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Methodology for a Sustainable Rehabilitation

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Abstract
This work intends to show a methodology developed for the identification and resolution of buildings rehabilitation problems. The main goal of the present methodology is to support and help the decision-makers in order to achieve a capable and sustainable resolution of present problems, without compromising the needs for future interventions. This kind of tools is fundamental to avoid current mistakes and errors. In Portugal this type of tools is scarce.
This methodology consists of a database system containing the available information concerning all the parameters involved in the rehabilitation process.
The developed methodology was implemented with the assistance of a computational system developed from the start which, by means of pre-established relationships, allows the identification of the best intervention solutions and rehabilitation works to be carried out.

1 Introduction

Rehabilitation, understood as the set of activities leading to the increase in the quality level of buildings, i.e., the levels of services supplied in terms of construction, environment, function, aesthetics and safety that they provide, was systematically relegated to a lower rank regarding new buildings, until a few years ago in Portugal. Nowadays, the Portuguese rehabilitation rate is about 20% lower than the average EU levels. This situation can easily be proved by the existence of just a few

examples of research projects carried out, by the lack of specific regulations on the rehabilitation subject, or by the lack of experience of most technicians.
This specific situation, which has been felt for the last two decades in Portugal, is now going through a reversal towards the gradual and progressive increase, in the next few years, in the weight of rehabilitation on construction [1]. If, on the one hand, most of the Portuguese housing is quite recent (around 20% of the buildings are less than ten years old), on the other hand, it presents significant anomalies caused by lack of accuracy and quality of the plans, bad execution and ill-applied materials which will inevitably accelerate the need for conservation and rehabilitation operations, so much so that quality patterns related to comfort, new technologies, safety and aesthetics are becoming more demanding [2].
Thus, there is the need to adjust the current regulations, related to new construction, to rehabilitation, the need for certification and availability of the properties of products by their manufacturers, the need for practical tools to support those taking part in a rehabilitation process.
This way, one of the main contributions of the methodology presented here is the systematisation and organization of the available information on the rehabilitation of buildings and, at the same time, the establishment of connections between the different parameters involved in a rehabilitation process, such as the construction elements, the anomalies, their causes, the intervention solutions and the repair works. The fact that this information is scattered does not facilitate the interconnection between the different parameters integrated in a rehabilitation process. This situation makes any attempt to rehabilitate by a less experienced technician more difficult.
A software[1] [3] was developed in order to allow a practical and effective implementation of the presented methodology. The developed program presents an interactive and easy manipulation interface with countless expansion possibilities for the acquisition of other important rehabilitation parameters, namely intervention costs, necessary works, measurements, among others.

2 Methodology for the Implementation of Checklists

2.1 General overview

As it was previously mentioned, the methodology presented here allows the manipulation and the establishment of relationships between the different parameters generally involved in a rehabilitation process, such as the anomalies, the causes, the intervention solutions and the respective works.
In an objective way, the methodology allows obtaining lists (checklist) of the necessary solutions and rehabilitation works for those cases in which it is possible to identify the construction element, the anomaly and the causes to which it is subjected.
One of the main priorities in developing the methodology was based on the need to conceive a flexible structure that could be implemented on any time, allowing expansions at the level of obtaining different results, such as intervention costs to elaborate coherent budgets, or the definition of equipments, work teams or materials to be used in rehabilitation operations.
The particularity of this kind of works, due to the variety of elements, anomalies, causes and intervention solutions, among others, requires an extremely complex and thorough analysis of the various variables and the relationships between them, for the construction of the “checklists” of the intervention solutions and of the works needed for the maintenance or repair of the construction elements.
Thus, due to the great amount of information needed, it was chosen to create a set of databases relating to the elements, the most frequent anomalies in them and the causes of those anomalies, since the

[1] Software “Patsolutions”, developed by Dinis Leitão

necessary primary conditions for the development and implementation of the methodology are established from the specific interconnection settled in the information included in these databases.

2.2 Methodology

The methodology presented here was based on the principle defined by the European Regulations on Products and Systems for Protection and Repair of Concrete Structures, EN 1504, particularly part nine[2] [4]. Although the aforesaid Regulations concern concrete elements exclusively, nevertheless the general principles by which the interventions are ruled can be applied to the remaining construction elements made up of other materials.

In most cases, the observation of a possible fault, or an indication of a possible situation in which one or more elements are not performing well, is what sets about the need for intervention in a given construction element. Therefore, it is necessary, in the first place, to identify the set of anomalous situations that can happen to the different construction elements. Afterwards, and before defining which interventions to perform, it is necessary to determine which agents are responsible for the appearance of the anomaly, otherwise there is the risk of proposing intervention solutions that will not solve the problem in a definite and suitable way.

