Extended Abstract

Market Analysis on Diagnostic Techniques in Building Elements

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1. Introduction

The housing park of each country is part of the identity of its people and must be preserved. In Portugal, 80% of the housing park is composed by current buildings and although their conservation status is not serious, there is a large portion of these buildings requiring some type of intervention (INE, 2011).

Nowadays, it is known that for an economic point of view or for environmental sustainability, there is a need to extend the life of buildings as much as their natural physique allows. In a life cycle analysis, infrastructure maintenance and rehabilitation are very importante. In this context, the ability to follow through inspections that accurately describe the pathological condition of buildings and foresee their evolution is fundamental in the diagnosis of anomalies (Correia, 2014).

In order to carry out maintenance or rehabilitation in a building, it is necessary, in adittion to an adequate prior inspection of the site, to carry out *in-situ* and laboratory tests to support a correct diagnosis of the real state of degradation of the building elements.

These tests are performed by entities that, depending on their nature, exhibit different characteristics, functions and constraits. These entities include IPAC (Portuguese Institute of Accreditation) test laboratories, university laboratories and private companies that perform diagnostic tests in building.

Given the diversity of tests that can be performed and the various entities in the market in Portugal, there is a need to carry out field work, based on information gathering, to various laboratories and companies.

In this context, a need arises with the objective of trying to analyze which tests are carried out by the entities, which are the most tested building elements, which are the tests with the largest offer in the market and how is the offer taking the type of entity into account.

2. Pathology and diagnosis

2.1. Pathology and diagnosis in buildings

Anomalies consist of manifestations of possible defects in buildings, where one or more elements may have failed to fulfill the functions for which they were designed (CIB W086, 1993).

Building pathology is the science that systematically studies building anomalies and their causes, consequences and treatments (CIB W086, 1993).

The set of procedures to ensure knowledge of a building or structure, including the assessment of its condition, safety and the determination of the causes of observed anomalies, is called a diagnostic study (Appleton, 2002).

Inspection of buildings is crucial in order to be able to diagnose anomalies, yet it must use diagnostic techniques to maximize the collection of information useful for understanding the degradation that has been achieved.

2.2. Constructive typologies

For a better analysis of building degradation levels and inspection, it is important to distinguish between old buildings and current buildings as their materials and characteristics are different.

Old buildings, built before 1945, are buildings whose construction is mostly based on the use of wooden structures in floors and roofs and the use of masonry, adobe or mud, on load-bearing walls (Freitas, 2012), (Sousa *et al.*, 2016).

In turn, the current buildings, after 1945, consist of portico structures in reinforced concrete that support light or massive concrete slabs. The walls have no structural function and are filled with perforated brick masonry leaves (Pereira, 2017), (Sousa *et al.*, 2016).

2.3. Anomalies in building elements

Determining the causes of anomalies is not always an easy task, because in many situations the same cause can trigger different anomalies and the same anomaly can be originated by different causes. This is mainly due to the great diversity of building elements and materials and the multiple functions that the various parts of the building perform (Paiva *et al.*, 2006).

Generally, the causes of building anomalies are very often of natural origin and can be grouped into causes of physical, chemical and biological nature.

Since anomalies affect building elements of constructions, this dissertation addresses the building elements of masonry, wood and reinforced concrete. As for the masonry elements, walls are highligthed, which can be of stone, brick or concrete blocks, and the coverings. In relation to wooden elements, importance is given to roofing and floor structures as well as wood floor coverings. In the reinforced concrete elements, the study focuses on the pillars, beams and slabs that compose the portico structures.

For each building element the most frequent anomalies and their causes are studied. It is found that there are anomalies that affect all elements under study, such as cracking, although it may be due to numerous factors. Wood elements are especially affected by biological agents, while masonry elements have a significant number of water-related anomalies. Table 1 summarizes the most frequent anomalies in each constructive element, as well as the causes that may be the origin of these anomalies.

3. Diagnostic techniques

The existing testing techniques are generally classified as destructive, semi-destructive or non-destructive. In this sense it is important to make the following distinctions:

- Non-destructive techniques are any type of test performed on a material that does not permanently alter its physical, chemical, mechanical or dimensional properties. These assays do not require direct invasive actions and serve to evaluate the properties of a material, component or system without causing considerable damage to the sample examined (Freitas & Guimarães, 2012), (Flores-Colen *et al.*, 2006), (Arêde & Costa, 2002). However, not all non-destructive techniques are completely, as some do cause minor localized damage to the building, usually easily repaired, these are called semi-destructive techniques (Cóias, 2009), (Paiva *et al.*, 2006).
- Destructive techniques are any type of test where exists a complete or parcial destruction of the sample (Cóias, 2009), (Paiva *et al*., 2006).

