

Extended Abstract

**Catalogue of diagnosis techniques in non-structural  
elements of current buildings**

**Laura Araújo Machado**

Supervisor: Doutora Inês dos Santos Flores Barbosa Colen

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## **1 Introduction**

The importance of the characterization of the state of degradation of a building is directly connected to the evaluation of the maintenance needs. In the case of Portugal, this activity has a major importance these days, for a great number of the existing buildings were built in the sixties. Over the past 20 years, Portugal has witnessed a level of development in construction that enabled a rapid growth of building construction. Currently the pace of construction of new homes has slowed drastically and it becomes essential to evaluate the recovery of buildings that require rehabilitation work. According to data published by the National Statistics Institute (INE), in 2011, 27,3% of all the housing stock are in need of rehabilitation works (INE, 2011).

Rehabilitation aims to correct any defect that the buildings gradually acquire throughout their lifetime, since much are dangerous for public safety, safety of building users or even to the security of the building (collapse). In the case of non-structural defects, the collapse of the structure is not in question, except in cases where the non-structural defect worsens so much that eventually become a structural problem.

To perform a rehabilitation at a non-structural level in any building its necessary an adequate prior inspection of the site, possibly complemented with *in situ* and laboratory testing techniques, to sustain a correct diagnosis of the actual state of degradation of non-structural elements.

Because of the many techniques of available tests, the work of diagnostic becomes difficult in different non-structural elements. Thus, in the case of new constructions it is necessary a set of techniques that allows to perform a detailed inspection of its non-structural elements, ideally organized in the form of a catalogue that enables the creation of a database of sheets with technical information for the diagnosis of current buildings.

In this context, it is relevant to make a systematization of these techniques suitable for characterization of the real status of recent constructions for the diagnosis of defects in non-structural elements, rigorously but also able to provide conditions for greater productivity of labour inspection.

## **2 Pathology and diagnosis of current buildings**

### **2.1 Constitution and defects of current buildings**

The current buildings are mainly built in reinforced concrete structures often separate from each other, the exterior walls are non-structural, rendered and painted or coated with different materials. The roof is pitched or flat, in waterproofed terrace. The interior walls are made of hollow bricks and coated with plaster. In Table 1 is presented a summary of the non-structural elements of a current building.

Table 1 – Constitution and characterization of a current building

Building elements	Characterization
<b>Facades and exterior claddings</b>	<ul style="list-style-type: none"> <li>○ Permanent contact with the outside and subject to weather adversity, shocks, among others. Therefore, they must have some functional requirements such as mechanical behaviour, hygrothermal comfort, watertightness, noise insulation, fire safety and sustainability of buildings (Alves, 2001).</li> <li>○ The most common constitution of the facades of current buildings generally includes brick walls, for example, a double leaf of bricks or blocks with or without a drained and ventilated air-box, with thermal insulation. Typically, the exposed face is rendered and it is applied a painting or is covered with tile or stone materials (Cóias, 2004).</li> <li>○ The role of coatings in buildings is essentially aesthetic, contributing not only to the definition of their image, but also to the quality of urban space.</li> </ul>
<b>Roof</b>	<p>The roof furnishes the top of the building and has the function of protecting the building from rain, wind, snow, heat, cold and also to capture and distribute rainwater (Garcez <i>et al.</i>, 2012).</p> <p>There are two fundamental types of building roofs:</p> <ul style="list-style-type: none"> <li>○ Flat roofs or terraces, which consist of materials arranged in horizontal layers of the following main elements: resistant structure, waterproofing support, thermal insulation, waterproofing system and protective coating.</li> <li>○ The pitched roofs are the type of building coverage with the highest tradition in Portugal and can be presented with one or more leanings (Freitas, <i>et al.</i>, 2012). Can be lined with tiles, slates, slabs or plates of different materials.</li> </ul>
<b>Doors and windows</b>	<ul style="list-style-type: none"> <li>○ Elements that constitute the frames of the facades.</li> <li>○ These elements have very important repercussions on the building climatization and thus reducing energy consumption.</li> <li>○ There are several types of frames: the windows can be hinged, sliding, with tippers or guillotined; the doors can only be hinged or with tippers (Cóias, 2004).</li> </ul>
<b>Interiors</b>	<ul style="list-style-type: none"> <li>○ All the elements of a building that are not in contact with the outside world, including entrances, stairs, enclosed areas, garages, basements, storage rooms, interior walls, floors, ceilings, attics, and interior window frames (Cóias, 2004).</li> <li>○ Inside buildings, the greater deterioration agent is the water, leading to degradation of coatings, finishes and interior components (Paiva <i>et al.</i>, 2006; Sousa <i>et al.</i>, 2003).</li> </ul>