From what was mentioned before, it is possible to conclude that the structure of the developed methodology is based on the creation of two main databases, one with the identification of the construction elements and the other relating to the variety of anomalous situations that can be found.

The connection between the data of the two databases must be defined, right from the start, since the appearance of a given anomaly can be verified only in specific construction elements. For example, if the anomaly found is the appearance of iron oxide spots proceeding from corrosion of the metal bars embedded in the concrete of a support wall, such a thing can only be identified in support walls made up of reinforced concrete. If the wall is made up of concrete, this anomaly cannot show up. In the same way, and as another example, anomalies such as operational noises could only be verified in construction elements as installations or equipment.

The main nucleus of the methodology is set with the aforementioned databases, and especially with the connections between their data. The following step is the proposal of intervention solutions, inside the scope of rehabilitation, and the establishment of possible relationships between the different parameters considered so far. These relationships are obtained from the previously established connections between the databases relating to the elements and anomalies. The correspondence between the causing agents of the database relating to causes and those connections may be, or may be not, accomplished.

For example, consider the case of light and widespread cracking on a reinforced concrete pavement slab and on a wooden pavement slab. In the first case, one of the reasons for that anomaly could be an excess of water in the mixture and a defective drying process. However, this reason cannot explain the appearance of the same anomaly on the wooden structure, and in this case it would be better to consider the effects of heat associated with restrictions imposed on the free dilation or contraction of the element. Nevertheless, it should be mentioned that this reason may also give rise to the same anomaly on the reinforced concrete pavement slab.

Having identified all the intervention possibilities for the different elements and listed the anomalies and their possible causes, it is now possible to move to the following item, which is the creation of a database of rehabilitation works.

As certain connections are established between the data of the databases that make up the main nucleus, it is also necessary to establish the respective correspondence between the data of the databases relating to solutions and works, and between these and the previously established in the

[2] The European Normative 1504 is composed of ten parts, being part 9 dedicated to general principles for the use of products and systems for protection and repair of concrete structures

main nucleus. For example, the appearance of fungi on an inner compartment brick wall[3], caused by wet environments associated to porous materials, constitutes three of the data of the databases of the main nucleus (construction element – inner compartment brick wall; anomaly – the appearance of fungi; cause – wet environments associated to porous materials). Out of all the data of those databases, it is necessary to establish the connection between these three data. This previously established connection is going to produce a code to its identification. On the other hand, of all the possible repair solutions to the aforesaid case, there is one to which certain works correspond to. The same aforementioned code is associated with the connection of that solution to the necessary works to implement it. This way, the correspondence between the data of the different databases is established, as it is depicted on Figure 1.

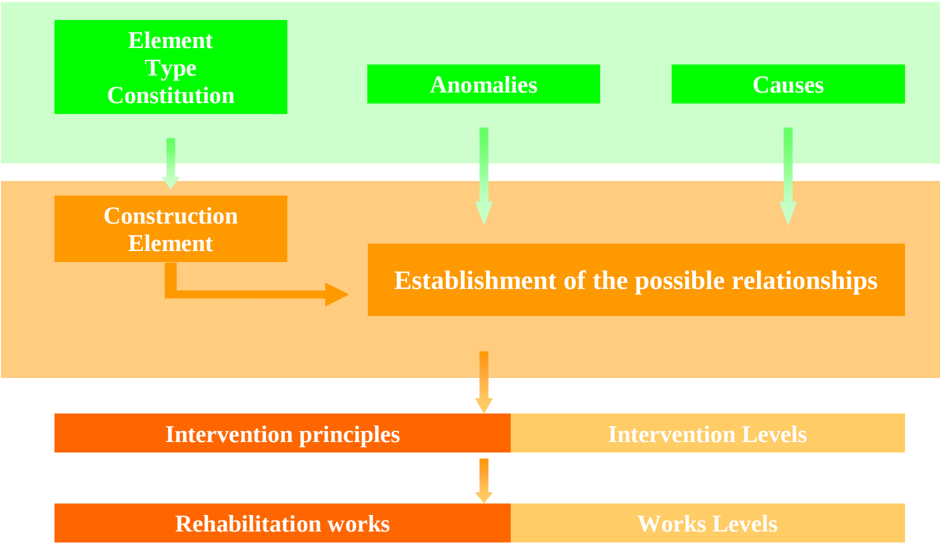

Figure 1 – Diagram of the methodology

The actual amount of information in the databases requires the creation of a system of codes that allows the connection between the data and the introduction of new data not needing a change in the existent codes. Beyond that, codes must enable an easy reading, allow a good memorizing, quick apprehension and intuitive comprehension and must also enable its integration into an information technology tool.

