TÉCNICO LISBOA

Extended Abstract

Catalog of laboratorial diagnostic techniques based on samples collected from buildings in service

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1 INTRODUCTION

Society has available a vast infrastructure of buildings today with which it seeks to respond to the needs and expectations of the population. This infrastructure is exposed to the most various actions and must constantly be maintained, rehabilitated and adjusted to new requirements of use and comfort [1].

Although they are generally considered to be highly durable, all buildings enter into a degradation process as soon as their construction is complete. Initially, this process is relatively slow, but if a building is not maintained regularly, its degradation rate will accelerate until it is no longer usable [3].

Defects occurring in buildings is a common problem, whether it be residential or commercial buildings that are old or new. The manifestation of these anomalies can interact on a buildings functionality or its structural integrity, which in turn can compromise the health and safety of its occupants, which comes to show the importance of building maintenance and rehabilitation [1].

Before intervening on a building, it is essential to know its state of conservation, what kind of anomalies exist and what are their extent, in order to act accordingly and efficiently. Acting in this way can help ensure the successful rehabilitation and maintenance of buildings [2].

The necessary interventions should be based on reliable information, collected through inspections on site and possibly complemented with in situ and laboratory testing techniques, which can provide crucial data, easing the professionals in:

- Establishing causes of prevailing damage and anomalies;
- Correctly assessing the extent of the state of decay;
- Defining adequate corrective measures;
- Planning interventions promptly.

The subject of building pathology has been the theme of numerous studies, which has led to the availability of a significant amount of technical information. However, all this data is dispersed and finding relevant information can be an overwhelming task. So, it is essential to systematize this knowledge to help expedite the analysis of buildings anomalies. Therefore, the creation of a catalog enables the development of a suitable database of sheets with relevant technical information which could become a powerful tool and a significant contribution to professionals in the field of construction [2].

2 PATHOLOGY AND DIAGNOSIS

2.1 Inspection and diagnosis of anomalies

The inspection and diagnosis of building anomalies are determining factors in the sustainable rehabilitation of our built heritage. Understanding the pathological phenomenon allows for direct actions on building defects, ensuring a concise and viable rehabilitation. An accurate diagnosis ascertains the anomalies origins, causes and occurrence mechanisms. [1] [4]

The methodology to identify anomalies and establish their probable cause can go through several phases. A flowchart illustrating these phases is presented in Figure 1.