In the Tables 2 and 3 are shown the most important defects on non-structural elements.

Table 2 - Summary of most common defects in non-structural exterior elements of buildings  
 (Fais & Casula, 2010; Amaro *et al.*, 2013; Flores-Colen *et al.*, 2008; Gaião *et al.*, 2012; Garcez *et al.*, 2012; Medeiros, 2010)

Defects	Facades			Roofs			Spans		
	Brickwork	Coatings	Other	Coatings	Installations	Other	Frames	Glazing	Other
Fissures		X	X	X		X		X	X
Fractures	X	X	X	X		X		X	
Blistering		X	X	X		X			
Detachment		X	X	X	X	X	X		X
Laminar detachment, granular disaggregation, alveolarization		X	X	X			X		
Degradation / loss of grouting material in joints	X	X	X				X		
Lack of material		X	X	X		X			X
Biological colonization		X	X	X		X	X		X
Parasitic vegetation		X	X	X	X	X	X		X
Efflorescence / criptoflorescence	X	X	X	X					X
Stains due to moisture		X	X				X		X
Dirt		X	X			X			
"Ghosts"		X							
Runoff marks		X	X			X			
<i>Graffiti</i>		X	X						
Chromatic alterations / discolorations		X	X	X			X		
Deficient thermal and / or acoustic isolation	X	X		X			X	X	
Accumulation of debris			X	X	X		X		
Condensations							X	X	
Deficient watertightness		X		X		X	X		

Table 3 - Summary of most common defects in non-structural interior elements of buildings  
 (Fais & Casula, 2010; Amaro *et al.*, 2013; Flores-Colen *et al.*, 2008; Gaião *et al.*, 2012; Garcez *et al.*, 2012; Medeiros, 2010)

Defects	Lobby and interior common areas		Kitchens and bathrooms		Floors	Ceilings	Interior Walls	
	Brickwork	Coatings	Coatings	Installations	Coatings	Coatings	Brickwork	Coatings
Fissures		X	X	X	X	X		X
Fractures		X	X	X	X			
Blistering			X		X	X		
Detachment		X			X			
Laminar detachment, granular disaggregation, alveolarization		X	X		X			
Degradation / loss of grouting material in joints	X	X	X		X			
Lack of material		X	X		X			
Biological colonization					X			
Parasitic vegetation								
Efflorescence / criptoflorescence			X		X	X		X
Humidity stains			X			X		X
Dirt					X	X		X
“Ghosts”								
Runoff marks								
<i>Graffiti</i>								
Chromatic alterations / discolorations					X			
Deficient thermal and / or acoustic isolation			X	X	X	X		X
Accumulation of debris								
Condensations		X	X	X	X	X		X
Deficient watertightness		X	X	X	X			

## 2.2 Diagnosis techniques for non-structural elements

Diagnosis techniques are any type of test performed on a sample in order to evaluate their properties and they can be classified in terms of:

- level of destruction made to the construction material/element (non-destructive semi-destructive or destructive);
- place where they are performed (*in-situ* or in laboratory);
- principles on which they are based (mechanic, electric, magnetic, electro-magnetic, ultrasonic, radioactive, sensorial, thermal, chemical, electro-chemical, and others);
- activities which they intervene (quality control, building inspection, compliance with regulations and others);
- type of achieved results (properties to be evaluated);
- elements which they apply (examples: coating, support);
- existence or absence of artificial requests (passive, also known as non-invasive and active, known as invasive).