The codes thus elaborated are of an alfa-numerical kind, in which, in the case of the database relating to the construction elements and to the anomalies, the first letter indicates if the data is an element (e) or an anomaly (a). The second letter concerns the different construction elements considered. The numbering is sequentially increasing by construction element or anomaly, according to the case. In the database relating to the causes, the first letter and number represent the anomaly resulting from the identified causes (letter (c)) and sequentially numbered. According to the solution codes, the sets letter / number from left to right represent, respectively, the element, the anomaly, the possible cause, the solution code (s) and its respective number. As to the rehabilitation works, the presented sequence for the respective code is similar to the one described for the solutions, excepting the last letter which, in this case, is (w) instead of being (s).

[3] Element: wall; Type: Compartment; Constitution: brick

2.3 Information bases of the methodology

As mentioned, the developed methodology is based on a set of information bases and on the possible relationships between them. On the following sections, the way the data of those bases should be obtained and structured is briefly described.

2.3.1 Structure of the constructive elements

The criterion used to divide the buildings into their comprising elements will influence the analysis of the anomalies and the respective repair solutions. The traditional division of a building according to work tasks and construction elements, mainly used to budget new buildings, does not suit the specific needs of maintenance or rehabilitation interventions, since these interventions regard the already built edifice and not the tasks necessary to build it.

Given the need to create a structure of elements of the building, more detailed and adapted to the maintenance and rehabilitation interventions, a choice was made to use a methodology based on the division of the building into construction elements, making a list of the commonest and most frequent elements that make part of it, subdivided according to the type of element and its composition, i.e., the material in which it is executed. This methodology is based on structures of division according to construction elements[4] for estimates of costs [5], duly adapted to the particularities of maintenance or rehabilitation interventions.

This list of the composing elements of a building intends to be as broad as possible in order to answer to anomalous situations found in buildings executed with the aid of traditional techniques and also in those following more recent construction technologies.

2.3.2 Anomalies in construction elements and possible causes

The most complex and important of all the steps defined by the present methodology is certainly determining the causes of anomalies.

Before going any further, it is important to say that an anomaly may be understood as a sign of a possible fault, i.e., a sign of a possible situation in which one or more elements are not fulfilling their function[5]. However, it is not always possible to clearly identify a specific cause for the appearance of a certain anomaly, since generally speaking, the various causing agents are performing simultaneously. The accurate identification and understanding of the causes is very important, so that one might be able to evaluate the need for, the degree and the type of intervention to execute.

There are neither rules nor previously established procedures to determine the causes of an anomaly. Each case is unique and it must be analysed as such [6, 7]. The accurate identification of the causes is only possible by carrying out complete and suitable inspections and diagnoses, performed by experienced technicians.

The main goal of this methodology is neither the sensible or detailed analysis, nor the reasons that lead to the appearance of the anomalies in the construction elements, since that information should be gathered from specific bibliography. Considering the practical cases and the successive studies on anomalies and their causes, it is only intended to establish, without damage to what was mentioned before and in a coherent way, some kinds of standardized behaviour. The cases of diagonal cracking on walls, which is generally associated with the separate laying of the foundations, could be mentioned as an example.

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[4] Methodologies of division according to construction elements to which item 1 refers to: methods developed by the “Royal Institution of Chartered Surveyors” to the program “Standard Form of Cost Analysis”; by “Union National de l’Economie de la Construction”, “Institute pour l’Economie et l’Organisation du Bâtiment”, “Architects’s Journal”, "Omniun Technique d’Habitation” to the program ESTIM; division according to the SfB e BSAB

[5] Defined according to W86 – CIB, Building Pathology A State-of-the-art Report, CIB 1993

Therefore, comparing the existing data on anomalies and their causes with the knowledge of the behaviour of materials and construction elements, the main anomalies verified in the considered construction elements are identified as well as the main causes, i.e., the most probable causes that can lead to their appearance.

2.3.3 Intervention principles

Due to the great diversity of existing construction elements, techniques and materials, it is not possible to define specific intervention solutions, but only to consider the intervention principles. These principles are suitable for choosing the rehabilitation intervention that could be performed.
In the scope of this methodology, only the alternatives of repairing or hiding the anomaly were considered, as long as it is stabilized, since the abandon option should be considered as the last one and be followed by preventive safety measures in order to ensure people's well-being. Substitution is also faced in the scope of this methodology as an ultimate solution only applied to the cases in which the element is damaged in such a way that it is better to substitute it than to repair it.
The intervention solution could be performed bearing in mind different purposes. In most cases, the adopted solution fits the purpose of suppressing the causes that led to the appearance of the anomaly and to its end. This can be seen as a preventive solution. In other cases, the intervention only aims at the suppression or the concealment of the anomaly, and does not intervene in the causes. This solution should only be adopted in those cases in which the causing agents are not able to make the anomaly appear again.
This way there is an option to create three levels relating to the intervention principles, according to the intervention purpose, as it is presented on Table 1.