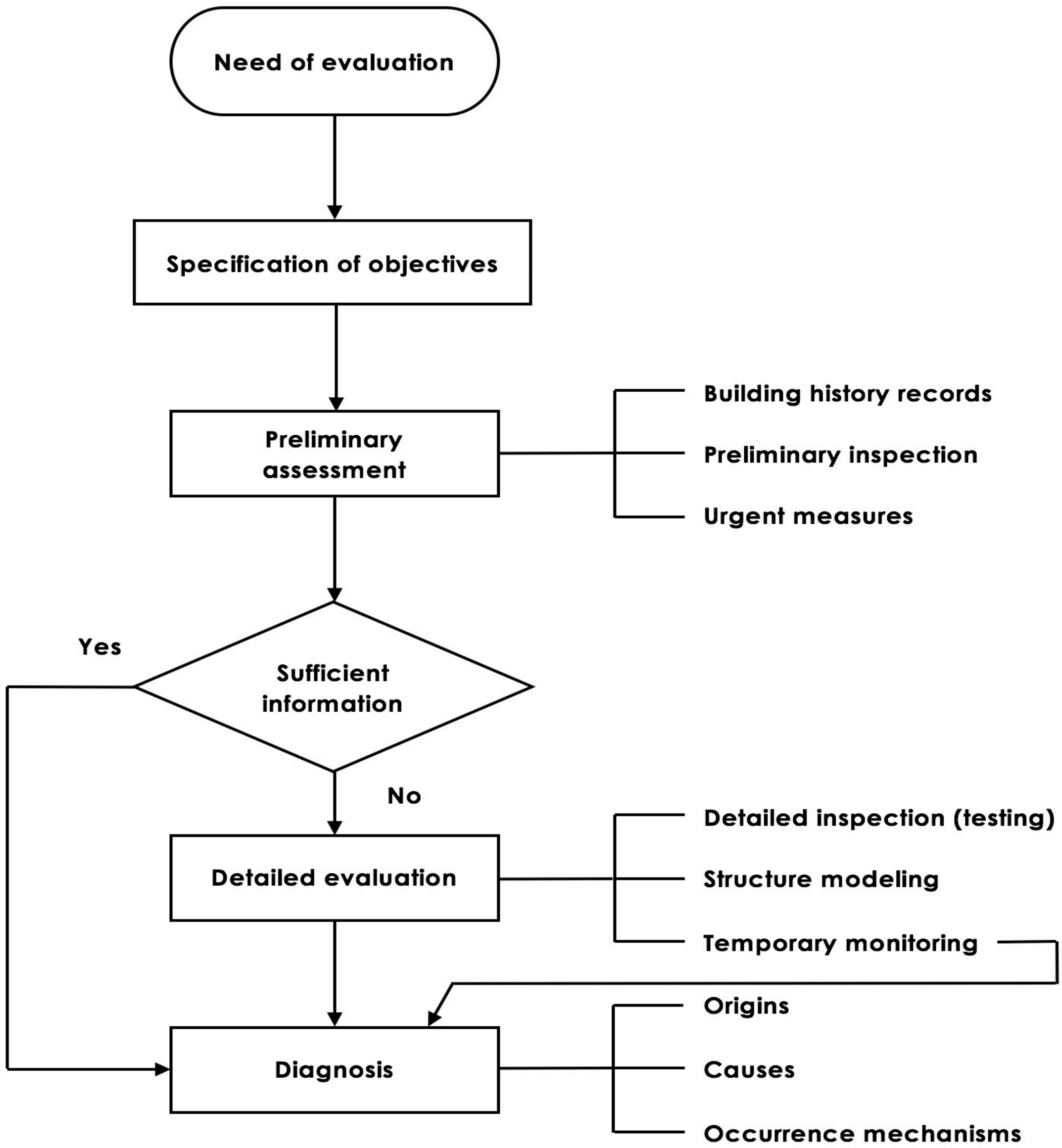

Figure 1 – Actions of a method of diagnosis of building anomalies, adapted from [5]

A summary of the most frequent anomalies in old and recent buildings and their corresponding probable causes is shown in Table 1.

Table 1 – Frequent anomalies and their probable causes [1]

	Anomaly	Probable causes
Buildings in general	Spots and localized alterations of coatings on the top floors	Water Infiltration caused by damaged roof tiles, deteriorated waterproofing, clogged or deteriorated roof drainage
	Same, next to windows	Water Infiltration due to non-watertight window frames
	Same, on the interior floors	Leaking water from sewage pipes
	Same, near the ground floor	Rising humidity due to lack of insulation of foundations on buried walls
	Efflorescences and crypto-florescences	Rising humidity leading to the migration of salts inside the exterior walls
	Cracked walls and bulging plasters	Differential settlement of foundations. Temperature variations
	Black crusts and other types of dirtiness	Atmospheric pollutants
	Biological surface breakdown	Presence of lichens
Old buildings	Deformations in masonry walls, bulging	Yielding masonry walls due to modifications or the increase of loads. Degradation of masonry load capacity. Signs of masonry shifts
	Cracks and fissures	Signs of masonry deformation that can be old or recent and may still be active or stabilized
	Localized cracking of plasters and masonry	Expansion resulting from corrosion of embedded steel elements
	Opened masonry joints	Alteration and erosion of the mortar. Vegetation infestation
	Distorted door openings, misaligned doors	An indication of differential settlements associated with changes in lower floors or foundations problems
	Weakened wood elements	Wood-damaging insects: • Xylophagous insects (dry wood) • Termites (Damp wood)
Current buildings (reinforced concrete)	Sub-horizontal cracking near the roof slab	Temperature variations
	Rust stains	Poor execution of reinforced concrete elements, loose wire ends or other fastening devices that oxidized, prolonged deposition of steel rods on wet formwork before pouring concrete
	Delamination or superficial scaling	Excessively compressed element. Chemical attack
	Superficial delamination and rebar exposure	Expansion caused by rebar corrosion due to insufficient cover, porous concrete, carbonated or high chloride content
	Excessive deflection of slabs or beams	Excessive loads, foundation settlements, inadequate quantity or poorly positioned rebar. Poor quality concrete. Calculation deficiency

2.2 Laboratorial diagnostic techniques

Laboratory testing is an essential tool in obtaining detailed information about a building and its materials. Although laboratory techniques are more expensive and time-consuming, they allow precise qualitative and quantitative indications of the analyzed material's nature (chemical characterization, mineralogical composition, petrographic characteristics, physical, chemical and mechanical properties) [9] [10].