According to Córias (2006) and Freitas *et al.* (2012), the diagnosis techniques are used primarily in:

- detection of hidden elements, such as, pillars, arches, structures of intermediate floors and others;
- evaluation of the damage extension in fissured structures;
- detection of voids, internal fissures and cavities;
- qualification of the materials and characterization of heterogeneity zones;
- detection of superficial deterioration;
- evaluation of the moisture content and the height of capillary rise;
- analysis of the materials proprieties.

In the next Table , is made a summary of the diagnosis techniques and the possible defects to which they apply. The list contains a combination of the most common defects found in Portugal.

## 2.3 Methods of analysis and diagnosis of existing defects

In a time when the building process evolves rapidly assimilating new technologies, new techniques and materials, the number of problems that affect the buildings also increase at a similar pace. The poor knowledge of materials and techniques, the tight delivery dates and weak execution projects, contribute to the appearance of defects in the buildings (CIB, 2013). Therefore, some information has been systematized, in which each country has created over the years, its own database catalogues of defects in buildings. Some examples of the most relevant methods of analysis and diagnosis used, both internationally and nationally, are presented in the next paragraph. The choice focuses on methods that systematize the information through sheets, since it is the objective of this work.

Table 4 - Synthesis of application of diagnosis techniques to anomalies (Flores-Colen *et al.*, 2008; Silvestre & Brito, 2011; Neto & Brito, 2011; Amaro *et al.*, 2013; Garcez *et al.*, 2012; Cóias, 2006; Flores-Colen, 2009; Ferreira, 2010; Abreu, 2013)

Techniques	Defects *																			
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
Visual inspection	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
Proprietary crack width gauge	X	X																		
Variation of cracks widths – “Tell-tales”	X	X																		
Optical meter of fissures	X	X					X													
Detection of surface delamination – percussion, dragging of chains and toothed wheels device			X	X	X															
Measurement of colour – Portable colorimeter								X	X	X	X	X	X		X	X				
Endoscopy		X		X		X	X			X	X									
Measurement of coating adherence – <i>Pull-off</i>				X			X			X	X					X				
Resistance to sphere impact ( <i>Martinet Baronnie</i> )											X					X				
Evaluation of surface hardness – Pendulum rebound hammer					X						X									
Helix test						X														
Microdrilling						X														
Compressive strength of samples of coatings					X															
Penetration resistance ( <i>Martinet Baronnie</i> )					X						X									
Infrared thermography				X				X	X		X	X	X					X		
Determination of salts – Field kit										X	X					X				
Determination of salts – Colorimetric strips								X	X	X	X					X				
Determination of fungi and algae				X				X	X			X								
pH measurement								X	X	X						X				
Conductivity measurement										X	X					X				
Measurement of the surface moisture – Moisture meter				X				X	X	X	X		X			X				
<i>Karsten</i> tube											X		X			X				
Measurement of the thermal conductivity																	X		X	X
Permeability to water vapor											X	X	X			X				
Registration hygrothermal conditions								X	X		X	X	X							

\* Caption: A1 – Fissures, A2 – Fractures, A3 – Blistering, A4 – Detachment, A5 – Laminar detachment, granular disaggregation, alveolarization, A6 – Degradation / loss of grouting material in joints, A7 – Lack of material, A8 – Biological colonization, A9 – Parasitic vegetation, A10 – Efflorescence/criptoflorescence, A11 – Stains due to moisture, A12 – Dirt, A13 – “Ghosts”, A14 – Runoff marks, A15 – *Graffiti*, A16 – Chromatic alterations / discolorations, A17 – Deficient thermal and/or acoustic isolation, A18 – Accumulation of debris, A19 – Condensations, A20 – Deficient watertightness.

