A fully customizable data management system for Built Cultural Heritage surveys through NDT

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A INTRODUCTION

The diagnosis of **Built Cultural Heritage** using non-invasive methods is useful to deepen the understanding of building characteristics, assessing the state of conservation of materials, and monitoring over time the effectiveness of restoration interventions. Historic buildings are complex structures that are the result of a layering of materials and techniques that occurred over the centuries. They consist of different types of **masonry**, characterized by different materials and construction techniques, and **architectural elements**, often made of stone, which can have both structural and decorative function. Ultrasonic and sonic tests are Non-Destructive Techniques widely used to evaluate the consistency of historic masonry and stone elements, to study their physico-mechanical properties, and to identify on-site internal defects such as voids, detachments, fractures [1-5]. These tests, in addition to being suitable for Cultural Heritage for their **non-invasive nature**, provide a fundamental preliminary screening useful to better address further analysis.

Ultrasonic and sonic velocity tests performed on monuments involve a lot of different information obtained from many surveys. It is therefore important to optimize the amount of data collected both during documentation and diagnostic phase, making them easily accessible and meaningful for analysis and monitoring [6]. In addition, investigations set-up should be following a **standard methodology**, repeatable over time, suitable for different types of artifacts, and prepared for comparison with other techniques. An integrated data management system is then also useful to support the decision-making processes behind maintenance actions. This work proposes the development of a complete management IT solution for the Ultrasonic and sonic measurements of different types of masonry and stone artifacts. The system consists of a browser-based collaboration and document management platform, two mobile/desktop applications for data entry, and a data visualization and reporting tool. This solution enables the **complete processing of data**, from the on-site survey to their analysis and visualization. The proposed methodology allows the standardization of the data entry workflow, and is scalable, so it can be adapted to different types of masonry and artifacts. Moreover, this system provides real-time verification of data, optimizes survey and analysis times, and reduces errors. The platform can be integrated with machine learning models, useful to gain insight from data.

This solution, aimed to improve the approach to diagnostics of Cultural Heritage, has been successfully applied by the **LAM Laboratory of the Department of Earth Sciences (University of Florence)** on different case studies (e.g., ashlar, frescoed walls, stone columns, corbels, etc.) belonging to many important monuments [3-5].

B METHODOLOGY

Non-destructive techniques based on elastic waves are commonly used to **inspect construction and stone materials**, where wave propagation can reveal information about the material's strength, stiffness and various type of damage such as cracks or voids [1, 2]. Wave propagation velocity is measured by exciting the material (in direct, indirect or semi-direct mode) with an emission probe and detecting the time of flight with a receiver probe. According to the frequency of propagation, waves can be classified as sonic (20 Hz – 20 kHz) or ultrasonic (20 kHz – 200 kHZ). Sonic and ultrasonic investigation requires the collection of an **extensive quantity of data**, and for a deeper understanding of masonry, it is also advisable to integrate information on materials, images, and results from other investigations. The large volume of data involved in this type of workflow highlights the importance of creating an easily accessible database, useful for analysis and monitoring. Research should also focus on understanding and integrating data from multiple sources. A comprehensive **data management system** (Fig. 1) has been developed and implemented for the aforementioned NDT surveys (Fig. 2), including three tools to effectively compare a wide range of information: a **web-based platform** for team collaboration and document sharing, two **custom apps** for on-site data entry and attachment managing, and a tool for **interactive data visualization** (Fig. 3), analysis and dissemination (Fig. 4). This system has been used to support sonic and ultrasonic tests performed on various artifacts. We present a selection of the most representative results obtained on 4 different types of stone artifacts:

SONIC TESTS

- Indirect measurements on frescoed walls. Main purpose: verify the **adherence of the pictorial plaster** to the surface.
- Direct measurements on stone columns. Main purpose: assess the **physical-mechanical decay** of the sandstone.

ULTRASONIC TESTS

- Direct measurements on corbels. Main purpose: evaluate the **stability of overhanging stone elements**.
- Indirect measurements on ashlar. Main purpose: verify the presence of **detached portions** and **internal discontinuities**.

