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Implementation of a wireless structural monitoring system and reverse engineering for numerical analysis purposes of a 16th century church

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Abstract: The conservation of built heritage structures requires constant attention to the progression of existing damage and the assessment of their probable structural response to different phenomena or interventions. Using state-of-the-art technologies such as quasi-real time monitoring and reverse engineering of LiDAR data, one can address these pressing concerns, besides generating baseline data for archival purposes or future applications. Quasi-real time structural monitoring allows the observation and measurement of the structure's response over time, registering different kinds of metrics, which enable early detection of damage or changes on the structure. When combined with structural analysis it allows for a better contextualization of physical metrics and the possibility of assessment of global response, even analysing parts of the structure not being monitored directly or that do not yet have visible damage. Within the scope of the SIAP project (Artificial Intelligence System for Risk Detection and Alerts on Heritage), the first steps are being taken towards the development of a quasi-real time risk detection and warning system, based on these tools. In the long term, through machine learning, the system will be able to issue alerts, based on the analysis of monitoring data and integration into numerical models. This paper focuses on the implementation of the structural monitoring system in the main church of Freixo-de-Espada-à-Cinta and the process of reverse engineering based on the three-dimensional model acquired with LiDAR technology. The monitoring system included the installation of wireless smart sensors in two areas of the church, where significant cracking is found, one next to the main façade (West) and the other next to the wall adjacent to the triumphal arch (north nave). In order to measure crack openings, rotations of the walls and the vibration of the structure, nine crackmeters, three tiltmeters (each one measuring the in-plane and out-of-plane rotations of the wall) and five accelerometers were installed in the church, respectively. Additionally, four temperature and humidity sensors were installed to study their influence on the results obtained from the other sensors. Through the reverse engineering process, it was possible to build a three-dimensional finite element model from the point cloud obtained by laser scanning the church. In this exploratory phase of the model, different conditions and scenarios are being studied, through preliminary linear and nonlinear phased analyses.

Keywords: LiDAR, monitoring, reverse engineering, 3D-structural modelling, heritage

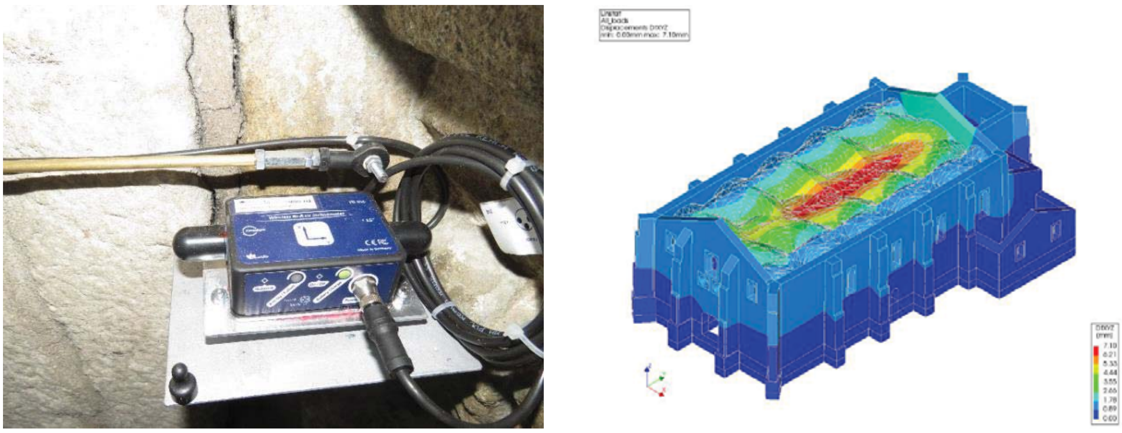
1. Introduction

Management and maintenance of several heritage assets is a complex task that mobilizes a great number of resources, human and otherwise. The project SIAP - Artificial Intelligence Warning and Alert System for Cultural Heritage was developed as an attempt to tackle these challenges and therefore, proposes a shift from a reactive to a proactive management system. This paper focuses on the Freixo-de-Espada-à-Cinta church, particularly on the works related with the implementation of the monitoring system and the preliminary structural analysis made with the finite element model created from the LiDAR acquisition.

2. Developments

The monitoring system was designed with the purpose of controlling the opening of existing cracks and formation of new ones on the walls and rib vault, as well as the inclination and vibration of the walls. It comprises a total of twenty-one sensors, among crackmeters, biaxial tiltmeters, triaxial accelerometers, and temperature and humidity sensors (see Figure 1a).

Through the process of reverse engineering, it was possible to construct a 3D finite element model, ready for numerical analysis, from the 3D point cloud data obtained with the LiDAR technology. Preliminary linear and nonlinear phased analyses were carried out (see Figure 1b).



(a) (b)

Figure 1 Tasks developed: (a) implementation of monitoring system (e.g., tiltmeter); (b) numerical model (e.g., total deformations).

3. Results and Conclusions

The wireless monitoring system is fully operational and enables a better control over the evolution of the existing damage. Data can be later integrated in the numerical model.

Transitioning from a cloud point model to a finite element model requires several steps, being the main output the CAD model that describes a simplified structural geometry. These operations are time consuming and will benefit from a semi-automated construction of CAD models from point clouds.

Preliminary results, point out that improved modelling the structural connections might be necessary and the removal of the annexes that had existed adjacent to the main façade probably had low impact on the church structural performance. Future developments should include material characterization through non-destructive testing and ambient vibration tests to calibrate the model material properties and levels of connectivity between elements.