To the present day has been systematized some information on the work of inspection and rehabilitation:

- Defects sheets, such as: “Defect Action Sheet – DAS” prepared by the English BRE (Building Research Establishment) in 1982, “Cases of Failure Information Sheet” published by CIB (*Conseil International du Bâtiment*) in 1993, “*Fiches Pathologie du Bâtiment*” created by the french AQC (*Agence Qualité Construction*) in 1995, “Pathology Sheets” provided by PATORREB in a website in 2004;
- Rehabilitation sheets, especially: “Good Repair Guides” produced by BRE in 1996, “*Fichas de Reparação de Anomalias*” prepared by LNEC (*Laboratório Nacional de Engenharia Civil*) in 1985, the *Método Simplificado de Diagnóstico de Anomalias* (SDA) suggested by Abrantes in 2005 and later published in a book (Abrantes & Silva, 2012), “*Ficha de Intervenção*” suggested by Medeiros in 2010;
- Diagnosis techniques sheets such as: “Survey Information Sheets” published by CIB in 2013, “*Fichas de inspeção e ensaio*” developed by Córias (2006) and “*Fichas de técnicas de diagnóstico*” proposed by Abreu (2013).

### **3 Design of a model sheet of diagnosis techniques**

The proposed model consists in a sheet with only two pages, where it is condensed all relevant information for each diagnostic technique in non-structural elements of current buildings. It is a model easy to use and understand, even for a user without expert knowledge can get the necessary information about each technique. Both pages of the sheet are divided into frames to a better organization of space and the visualization of the information of each technique, allowing an easy and accurate consultation for the user.

In the header was decided to put just the technique designation and the respective reference. The sheet first page body continues with the non-structural elements in which the technique can be applied, the degree of destruction of the technique, the location of its use (*in situ* or laboratory), the description of technique, its principle of operation, the equipment, the vantages and limitations. The footer includes the principle of use and reference of the sheet in question.

The second page of the sheet continues with a range of the cost and difficulty of the technique, test procedure, measurement parameters, applicable normative or technical documents, reference values and interpretation of results. As in the first page, the reference is displayed at the bottom together with the designation of the technique.

In this context, it is proposed the following model of diagnosis techniques sheet, presented in the Figures 1 and 2, in which its fields are explained.

<b>DESIGNATION OF THE DIAGNOSIS TECHNIQUE</b>		Ref.
Keywords:		2014
<b>DESTRUCTIVE LEVEL OF THE TECHNIQUE:</b> <input type="checkbox"/> Destructive <input type="checkbox"/> Semi-destructive <input type="checkbox"/> Non-destructive		<input type="checkbox"/> <i>In situ</i> <input type="checkbox"/> Laboratory
<b>NON-STRUCTURAL BUILDING ELEMENTS IN WHICH CAN BE USED:</b>		
<u><b>Facades</b></u> <input type="checkbox"/> Brickwork <input type="checkbox"/> Coatings <input type="checkbox"/> Other	<u><b>Roofs</b></u> <input type="checkbox"/> Coatings <input type="checkbox"/> Installations <input type="checkbox"/> Other	<u><b>Spans</b></u> <input type="checkbox"/> Frames <input type="checkbox"/> Glazing <input type="checkbox"/> Other
<u><b>Kitchens/bathrooms</b></u> <input type="checkbox"/> Brickwork <input type="checkbox"/> Coatings	<u><b>Floorings</b></u> <input type="checkbox"/> Coatings	<u><b>Ceilings</b></u> <input type="checkbox"/> Coatings
		<u><b>Lobbies and interior common areas</b></u> <input type="checkbox"/> Brickwork <input type="checkbox"/> Coatings
		<u><b>Interior walls</b></u> <input type="checkbox"/> Brickwork <input type="checkbox"/> Coatings
<b>PRINCIPLE USED:</b>		
<input type="checkbox"/> Sensorial perception <input type="checkbox"/> Mechanical action <input type="checkbox"/> Hydrodynamic <input type="checkbox"/> Propagation of electromagnetic radiation <input type="checkbox"/> Chemical reaction <input type="checkbox"/> Electric <input type="checkbox"/> Hygrothermal		
<b>DESCRIPTION:</b> In this field is presented, in a synthetic way, the diagnostic technique in analysis, where the type of test is indicated and where is made a short introduction to the method. It may contain information regarding the phase of the lifespan of the building on which the method is applied, whenever necessary.		<b>EQUIPMENT/NECESSARY MATERIAL:</b> This field is used primarily to list and illustrate the equipment and materials required for the application of the technique in question, such as machinery and equipment, mechanical appliances, among others. Are illustrated in the form of photographs or diagrams and serve to a better perception the application of the technique.
<b>VANTAGES:</b> As the name implies, this field is referred to the major advantages of the technique in question. It is an important field that provides useful information on the virtues of the technique, which allows the user of the catalogue a base of comparison of the various techniques.		<b>LIMITATIONS:</b> Contrary to the left field, in this field are the main disadvantages of the technique in analysis. It is an important field that provides useful information on the limitations of the technique, which allows the user of the catalogue a basis of comparison between the various techniques.
Ref.	PRINCIPLE USED	