1. DIAGNOSTIC PROJECT WORKFLOW

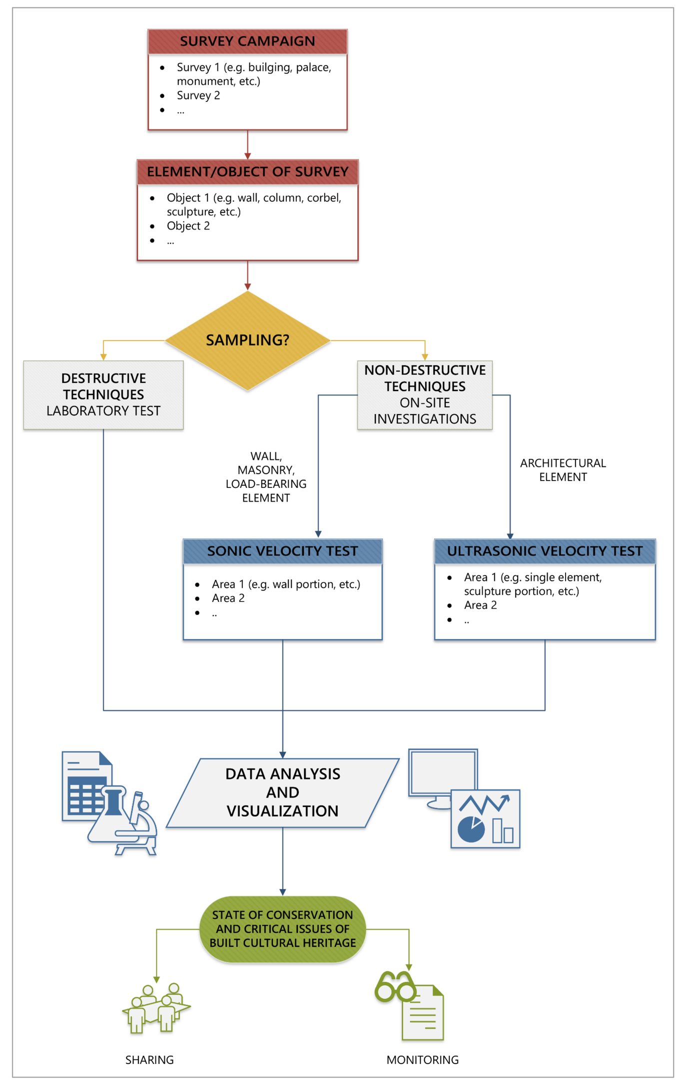

Fig. 1. Workflow and data collection logic of the management system.

2. ON-SITE INVESTIGATIONS AND DATA COLLECTION

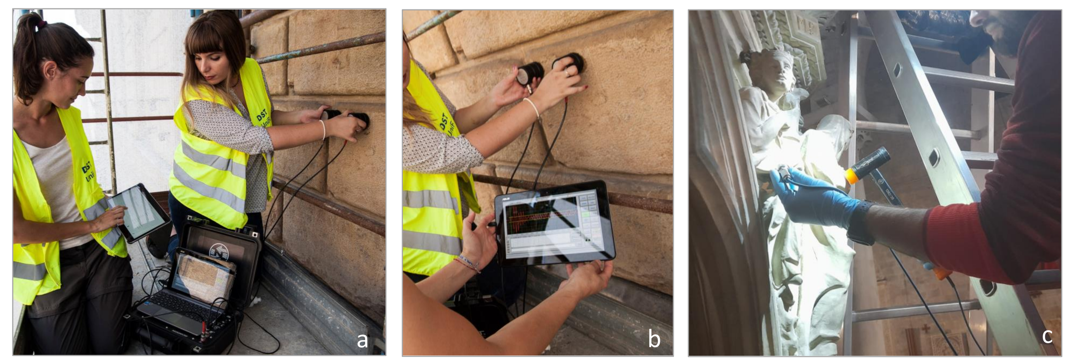

Fig.2. Ultrasonic (a, b) and sonic (c) tests: instruments used and examples of on-site applications.