Currently, there are a wide variety of testing techniques that can be used to assess in-service performance of building materials. The diversity of principles and characteristics of these methods makes it difficult to structure a global classification, which is why it is normal to classify testing techniques according to shared features. As stated by some authors, these techniques can be categorized in terms of [1] [5]:

- Level of destruction (destructive, semi destructive and non-destructive);
- Operating principle (mechanical, electrical, magnetic, electromechanical, ultrasonic, radioactive, sensory, thermal, chemical and others);
- Location where they are performed (*in situ* or laboratory);
- Obtained results (properties to be evaluated);
- Applied building elements (structural or non-structural);
- Involved activities (quality control, building inspection, among others).

A synopsis of the process and application of some laboratorial diagnostic techniques based on in-service collected samples is presented in Table 2.

Table 2 – Synopsis of the application and process of some laboratorial diagnostic techniques [1] [10] [11]

Diagnostic technique	Process	Application
Binocular microscope examination	The binocular microscope enables magnifications up to 20X allowing the study of grain structure and crystal identifications.	Observation of samples textures. Stratigraphic analysis. Study of crusts and efflorescence outcomes. Study of fungi and lichens.
Petrographic analysis of concrete and mortars	Analysis with an optical microscope of thin slices of core samples. Microstructural analysis with magnifications up to 400X.	Microstructure analysis of concrete, mortars, rocks and other materials. Evaluation of concrete or mortar qualities. Chemical reactions identification.
Compressive strength test on drilled concrete cores	Tests are conducted by loading the core sample between two plates and applying force. Deformation versus applied load is recorded.	Used to determine the elastic limit, proportional limit, yield point, yield strength, and (for some materials) compressive strength.
Abrasive testing	A sample is placed on a turntable where two abrasion wheels are set with a specific pressure.	Determination of wear rate of materials. Stone characterization.
X-Ray computed micro-tomography	The small unaltered sample is placed between an X-ray source and a detector on a turntable.	Tomographic density and porosity of small samples of masonry, brick, stone or mortar. Obtains a three-dimensional structure of the sample.
Fourier transform-infrared spectroscopy	This technique measures the absorption of infrared radiation by the sample material versus wavelength.	Identification of bulk material compounds.

Table 2 (Continued) – Synopsis of the application and process of some laboratorial diagnostic techniques [1] [10] [11]

Diagnostic technique	Process	Application
X-Ray diffraction	A monochromatic beam of X-rays reaches the pulverized sample, when it is incident on the crystalline material, the diffraction occurs.	Study of the composition of mortars and concretes. Mineralogical composition of crystalline phases.
X-Ray fluorescence spectrometry	The analysis consists of 3 phases, excitation of elements from the sample, dispersion of the characteristic X-rays emitted by the sample and detection of these X-rays.	Quantitative and qualitative analyses of the chemical elements present.
Wet chemical analysis	Most analyzing is done in the liquid phase	The composition of mortars and other building elements.
Ion chromatography	Separation and quantitative analysis of anions and cations in an ionic solution	Determination of soluble salts present in samples. Analysis of the surface changes of the stone.
Capillarity absorption	Measures the water absorption rate through the difference in mass.	Evaluation of water behavior applied to an element.
Water absorption by immersion	After oven drying, samples are immersed in distilled water, and the water absorption is measured by weighing.	Characterization of porous building materials and evaluation of their degree of deterioration.
Mercury intrusion porosimetry	Samples are dried at an elevated temperature and then brought into contact with mercury at a very high pressure.	Analysis of pore distribution of stones and mortars and evaluation of the effects of applied treatments.
Thermogravimetric analysis	The sample is placed in a small pan connected to a microbalance and heated in a controlled manner and held isothermally for a specified time.	Analysis of concrete degradation (Rebar corrosion, alkali reaction, sulfates, chemical agents). The composition of mortars.
Differential thermal analysis	The temperature difference between a sample and a reference material is measured as a function of temperature, while both are subjected to controlled temperature variations.	Analysis of heat capacity and thermal conductivity.
Non-steady-state Chloride migration test	Testing is done on a concrete core by causing an accelerated flow of chloride ions through an electrical field.	Expeditious determination of concrete chloride permeability.
Scanning electron microscopy	Observation of surfaces with the use of a beam of electrons with specific energy to bombard the surface of the sample, rendering images at very high magnifications.	Analysis of concrete microstructure, wear process and deterioration. Characterization of fracture morphology.