Figure 1 - Proposed model type of diagnostic technique (front)

<p><b><u>COST:</u></b>  <b><u>Equipment cost:</u></b>  <input type="checkbox"/> Economic      <input type="checkbox"/> Medium      <input type="checkbox"/> Expensive  <b><u>Test realization cost:</u></b>  <input type="checkbox"/> Economic      <input type="checkbox"/> Medium      <input type="checkbox"/> Expensive</p>	<p><b><u>NORMATIVE OR TECHNICAL DOCUMENTS:</u></b>  In the space related to applicable standards are placed Portuguese, European or other existing standard of the test concerning the technique in analysis. For tests in which there are no applicable standards, technical documents relating to testing are used.</p>		
<p><b><u>DIFICULTY:</u></b>  <input type="checkbox"/> Low                      <input type="checkbox"/> Medium                      <input type="checkbox"/> High</p>	<p><b><u>REFERENCE OR ORIENTATES VALUES:</u></b>  The reference values are derived from reference documents or values obtained through studies, papers or reports of previous tests and serve as a good basis of information for the user, who can consult them effectively during or after the test in question, in order to infer the validity of the results obtained with the test performed or even to compare values.</p>		
<p><b><u>TEST PROCEDURE:</u></b>  In this field relating to the testing procedure, such as the name indicates, is explained in numerated bullets, all the following procedure to properly perform the test corresponding to the technique in analysis. Procedures were removed of books, technical documents and test sheets or studies of any previous tests.</p>	<p><b><u>INTERPRETATION OF RESULTS:</u></b>  The results are in this field analysed and is made a study, with the objective to conclude about the values obtained during the test and predict the diagnosis of the element or material to which the technique was used.</p>		
<p><b><u>MEASUREMENT PARAMETERS:</u></b>  This field corresponds to the space where the test results are presented, both numerical results, either in the form of graphics or images. Results can be obtained by the equipment, readings performed by experts, among others.</p>	<table border="1"> <tr> <td data-bbox="798 1962 1252 2000">DESIGNATION OF THE DIAGNOSIS TECHNIQUE</td> <td data-bbox="1254 1962 1418 2000">Ref.</td> </tr> </table>	DESIGNATION OF THE DIAGNOSIS TECHNIQUE	Ref.
DESIGNATION OF THE DIAGNOSIS TECHNIQUE	Ref.		

Figure 2 - Proposed model type of diagnostic technique (back)

## 4 Catalogue of diagnosis techniques

The catalogue of diagnosis techniques for non-structural elements includes a general index, a collection of sheets organized according to the principle of use and the respective bibliography. The catalogue is also accompanied by an illustration showing the various non-structural constructive elements indicated in the sheets.