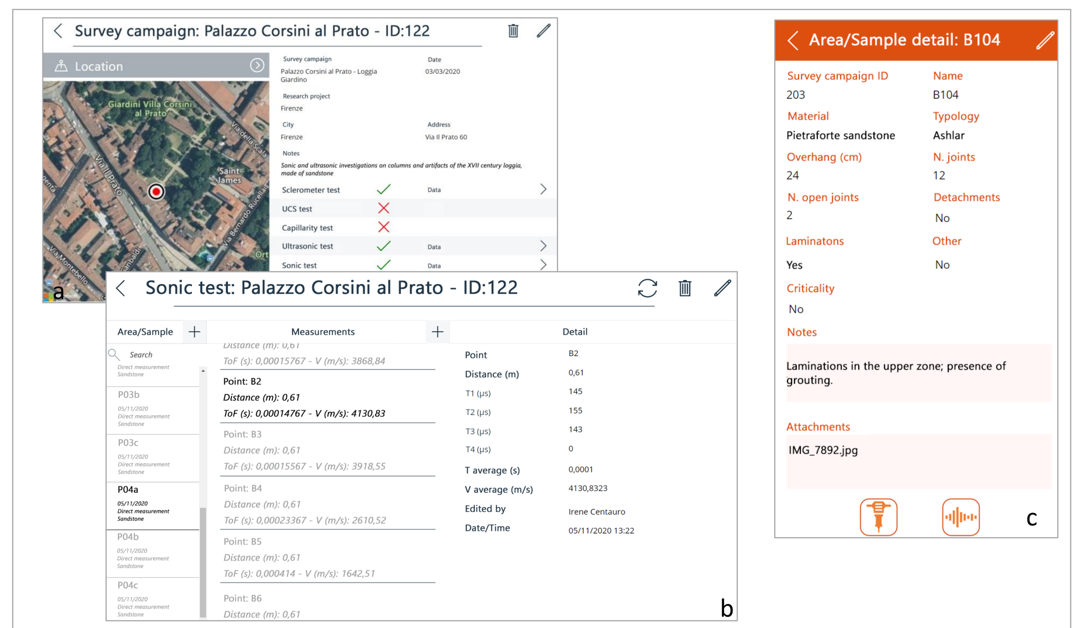

Fig. 3. Example pages of the data-entry apps, layout for tablet and desktop (a, b) and for smartphone (c).

3. DATA ANALYSIS, VISUALIZATION AND SHARING

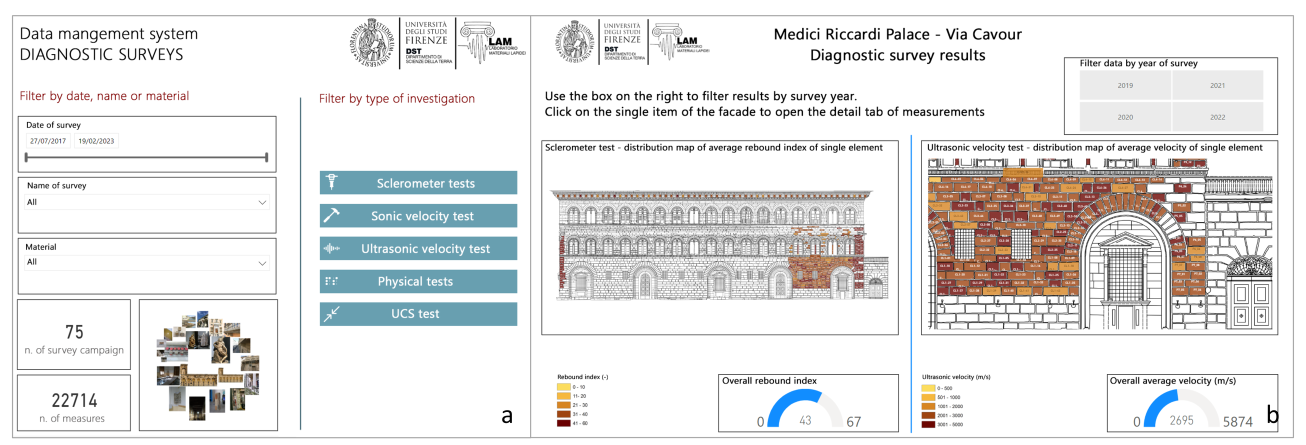

Fig. 4. Example pages of tool for data visualization, analysis and dissemination: landing page of the data management system (a), case-study dashboard for sharing survey results (b)

