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A case study of the use of GPR for rehabilitation of a classified Art Deco building: The InovaDomus house

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ABSTRACT

Ancient buildings in historical town centers can be protected by Cultural Heritage legislation, thus implying that any rehabilitation must respect their main architectural features. These concerns also apply to Modern and Contemporary buildings, in particular if they are important examples of architectural styles from those periods.
These extra problems, or motivations, add to the inherent structural delicacy of ancient building restoration that requires detailed knowledge of the building foundations, characteristics and materials, modification history, infrastructure mapping, current pathologies, etc., all relevant information for an informed rehabilitation project.
Such knowledge is seldom available before the actual rehabilitation works begin, and the usual invasive preliminary surveys are frequently expensive, time-consuming and likely significantly alter/damage the building's main features or structural integrity. Hence, the current demand for indirect, non-invasive, reliable and high resolution imagery techniques able to produce relevant information at the early stages of a rehabilitation project.
The present work demonstrates that Ground Penetrating Radar (GPR or Georadar) surveys can provide a priori knowledge on the structure, construction techniques, materials, history and pathologies in a classified Modern Age building. It is also shown that the use of GPR on these projects requires carefully designed surveys, taking into account the known information, spatial constraints, environmental noise, nature and dimensions of the expected targets and suitable data processing sequences.
Thus, if properly applied, GPR produces high-resolution results crucial for sound engineering/architectural interventions aiming to restore and renovate Modern and Contemporary buildings, with (1) focus on the overall quality of the end-result, (2) no damage inflicted to the existing structure, (3) respect of the building's historical coherence and architectural elements and characteristics, that is, its Cultural Heritage value.
Most of the findings and applications discussed in this work can be seen as an approximation to model studies, so that, relevant information can be drawn from the different investigated situations. Therefore, owing to the nature and the range of the problems encountered in this case study, it is also expected that the presented GPR data and interpretation will provide important clues and guidance in the planning and investigation of similar projects and problems.

1. Introduction

Nowadays the use of Geophysics in Civil Engineering is a well-established practice. In particular, the application of Geophysical methods to geological mapping, underground characterization for building foundations, construction material characterization and integrity of structures has already been developed (Nazarian et al., 2007; Coutinho and Mayne, 2012).

Recently there is an increasing interest in the restoration, renovation and rehabilitation of ancient buildings and monuments, relevant for Cultural Heritage, which are often protected as local, national or world heritage. In these cases, building rehabilitation must conform to strict regulations aiming to preserve their features. This interest is now being extended to Modern and Contemporary buildings, landmarks of important architectural styles from those periods.

Rehabilitation projects are an increasing activity in urban renewal and can pose new problems and challenges to engineers and architects, demanding as much information as possible on the buildings about to be intervened. This includes detailed knowledge of construction techniques, phases and modifications, materials, infrastructures, pathologies, foundations and nature of the underlying ground, among other problems. However, this information is seldom available at the beginning of the project, as records are frequently missing or very difficult

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to access. The most common way to obtain this information is through preliminary surveys using invasive/destructive methods. However this approach is expensive, time-consuming and, moreover, very likely to significantly damage or alter building structural or cultural/architectural features.

Hence there is a demand for indirect, noninvasive, high resolution and fast technologies that can produce accurate images of the buildings and the information needed for a reasoned rehabilitation project.

Geophysical survey methods provide non-invasive approaches that have been used to investigate this type of problems (Cosentino and Deganello, 2003; Piro et al., 2015), and the adaptation of geophysical methods to built heritage has led to the development of the so called Microgeophysics (Cosentino et al., 2011). Microgeophysics uses geophysical techniques modified and adapted to diagnose, monitor and provide information relevant for the solution of problems concerning Cultural Heritage studies, such as, characterization of construction materials, identification of pathologies, infrastructure location, continuity and type of construction elements, etc., in monuments, historical buildings and artworks.

The most popular Geophysical methods to investigate historical buildings and monuments (sculptures, stone engravings and panels, artworks in general, etc.) consist on 2D and 3D seismic tomography, GPR, electrical resistivity tomography, ultrasonic waves and infrared emission (Cosentino et al., 2011). Other methods have also been introduced, such as, microgravimetry (Panisova et al., 2013), seismic ambient noise (Castellaro et al., 2008) and nuclear magnetic resonance (Capitani et al., 2012).

The investigation of those problems often requires a multimethod approach as different techniques provide complementary information. Furthermore, their use must be considered in accordance with the aims of the study and integrated studies are preferred (Cataldo et al., 2005; Faella et al., 2012; Martinho and Dionisio, 2014).