Test techniques can also be separated into *in-situ* and laboratory tests. Laboratory testing on samples of building components or materials collected is an important and often indispensable complement to *in-situ* testing (Santos, 2003).

In situ testing is generally non-destructive or medium destructive and allows an indirect qualitative or quantitative classification of the most significant characteristics. Laboratory tests are always somewhat destructive (performed on samples) but yield direct quantitative results (Veiga *et al.*, 2004), (Flores-Colen, 2009).

In order to systematize the presentation of the various techniques, a classification was adopted, used by several authors (Amaro *et al.*, 2013), (Cóia, 2009), (Lombillo *et al.*, 2013), according to the principles they are based, sensory perception, mechanical action, elastic wave propagation, electromagnetic radiation propagation, electrical and magnetic effects, chemical and electrochemical reaction, hygrothermal and hydrodynamic reactions.

This way, table 2 was elaborated, wich summarizes all the techniques and the elements studied.

Table 1 – Synthesis of the most common anomalies in constructive elements according to their origin

			Masonry				Wood			Reinforced concrete		
	Possible causes	Anomaly	Structure			Coatings	Structure		Floor coverings	Slabs	Rafters	Pillars
			Stone	Brick	Concrete blocks		Floor	Roof				
Causes of physical origin	-Temperature and humidity variations - Overloads - Differential settlements - Freeze / thaw cycles	Crack	x	x	x	x	x	x	x	x	x	x
	- Overloads - Creep effects - Structural changes	Crush	x	x	x							x
		Bulging/Excessive deformation	x	x	x		x	x		x	x	
	- Cold and heat alternation (contractions and expansions) - Crackening worsening - infiltrations - Freeze / thaw cycles	Breakdown	x	x						x	x	x
	- Moisture content variations	Blistering and warping					x	x	x			
Causes of chemical origin	- Alkali-Silica reactions - Oxidation - Carbonation	Crack				x				x	x	x
	- Efflorescence - Cryptoflorescences - Cracking	Crush				x				x	x	x
	- Salts	Efflorescences and cryptoflorescenses	x	x	x	x				x	x	x
	- Efflorescences - Cryptoflorescences - Carbonation	White spots				x				x	x	x
	- Drips - Infiltrations - Condensations	Dark spots				x				x	x	x
	- Cryptoflorescences	Posting/Detachment				x						
		Blistering				x						
Causes of biological origin	- Moisture presence	Parasitic vegetation										
		Fungi, lichens and patina										
	- Rot fungi	Rot					x	x	x			
	- Underground termites - Worm	Gallery opening					x	x	x			
	- Attack of fungus, rot and worms leading to loss of section and resistance of the element	Excessive deformation					x	x	x			

Table 2 – Summary of the application of diagnostic techniques in the building elements

Test	Masonry				Wood			Reinforced Concrete		
	Structure			Coatings	Structure		Floor Coverings	Slabs	Rafters	Pillars
	Stone	Brick	Concrete Blocks		Floor	Roof				
Visual inspection	X	X	X	X	X	X	X	X	X	X
Crack comparator	X	X	X	X	X	X	X	X	X	X
Optical meter	X	X	X	X	X	X	X	X	X	X
Tell-tale	X	X	X	X	X	X	X	X	X	X
Lenghtmeter	X	X	X					X	X	X
Hammer, chains, sprockets	X	X	X	X	X	X	X	X	X	X
Acoustic detection of xylophagous insects					X	X	X			
Boroscopic inspection	X	X	X		X	X		X	X	X
Pylodin					X	X	X			
Resistograph					X	X	X			
Pull-off	X	X	X	X			X	X	X	X
Sphere impact *(Martinet Baronnie)*	X	X	X	X						
Schmidt Sclerometer								X	X	X
Schmidt Pendular sclerometer	X	X	X	X						
Flat jack	X	X	X							
Dilatometer	X	X	X							
Core extraction and testing	X	X	X	X	X	X	X	X	X	X
Determination of compressive strenght	X	X	X	X	X	X	X	X	X	X
Determination of tensile strenght	X	X	X	X	X	X	X	X	X	X
Determination of flexural strenght	X	X	X	X	X	X	X	X	X	X
Ultrasonic testing	X	X	X	X	X	X	X	X	X	X
Sonic tomography	X	X	X	X	X	X	X	X	X	X
Impact-echo test	X	X	X	X	X	X	X	X	X	X
Infrared termography	X	X	X	X	X	X	X	X	X	X
Radiography	X	X	X		X	X		X	X	X