C RESULTS AND DISCUSSION

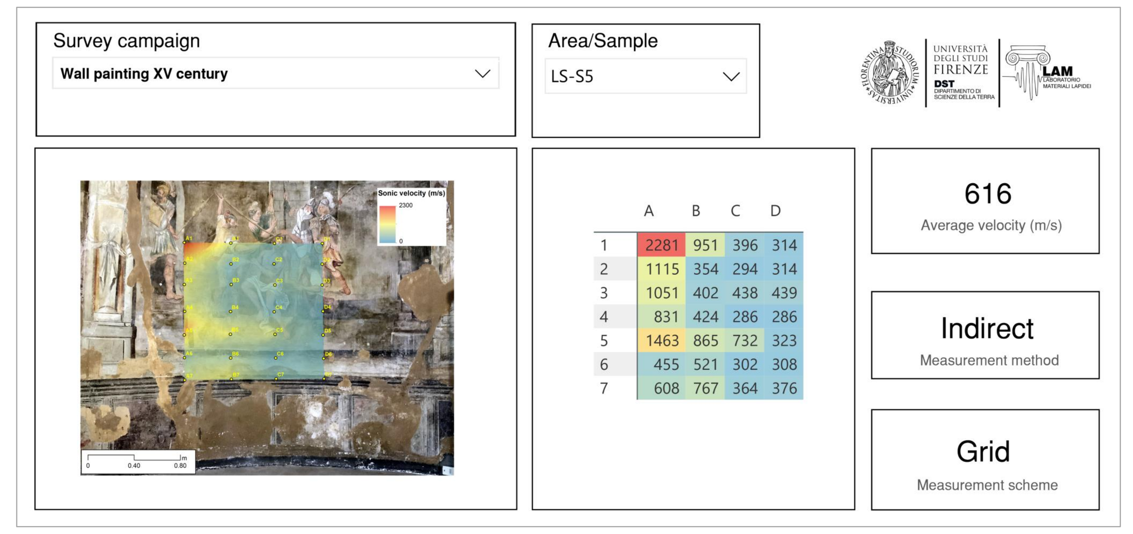

Fig. 5. Interactive dashboard of the sonic test results with the comparison between the table of the velocity values distribution with the false color map elaborated in GIS, attached to the record

Sonic test: indirect measurements on frescoed walls

Investigations were performed in indirect mode on different areas of frescoed masonry (XV century) of a church. The main scope was to verify the adherence of the pictorial plaster to the substrate. The results obtained on one of the 4 analysed areas are reported as an example (Fig. 5).The comparison between the false color map and the results' table shows that the lowest velocity values are distributed on the right portion of the investigated area. This is found in correspondence with a detachment and lifting of the painted plaster.