2.3 Diagnostic methodologies

The direct intervention on anomalies in the perspective of rehabilitation reduction costs requires the development of diagnostic methods of optimized and practical appeal, that aim at an easy implementation in the most diverse situations of building anomalies [4].

There are many diagnostic methods of building anomalies, either national or international, that allow specialized technicians to obtain information in the most diverse areas of defects. Several countries have created their building pathology catalogs with data collected over the years. The method of recording and organizing the information varies according to the objectives and data available. Table 3 offers a brief presentation of some of these methods.

Table 3 – Building pathology catalogs [6] [7] [8]

Entity / Author	Title	Year	Sheet pages	Description
Building Research Establishment (BRE)	Defect Action Sheet	1982	2	A catalog with 144 sheets of anomaly descriptions, causes and corresponding prevention measures.
Laboratório Nacional de Engenharia Civil (LNEC)	Fichas de reparação de anomalias	1985	1	The catalog's sheets are grouped into three categories, namely: Structural Pathology, Non-Structural Pathology and Facilities. Each sheet corresponds to an anomaly and they all have the same structure.
Conseil International du Bâtiment (CIB)	Cases of Failure Information Sheet	1993	Variable	The group W086 Building Pathology published a document entitled "Building Pathology: A State of the art report" in which the sixth chapter proposes a sheet template.
Agence Qualité Construction (AQC)	Fiches Pathologie du Bâtiment	1995	3	The catalog was updated in 2015 and now consists of 69 sheets. Each one identifies and establishes the diagnosis of defects, promotes proper procedures with the aid of diagrams and illustrations and makes a list of relevant reference texts.
PATORREB	Fichas de Patologia	2004	1	In 2004, the website www.patorreb.com was created, where seven portuguese universities compiled a building anomalies catalog. It has 98 sheets that are organized according to the building elements where the defect manifested.
Conseil International du Bâtiment (CIB)	Survey Information Sheets	2013	1	In the 2013 report released by CIB W086, new developments in the field of building pathology are announced, including a new proposal for diagnostic sheets called Survey Information Sheets.

3 DIAGNOSTIC TECHNIQUES CATALOG

3.1 Sheet template

The proposed template consists of a two-page sheet where all the relevant data of each technique is summarized and presented in the form of a table. Displaying the data in table fields allows for an organized and consistent arrangement among all sheets easing the examinations and comparisons between techniques by any user.

The title of the technique is the first field on the header of the sheet next to it is the alphanumeric reference. Below are five fields with information displayed in checkboxes indicating the building elements in which the technique can be applied, the location where the test is carried out, level of damage caused on the sample, type of sample required and its operating principle. The last four fields of the first page describe the diagnostic technique, the necessary equipment and materials, their potentials and limitations. The bottom of the page contains a footer that shows the reference of the technique and its operating principle.

The second page of the sheet contains the fields related to the cost and difficulty of the technique, followed by a description of the test procedure, indication of related normative documents, reference values, displayed results and interpretations. At the bottom of the page is the footer containing the title of the sheet and its reference. The proposed diagnostic techniques sheet template with brief descriptions of each field is presented in Figures 2 and 3.

3.2 Catalog structure

The catalog of laboratory diagnostic techniques based on in-service collected samples contains an index, a set of technical sheets and a list of references. The catalog has a total of 15 sheets that are ordered according to principle, i.e., sensorial perception, mechanical action, electromagnetic radiation interaction, chemical reaction, hydrodynamic, thermal analysis and electric / electronic effects. This method of organization was adopted in order to ease consultations. The reference encoding of each sheet is present on the catalogs sheet listing as shown in Table 4.

Table 4 – Sheets included in the catalog

Reference	Diagnostic techniques
	TPS – Sensorial perception techniques (optical)
01 TPS	Binocular microscope examination
02 TPS	Petrographic analysis of concrete and mortars
	TAM – Mechanical action techniques
03 TAM	Compressive strength test on drilled concrete cores
	TIRE – Electromagnetic radiation interaction techniques
04 TIRE	X-Ray computed micro-tomography
05 TIRE	Fourier transform-infrared spectroscopy
06 TIRE	X-Ray diffraction
07 TIRE	X-Ray fluorescence spectrometry
	TRQ – Chemical reaction techniques
08 TRQ	Ion chromatography
09 TRQ	Wet chemical analysis – Acid digestion (HCl)
	THd – Hydrodynamic techniques
10 THd	Mercury intrusion porosimetry
11 THd	Water absorption by immersion
	TAT – Thermal analysis techniques
12 TAT	Thermogravimetric analysis
13 TAT	Differential thermal analysis
	TE – Electric / electronic techniques
14 TE	Scanning electron microscopy
15 TE	Non-steady-state chloride migration test