The catalogue consists in 20 sheets organized according to the respective principles of use (sensorial perception, mechanical action, propagation of electromagnetic radiation, chemical reaction, electric, hydrodynamic and hygrothermal), to provide a quick and expeditious consultation, having been used to encoding illustrated in the Table .

Table 5 - Summary of diagnostic techniques sheets developed

Diagnosis techniques	
TPS - Techniques of Sensorial Perception	01 TPS - Measurement of crack widths – Proprietary crack width gauge
	02 TPS - Measurement of the variation of cracks widths – “Tell-tales”
	03 TPS - Measurement of micro fissures widths – Optical meter of fissures
	04 TPS - Detection of surface delamination – percussion, dragging of chains and toothed wheels device
	05 TPS - Portable colorimeter
TAM - Techniques of Mechanical Action	06 TAM - Pull-off
	07 TAM - Resistance to sphere impact – <i>Martinet Baronnie</i>
	08 TAM - Evaluation of surface hardness – Pendulum rebound hammer
	09 TAM - Helix test
	10 TAM - Microdrilling
	11 TAM - Compressive Strength of samples of coatings
TPRE - Techniques of Propagation of Electromagnetic Radiation	12 TPRE - Infrared thermography
TRQ - Techniques of Chemical Reaction	13 TRQ - Determination of salts – Field <i>kit</i>
	14 TRQ - Determination of salts – Colorimetric strips
	15 TRQ - Determination of fungi and algae
	16 TRQ - pH measurement
	17 TRQ - Conductivity measurement
TE - Electric Techniques	18 TE - Measurement of the surface moisture – Moisture meter
THd - Hydrodynamic Techniques	19 THd - <i>Karsten</i> tube
THt - Hygrothermal Techniques	20 THt - Measurement of the thermal conductivity

Some of the developed sheets (9) are the result of improvements in sheets initially proposed in a master's thesis conducted by Abreu (2013), in particular, the sheets 02 TPS, 06 TAM, 07 TAM, 08

TAM, 12 TPRE, 13 TRQ, 18 TE, 19 THd and 20 THt; and the remaining 11 are proposals for new sheets.

The techniques were organized under a sequential numbering, followed by each category code (for example: 01 TPS, 02 TPS, ... , 06 TAM, ...). This way, future sheets may be added by continuing the adopted sequential numbering, followed by the techniques respective codes.

## 5 Conclusions

The difficulty in finding elements of support for civil engineering professionals involved in rehabilitation projects of buildings raised the present research work, which focused on the development of a catalogue of diagnosis techniques in non-structural elements of current buildings. For the correct diagnosis of a current building, matters a good knowledge of the anomalies at which it is subject to, its constructive typification and an understanding of the various existing diagnosis techniques.

Taking into consideration the constitution of a building, from its exterior surroundings to its own inner constitution, was chosen to identify, in general, the non-structural elements of a current building:

- The elements on contact with the exterior, have been studied the exterior walls (brickwork and coatings), the toppings (pitched and flat) and their coatings and installations, and finally the spans (doors and windows frames, glazing and other elements).
- From the interior elements, were considered the floor and ceilings coatings; brickwork and coatings from the lobbies, common areas, kitchens, bathrooms and interior walls (those are not the only non-structural elements in interiors, but for this work were the ones considered in the relation with the diagnosis techniques).

The diagnosis and inspection techniques more relevant in non-structural elements were identified, systematized, organized and classified by the principles on which they are based, particularly in terms of sensorial perception, mechanical action, propagation of electromagnetic radiation, chemical reaction, electrical effects, hydrodynamic and hygrothermal.

Were identified and presented generally and chronologically, the methods of analysis and diagnosis of anomalies that appear more frequently in buildings. Those are essentially sheets, catalogues, tables of different organizations and countries. It was concluded that there is a deficit in the systematization of information related to this specific area of Civil Engineering.

This work resulted in the design of a model sheet, with two pages, for the description and principles of use of diagnosis techniques for non-structural elements of current buildings. It was prepared 20 sheets of diagnosis techniques, which are organized in a catalogue according to a codification based on the techniques principle of use.

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