Table 2 – Summary of the application of diagnostic techniques in the building elements (continuation)

Test	Masonry				Wood			Reinforced Concrete		
	Structure			Coatings	Structure		Floor Coverings	Slabs	Rafters	Pillars
	Stone	Brick	Concrete blocks		Floor	Roof				
Radar	X	X	X		X	X		X	X	X
Pacometer								X	X	X
Moisture meter	X	X	X	X	X	X	X	X	X	X
Field kit	X	X	X	X			X	X	X	X
Color ribbons	X	X	X	X			X	X	X	X
pH meter	X	X	X	X			X	X	X	X
Conductivity measurament	X	X	X	X			X	X	X	X
Humidity measurement inside walls – *speedy kit*	X	X	X							
Phenolphthalein				X (*)				X	X	X
Polarization resistence								X	X	X
Electrical potential measurement								X	X	X
Concrete resistivity								X	X	X
Chloride content determination				X (*)				X	X	X
Karsten tube	X	X	X	X				X	X	X
Figg method								X	X	X
Capillary water absorption	X	X	X	X	X	X	X	X	X	X
Water vapor permeability	X	X	X	X	X	X	X	X	X	X
Thermal conductivity	X	X	X	X	X	X	X	X	X	X
Hygrometer	X	X	X	X	X	X	X	X	X	X

Legend: X (*) – mortar test

- Sensory perceptionTechniques
- Mechanical action techniques
- Elastic wave propagation techniques
- Electromagnetic radiation propagation techniques
- Electrical and magnetic effects techniques
- Chemical and electrochemical reaction techniques
- Hydrodynamic techniques
- Hygrothermal techniques

4. Market Analysis

4.1. Sample methodology and description

The first phase of this chapter focuses on the selection of the sample to study. It was decided to bring together the entities to be analyzed in three distinct categories: (1) Accredited Laboratories, (2) University Laboratories and (3) Private companies that perform building inspections.

For the selection of accredited laboratories, it was used the IPAC (Portuguese Institute of Accreditation) online page which presents all the accredited testing laboratories. University labs were selected using the Shanghai Ranking 2019 [W1], the World University Ranking 2019 [W2], UniRank: Top Univerisities in Portugal [W3] and the Web Ranking of Universities [W4] to identify universities that would be the subject of study. Finally, for private companies, an online survey was carried out in order to identify and select companies that perform inspections, rehabilitation and / or maintenance work on buildings.

Although 42 entities were contacted in total, only 24 of them provided the necessary data for the market assessment. This way, the study sample was reduced to 24 entities, of which 42% are accredited laboratories, 33% are university laboratories and only 25% are companies that have anomaly diagnostic services.

4.2. Tests with the largest offer in the market

In the masonry building elements, the most recorded test was the pull-off, with about 67% of the entities having this service in coatings. Still in the masonry elements, it was found that the determination of compressive strength is one of the tests more accomplished, and 63% of the entities perform it in stone masonry and 58% in concrete block masonry. Also, the capillary water absorption test and the determination of flexural strength show values above 50%, namely 54% in both cases.

Concrete elements have the largest number of tests available on the market, with the Schmidt sclerometer being the most performed test, with about 80% of the entities making it available. Also, the determination of chloride content; the evaluation of carbonation depth using phenolphthalein; the determination of compressive strength and core extraction present values above 70%.

As for wood elements, it is in this group of constructive elements that there is the lowest supply, registering the lowest values. In these elements, the moisture meter is the most performed test, with half of the entities performing them, followed by infrared thermography that records about 42% of the entities. Still the resistograph, the boroscopic inspection and the hygrometer fit the most available tests to be performed in these elements.

In terms of entities that provide diagnostic tests, an analysis was made of the tests that each categorie has the greatest capacity to provide and it was found that private companies have the largest offer of tests, performing practically all tests with higher percentages. Thus, these companies are more dedicated to the inspection of buildings and have a larger offer of *in-situ* tests. On the other hands, university laboratories and accredited laboratories perform more restricted tests and have a more specific test offer.