Hence fracture detection has been investigated using GPR (Leucci et al., 2007), cracks and joint geometry by GPR and microwave tomography (Bavusi et al., 2010); 2D resistivity was proposed to investigate moisture in masonry walls (Sass and Villes, 2006 and 2010); masonry studies used GPR and sonic tests (Anzani et al., 2006); electrical resistivity tomography (ERT) was applied in the investigation of vulnerable hidden surfaces, such as mosaics (Fiandaca et al., 2009 and 2010), 3D resistivity for foundation studies under buildings (Chavez et al., 2015) and combined surveys using ERT and GPR were also proposed to investigate different construction phases, roman and medieval (Grangeia et al., 2011).

Most examples of the use of Geophysics in Cultural Heritage refer to ancient monuments and artworks but, herein, it is proposed to investigate a 20th century building representative of the Art Deco style. This building, protected by the town council, has suffered many internal alterations during its lifetime, leading to adaptations and modifications that have not been recorded. These adaptations were done with different materials and techniques, structural elements and nowadays some pathologies, such as cracks and moisture, are clearly identified by simple visual inspection.

Bearing in mind logistics, available space, the nature of the walls and floors it was decided to use GPR to investigate those problems. In fact GPR is a nondestructive and cost effective method with an impressive record of applications and success in Civil Engineering, in general, and in building assessment in particular (Benedetto and Pajewski, 2015). There are several examples in the literature of the use of GPR in the assessment and analysis of buildings (Pérez-Gracia and Solla, 2015). Thus, Binda et al. (2000) tested the use of GPR in the investigation of masonry building damage and defects, rebar detection and reinforcement were addressed by Barrili and Pucinotti (2005) and Pérez-Gracia et al. (2008). An experimental work of fracture detection on a wall, later cement injection on the fractures and masonry characterization is described in Hermozilha et al. (2009).

In the present case, other methods, such as resistivity, were tested but not considered because of the nature of the walls (covered with plaster and paint) and the intense seismic noise, generated by heavy traffic in adjacent roads, did not recommend the use of active seismic tomography. So investigations refer to GPR data only.

Owing to the expected modifications, both in structure, building materials, constructive element continuity, infrastructures, pathologies, as well as, the lack of information about foundations and local geology, this case study includes most of the more important aspects in building assessment and a preliminary account of the findings has already been given (Barraca et al., 2014). Therefore, this work is expected to provide most valuable information on the use of microgeophysics in these types of problems. The overall project is a very good approximation to analog model studies and, therefore, the techniques the data processing and interpretation can be replicated in similar projects.

At last, the ongoing renovation of the building is taking into account the results herein discussed, confirmed the findings and further similar projects are already considered for other buildings of architectural value.

2. The "InovaDomus house" case study (Ílhavo, Portugal)

Herein are presented and discussed the results of a GPR survey planned and executed as part of the project for the rehabilitation of an early 20th century Art Deco house protected by its Cultural Heritage relevance (Fig. 1; Barraca et al., 2014).

The building currently demands maintenance and restoration works but its Cultural Heritage value implies that any engineering or architectural intervention must respect its characteristics and integrity. However, the restoration team had scarce information, as records and documents about the house do not exist. In order to overcome this lack of information, a GPR survey was planned in accordance with all the available engineering and architectural knowledge, aiming to investigate the general structure of the building.

The history of this building suggests that there is a wide variety of problems to be encountered. These problems range from foundation and local geology investigations, modifications and continuity of construction elements, different construction materials and phases, pathologies (fractures, moisture) to infrastructure location. Hence it is a unique opportunity to study a whole range of problems, test techniques and propose interpretations in a real situation.

A previous experimental model and controlled project, Hermozilha et al. (2009) tested the use of GPR in the location of individual bricks, fractures and cement injection to repair fractures on a damaged wall and provided the necessary guidance to carry out the present work. Therefore the survey main goals included:

- To investigate the local geological conditions, that is, layering, water table, anthropic layers and any other information relevant for the characterization of the building's foundations and structure.
- To map all existent infrastructures, such as, power cables, plumbing, etc., as the original electrical and water networks might have suffered considerable modifications during the building complex history.
- To locate any traces of removed, altered walls or other original construction elements, as throughout the building lifetime, modifications included removal and opening of several walls, doors, windows and stairs modifications. A detailed knowledge of these alterations will influence the evaluation of the building structural stability and on the overall quality of the rehabilitation.
- To locate modifications and changes in the construction materials (original building materials were adobe, masonry), rebar structure whilst later modifications included bricks and different structure rebar.
- To investigate pathologies and fracturing. During the building lifetime a complex system of fracturing occurred and several fractures and reparation attempts are visible. It was particularly important to locate fracturing in association with wall removal and internal changes of