (UPT), ground (surface) penetrating radar (GPR), and others. It will also explore whether NDTs available today can replace traditional destructive analysis methods in physical assessment.

2 REVIEW OF SELECTED NON-DESTRUCTIVE METHODS FOR HERITAGE ASSESSMENT

The primary difference between destructive and non-destructive testing is the fact that the former destroys the sample during the analysis. Non-destructive testing (NDT), on the other hand, allows repeatable testing as well as preservation of the sample material.

2.1 *Infrared thermography (IRT)*

IRT is a technique based on measured discrepancies in heat flow rate of surfaces due to various features such as subsurface voids, delamination, poor bonding, moisture retention, deteriorated surface, different building materials, materials of varying porosity or thermal heat transmission, and air leakages. The method does not need a direct contact with the structure's elements (Tavukcuoglu 2018) and has been successfully applied to study hidden structural elements, undocumented transformations as well as consequences of restoration activities (Goncalves, Rodrigues & Gaspar 2018).

Since the method relies heavily on thermal conductivity, it can be challenging to apply it in tropical climates due to low temperature variation during the day. This is often negated by performing IRT during sunrise and sunset hours or before and after the rainfall to achieve maximum possible temperature difference. Another workaround involves spraying the analyzed surface with water or heating it (common approach applied in the active IRT method) provided that the structure will not be damaged as a result (Chaban, Deiana & Tornari 2020).

In addition, the IR results are affected by distance and angle and the assessment can be impeded by wind, shade, blockage by trees, and recessed corners. This is why the IRT imaging assessment is often coupled with tactile and supplementary inspection.

2.2 *Ultrasonic pulse tomography (UPT)*

UPT is an acoustic method based on measuring travel time of ultrasonic waves sent through a solid material between the instrument's transmitter and receiver (Tavukcuoglu 2018). Due to this, the method is naturally better at studying structures made of homogeneous materials such as concrete (for detecting cracks) and timber (for studying rot and termite attack), but struggles with masonry due to resultant echo (Wong 2019).

Ultrasonic pulse velocity measured in the structure is correlated with physical and mechanical properties of the materials, state of structure deterioration, moisture content, presence and size of various discontinuities (e.g. invisible cracks). This makes UPT suitable for identifying used materials, their dimensions, and various embedded members, as well as determining the state-of-deterioration of buildings by assessing visible and invisible defects and failures such as deep or surface cracks and detachments (Tavukcuoglu 2018). The analytical technique can also be useful in detecting failures in functional systems of historic structures, such as water supply and drainage systems. Finally, it can be utilized for in-situ monitoring of the existing conditions before and after applied treatments to determine their efficiency.

2.3 *Ground penetrating radar (GPR)*

GPR is an electromagnetic pulse reflection method based on physical principles similar to those of seismic reflection, which emits very short electromagnetic pulses in a specific frequency band and measures their propagation through the studied material (Goncalves, Rodrigues & Gaspar 2018). It is usually used for shallow investigations requiring high resolution and can be performed to achieve three-dimensional visualization. GPR can be utilized for the following purposes: identifying hidden elements, detection of cracks, estimation of wall thickness, detection of moisture in structural elements, detection of reinforcing steel bars, subsoil investigation, and more. Goncalves, Rodrigues & Gaspar (2018) list several cases where GPR was successfully applied, including studies on a medieval church, a stone masonry bridge, and a masonry house.

GPR offers a rapid and relatively simple way to acquire data, but requires direct contact between the instrument's antenna and the analyzed surface, which adds to an already challenging heritage assessment (Chaban, Deiana & Tornari 2020). The selected center frequency affects the resolution, where the standard range is between 200 MHz and 1 GHz, but high frequencies of 1-2 GHz can yield detailed low-depth imaging (Wong 2019). One of the profound challenges of this method is the complexity of result interpretation and the subsequent need for highly-skilled specialists (Goncalves, Rodrigues & Gaspar 2018). In addition, its results have to be often verified using other methods.

2.4 *Concerns related to use of NDTs*

There are numerous concerns with using NDTs in the assessment of historic and cultural heritage. NDTs have considerable limitations in their accuracy and analytical depth, most of them being performed only for surface analyses. They also often require extensive work with interferences such as echoes due to the composite nature of building materials utilized in construction and restoration of the heritage objects (Wong 2019). The inherent difficulty of interpretation and quantification of these methods leads to the need for highly trained personnel (Fais et al. 2018, Tavukcuoglu 2018). Another common limitation of non-destructive methods is an inability to provide data on the chemical composition as well as some physical and mechanical properties (Wong 2019). All of these contribute to the need to conduct destructive analysis to verify the results of and/or fill in the gaps left by NDTs.

Although, NDTs can supply data necessary to reduce the quantity of samples needed for invasive assessment by aiding in selecting strategic sampling points and highlighting areas requiring further investigation (Wong 2019). There are some cases, when a combined use of two or more NDTs enhanced their performance and enabled quantification (Fais et al. 2018, Tavukcuoglu 2018).

3 CONCLUSIONS

Non-destructive testing (NDT) methods today offer a non-invasive way to investigate various physical properties of the object of interest. This is crucial to exploration and conservation of structures with historical and cultural significance, as utilization of NDTs can become a common practice when preservation of the object's materials is imperative. Since the use of NDTs such as infrared thermography (IRT), ultrasonic pulse tomography (UPT), and ground penetrating radar (GPR) entails certain challenges, especially the need in an additional testing to investigate chemistry of the studied materials, it is commonly advised to pair NDTs with conventional invasive methods. NDTs can form the basis of preliminary analyses and become complementary analytical techniques informing strategic invasive assessment as well as aid in monitoring of structures' health and restoration processes.

REFERENCES

Chaban, A., R. Deiana & V. Tornari. (2020). "Wall mosaics: a review of on-site non-invasive methods, application challenges and new frontiers for their study and preservation". Journal of Imaging 6, 108. doi:10.3390/jimaging6100108.

Fais, S., Casula, G., Cuccuru, F., et al. (2018). "An innovative methodology for the non-destructive diagnosis of architectural elements of ancient historical buildings". *Scientific Reports 8*, *4334*. doi:10.1038/s41598-018-22601-5.

Goncalves, L., H. Rodrigues & F. Gaspar. (2018). Nondestructive Techniques for the Assessment and Preservation of Historic Structures. CRC Press Taylor & Francis Group, Boca Raton. Pp. 1–9.

Hughes, J. & K. Callebaut. (n.d.). "In-situ visual analysis and practical sampling of historic mortars". Available online: https://www.rilem.net/images/publis/rep028-002.pdf.

Tavukcuoglu, A. (2018). "Non-Destructive Testing for Building Diagnostics and Monitoring: Experience Achieved with Case Studies". *MATEC Web of Conferences 149*. doi:10.1051/matecconf/201814901015.

Wong, C.W. (2019). "Applications of non-destructive tests for diagnosis of heritage buildings: case studies from Singapore and Malaysia". *Built Heritage 1*. doi:10.1186/BF03545732.pdf.