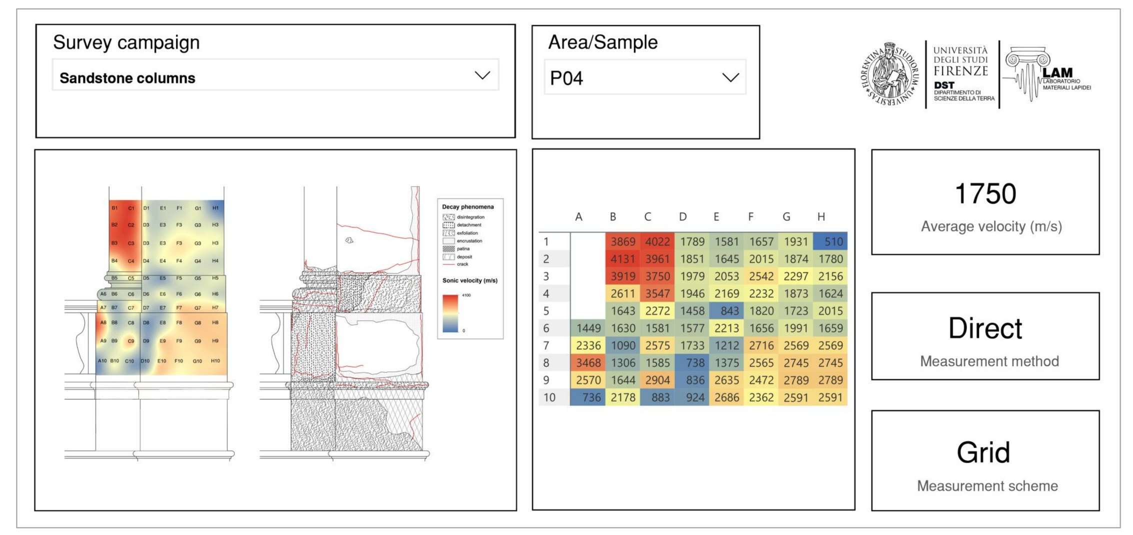

Fig. 6. Interactive dashboard of the sonic test results with the comparison between the table of the velocity values distribution with the false color map and the decay map elaborated in GIS, attached to the record

Sonic test: direct measurements on stone columns

Investigations were performed on 4 sandstone columns of a XVII century *loggia* of a Florentine historic palace. The main purpose was to assess the physical-mechanical decay and the state of conservation of the artifacts. The results obtained on one of the 4 columns are reported as an example (Fig. 6). The comparison between the false color map, the decay map and the results' table highlight areas of detachment of crusts and fractures, mainly located on the left base of the column.

Ultrasonic test: direct measurements on corbels

Investigations were conducted on 78 Pietraforte sandstone corbels of the late gotic Orsanmichele church, in Florence. The main scope was to evaluate the stability of these overhanging stone elements, located on the top cornice of the building. These analyses provided for the integrated use of ultrasonic test and sclerometer test. The comparison between the techniques allows to highlight the phenomena of degradation both superficial and in the stone matrix. In the example shown (Fig. 7), the lowest ultrasonic velocity values correspond to the highly degraded top portion of the corbel, affected by scaling and erosion.

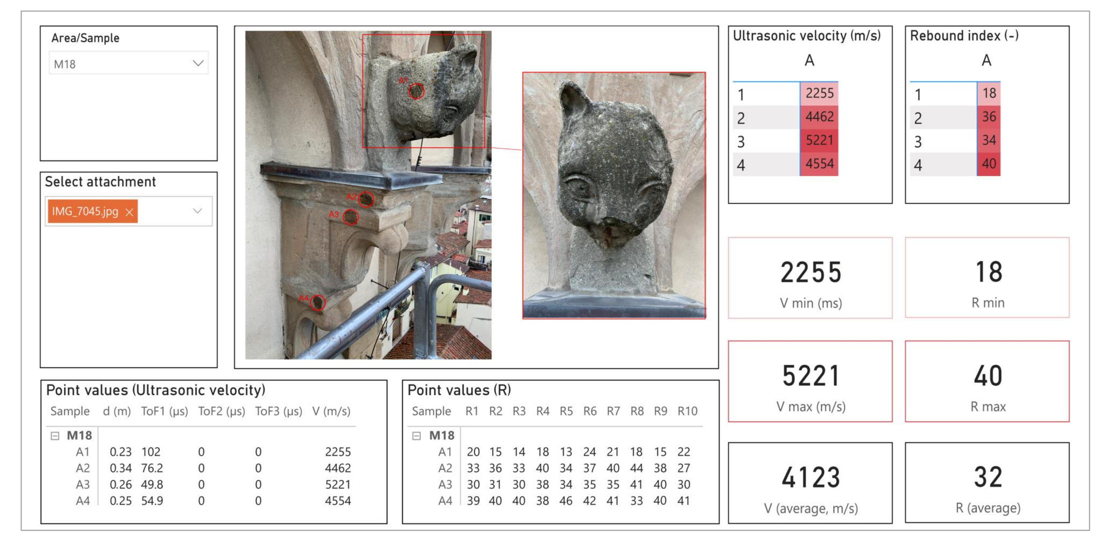

Fig. 7. Interactive dashboard of the ultrasonic test results with the comparison with rebound index values obtained from the sclerometer test. Results can be aggregated and filtered by single element