4.3. Number of tests performed per entity

Analyzing the tests that each entity performs, it appears that, in general, no entity performs more than 55% of the 309 tests that can be performed. There is only one private company and an accredited laboratory that record values just over 50%. The remaining entities perform less than 40% of the tests, and there are four that have minimum values below 10%.

Private companies are the entities that perform the largest percentage of tests, performing on average about 32% of the total. In contrast, accredited laboratories provide the smallest number of tests, averaging only 19%.

As far as accredited tests, only accredited laboratories have them and it appears that the entities providing the largest number of trials actually carry out a small percentage of accredited trials. In contrast, entities that perform fewer tests have high percentages of accreditation.

4.4. Most tested building elements

It was analyzed in detail the percentage of tests that each entity provides in each building element and it appears that there is only one entity, of the 24 studied, that provides more than 75% of the tests, namely in masonry coatings. It is found that in reinforced concrete construction elements, in wooden floors and coverings most entities allow to perform about 25% to 50% of the tests and that in the remaining elements, the most predominant is the accomplishment of less than 25% of the tests.

The concrete elements are the ones with the greatest offer to be tested, since they register the largest number of entities to perform tests and of these entities most offer between 25% and 50% of them. Masonry elements are less tested than concrete elements, yet coatings are the most offered elements of this group. Finally, wood elements have a lower supply with regard to the percentage of tests that entities provide, as it is found that only 16 entities are able to perform tests on these elements, the most frequent being less 50% of the possible trials.

4.5. Geographic distribution of supply in Portugal

Of the entities studied which offer the essays under analysis, 28% belong to the district of Porto and another 28% to the district of Lisbon. The district of Setúbal still accounts for 11% of the entities, however, Coimbra, Faro and Madeira do not go beyond 5%. The remaining areas, namely, Azores, Vila Real, Aveiro, Castelo Branco, Viana do Castelo and Viseu, only have 3%.

Most of the entities in the districts of Lisbon and Porto are private companies. The offer of accredited laboratories and university laboratories is greater in Porto than in Lisbon. Apart from these two districts, only Setúbal has entities that belong to the three groups studied, and private companies continue to predominate. The autonomous region of Madeira only has no university laboratory, while the Azores only have an accredited laboratory. Faro, Castelo Branco, Viana do Castelo and Viseu only have private companies, while Vila Real and Aveiro only have university laboratories.

Regarding the constructive elements, it is verified that Vila Real do not perform tests on building elements of wood. Viseu, Castelo Branco, Viana do Castelo, Faro, Coimbra and Lisbon have a good offer for all elements, and it is found that in these districts there are entities having a wide range of tests on wood elements. Of the three districts with the most entities offering services, it is noted that Lisbon has better supply values, followed by Coimbra and lastly Porto, which has the lowest number of tests on building elements.

5. Conclusions

As far as buildings are concerned, it is important to be able to distinguish between building typologies, depending on whether the building is old or current, the building elements are different.

In the process of identifying anomalies, it is essential to be able to identify the causes that led to their appearance and development.

Given the diversity of anomalies that may exist, the need to identify and characterize the diagnostic techniques currently used in building elements, corresponding to each element under study the techniques that can be applied to it.

This way, a significant number of laboratory and *in-situ* tests have emerged that can be applied to each element. Given the variety of existing essays, the main focus for the preparation of this dissertation was the market investigation that makes these essays available.

The existing market is made of entities comprising accredited laboratories, university laboratories and private companies that perform building inspections. For each of these entities were collected and identified the tests that they provide, verifying that private companies are the group of entities that has the largest number of tests, contrary to the accredited laboratories that are the ones with the least tests.

In general, the most widely available tests are pacometer, crack comparator, boroscopic inspection, Schmidt sclerometer, chloride content determination, humidimeter, infrared thermography and compression strength determination.

From the studied constructive elements, it is verified that the concrete elements are the most tested, while the wooden elements are the least tested. Still making a geographical analysis, it is possible to say that there are areas of the country, namely, Faro, Castelo Branco, Viana do Castelo, Viseu, Lisbon, Porto and Coimbra that have entities who have good offer of tests wooden building elements. On the other and, Vila Real do not test this element.

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