Sheet title	**Ref.**

BUILDING ELEMENTS THAT THE TECHNIQUE CAN BE APPLIED TO:

☐ **Structural** --

☐ **Non-structural** --

LOCATION:

☐ Laboratory
☐ *In Situ*

DESTRUCTIVENESS:

☐ Destructive
☐ Non-destructive

PRINCIPLE:

☐ Sensorial perception (optical)
☐ Mechanical action
☐ Electromagnetic radiation interaction
☐ Chemical reaction
☐ Hydrodynamic
☐ Thermal analysis
☐ Electric / electronic effects

SAMPLE TYPE:

☐ Normalized
☐ Irregular
Quantity / Dimension:
____

DESCRIPTION:

In this field, the diagnostic technique is briefly described. It can also reference the sampling process, the level of destruction caused and the anomalies identified.

EQUIPMENT/NECESSARY MATERIAL:

The materials and equipment used in the test procedure are listed in this field and can be illustrated with pictures or diagrams.

POTENTIALS:

The potential advantages of using the technique are listed in this section.

LIMITATIONS:

The main disadvantages that come from the application of the technique are listed in this section.

Ref.	**PRINCIPLE**

Figure 2 – Proposed sheet template (front page)

<table>
<tr><td>TESTING COST:

☐ Inexpensive ☐ Medium ☐ Expensive</td><td>DIFICULTY:

☐ low ☐ Medium ☐ High</td></tr>
<tr><td rowspan="2">TEST PROCEDURE:

This field methodically enumerates all the steps that occur during the test. The procedures shown here are based on books, standards, fact sheets and previous studies.</td><td>NORMATIVE DOCUMENTS:

This section presents Portuguese, European, international or other existing standards related to the test. They may refer to the test procedure or materials and can complement the information contained in the sheet.</td></tr>
<tr><td>REFERENCE VALUES:

Results of previous studies of the test are presented here. These values can serve as a basis for interpretation, comparison and validation of the results obtained by the user's tests. It may also include mathematical formulas, images, and diagrams.</td></tr>
<tr><td>DISPLAYED RESULTS:

The information presented here results from the measurements recorded by the technicians and equipment involved in the test. Displaying results in the form of tables, images or graphs and also mentions to the related mathematical formulas.</td><td>RESULTS INTERPRETATION:

In the last field of the sheet, a brief analysis of the results is made. This information can support the formulation of the diagnosis.</td></tr>
<tr><td>SHEET TITLE</td><td>Ref.</td></tr>
</table>

Figure 3 – Proposed sheet template (back page)

4 CONCLUSIONS

In the last decades, there has been a considerable deterioration of buildings, which has led to significant developments in the field of building pathology. This continuous development has led to an accumulation of knowledge, which can be found dispersed and disorganized.

Given this fact, it was important to gather and systematize the existing information, which originated the research carried out in this dissertation, resulting in the development of a catalog that encompasses laboratory diagnostic techniques based on samples collected from buildings in-service. Contributing this way to a useful database used for the diagnosis of anomalies and supporting a tool that assists engineers and technicians of the field.

It was determined that to precisely define the intervention process, it is essential to make an adequate diagnosis, where the compiling of information is one of the main tasks to be developed at an early stage. This task consists of analyzing building records and in situ observations of the buildings current state. The observations can be made through simple visual inspections, tests performed on the building or samples taken from it. With all the gathered information, it is possible to elaborate a diagnosis where the anomalies are identified, presenting hypotheses for their causes and possibly determine modes of intervention.

Templates of diagnostic sheets created in previous studies were presented and analyzed. Bearing in mind that this research follows previous studies, but has different objectives, which lead to the design of a sheet template that fits within its proposed theme while remaining consistent with the structure of previously created sheets of this catalog.

A two-page sheet template was proposed and the end result was the compilation of 15 new technical sheets in a catalog aimed at laboratorial diagnostic techniques based on samples collected from buildings in-service. The sheets were arranged according to a sequential numbering, followed by the code of each principle, thus allowing the possibility of adding new sheets in future studies.

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