Ultrasonic test: indirect measurements on ashlar

The last investigation examples involved more than 800 Pietraforte sandstone ashlars of Medici Riccardi Palace, one of the most important Renaissance palace of Florence [4]. The main purpose was to identify the presence of detached portions and internal discontinuities and to set up a monitoring protocol for the stone facades. The example (Fig. 8) shows how through the proposed management system for ultrasonic investigation it is possible to highlight zones of weakness, comparing the results with the images of the measuring points and additional data collected (such as the number of open joints, etc.).

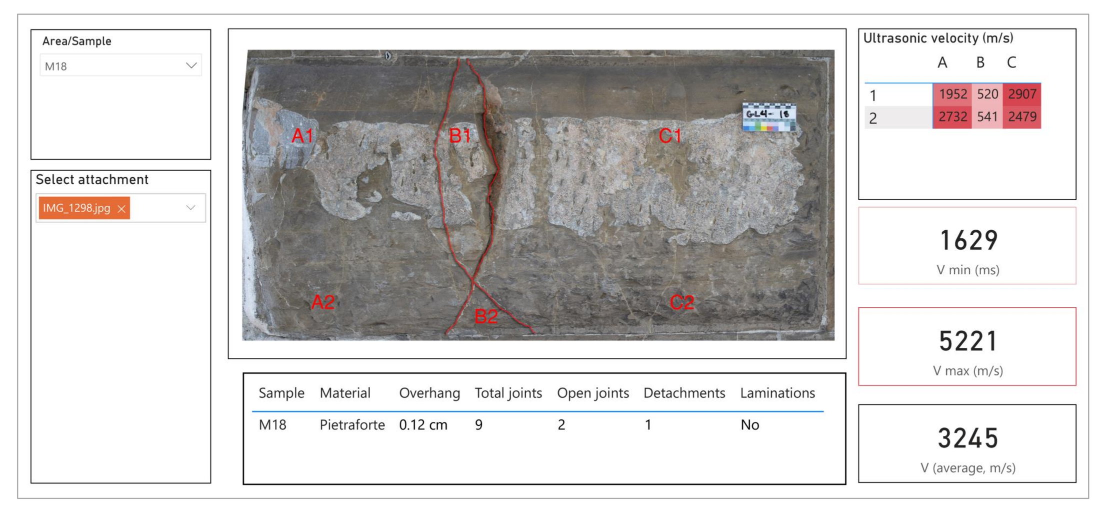

Fig. 8. Interactive dashboard of the ultrasonic test results obtained from each single element of the facade. The dashboard provides also a comparison with the measure scheme and other data collected.

D CONCLUSION

Stone Built Heritage is made by complex and heterogeneous elements which are often the result of stratification and interventions over time. A thorough understanding of the **structural and material characteristics** is required in conservation practices to ensure the safety of buildings, and the protection of Cultural Heritage. Sonic and Ultrasonic investigations are a useful technique because they are non-destructive and **respectful of the artifact**. They provide a fundamental preliminary screening that is useful for better addressing further insights. To be effective the measures must be conducted systematically and following a **standard methodology**, that is repeatable over time, suitable for different types of artifacts, and interoperable with other investigations techniques. The proposed methodology allows for the standardization of the data entry workflow and fits many operative need.

In addition, this system provides **real-time verification of data**, optimizes investigation and analysis times, reducing errors. It has been successfully applied on 4 different case studies: frescoed walls, stone columns, corbels and ashlars. This methodology has made it possible to **highlight decay phenomena**, such as plaster detachments and fractures, and to identify zones of weakness of stone architectural elements. Such surveys need to be carried out at different time intervals, i.e., before and after restoration, or to verify the evolution of a particular degradation phenomenon. This solution is designed for **monitoring** and allows rapid dissemination of results. The platform, as a future development, can be implemented with machine learning models to perform forecasting analyses or better classify and aggregate multidisciplinary data.

The proposed solution can therefore make a valuable contribution to the diagnostics of the Built Cultural Heritage.

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