Table 1 – Purposes of the intervention principles

Light interventions - type 1	**Medium interventions** - type 2	**Extreme interventions** - type 3
Anomaly concealment solutions or intervention in other elements but not in the specified one; only applicable to those cases in which a change in the safety and endurance characteristics of the element is not at stake	Involve repair work which may or may not include reinforcement and which do not require the demolition of more than 50% of the element or result in an approach to the initial quality level	Aim at the demolition of more than 50% of the element or result in a significant improvement regarding the initial quality level, accomplishing the present medium quality level in accordance with the regulations

The obstacles inherent in the intervention principles, such as the purpose of that intervention, the condition of the element subjected to the anomaly, or the variety of possible applicable solutions, lead to the composing of a base of intervention principles.
The choice of the intervention level, besides the aforementioned, should depend on the specific regulations in effect (in case there is one), on the economic aspects and on the owner's option, among others [8].

2.3.4 Rehabilitation works

After choosing the intervention principle to be applied to a given construction element, there is a need to identify the necessary works for its implementation. These works could be divided into two groups: preparatory works and rehabilitation works. Preparatory works are intended to create the necessary conditions related to means and safety in order to perform the intervention, while the purpose of rehabilitation works is the concealment, repair or reinforcement recommended by the considered intervention level.

In the scope of this methodology, only the necessary rehabilitation works for the implementation of the defined intervention principles are considered, since preparatory works must be evaluated on each specific case either at the stage of planning or while works are carried out.
Rehabilitation works, which deserve special attention here, consist in the operations performed directly upon the element subjected to anomaly or upon its causes. Therefore, these works can be intended to conceal or to eliminate the anomaly, to eliminate the causes of the anomaly or to reinforce the construction element.
The choice of the most suitable type of work will depend directly on the solutions found to each specific case, being each specific case understood as the possible connection between the element, the anomaly and its respective cause.
Seeing that three levels of intervention principle concerning the rehabilitation solutions for each specific case were defined, it was necessary to grant the corresponding rehabilitation works to each of those levels. This way, three levels for rehabilitation works were defined.

2.3.5 Example of application of the methodology

As an example, Table 2 presents one out of several situations accomplished with the application of the methodology introduced here. Nonetheless, technicians have a thorough list of the different situations that can be accomplished with this methodology [3] at their disposal.

Table 2 – Example of application of the presented methodology

				Codes
Constructive Element	reinforced concrete direct foundation			ea.2
Anomaly	cracking; disaggregation in foundations			aa.2
Cause	mechanical actions of roots			a2.c6
Intervention Principles	Level 1	Level 2	Level 3	a2.a2.c6.s1
	to eliminate vegetable species with strong roots which are close to the foundation	to eliminate vegetable species with strong roots which are close to the foundation and to proceed to the consolidation of the foundation by injecting epoxy resins or mortar	to eliminate vegetable species with strong roots which are close to the foundation and to accomplish the confinement and the consolidation of the foundation by injection and to proceed to the enlargement of the foundation	
Rehabilitation Works	Level 1	Level 2	Level 3	a2.a2.c6.w1
	to cut or transplant of the vegetable species, removing the roots by excavation. In the end proceed to the filling and compacting of the dug area and to its repaving	Rehabilitation works of level 1 + cleaning of the surfaces along the fissures, to remove the disaggregated material. To make injecting holes and to fill the fissures among holes. To send water under pressure to clean the fissure and to verify the obtained tightness. To inject the paste	Rehabilitation works of level 2 + placement of the formwork and of metallic staples of connection in the lateral faces of the foundation element. To fill with concrete the space between the formwork and the foundation. To remove the formwork	

2.4 Final statements

The analyses of the causes of anomalies and the proposal of solutions are made extremely complex by the interconnection between almost all the areas in civil engineering to which a rehabilitation technician must resort to and master.
On the other hand, the particularity of works and recommended solutions requires a full-time supervision of repair works by the responsible technician.
Methodologies as the one presented here do not intend to replace technical opinions. It is essential to resort to people with proved experience on rehabilitation works and to inspection and diagnosis techniques in order to identify the causes properly and to define in an effective way the corrective solution to be adopted. The application of this database system will make it possible to decide more consciously about what concerns the identification and rehabilitation works in buildings.
First of all, this methodology enables the construction of an important information base of methods that support decisions in the scope of rehabilitation/ conservation of buildings. It allows a more complete and comprehensive view of the diversity of existing causes or solutions, while at the same time it prevents occasional errors in diagnosis, such as granting a cause to an anomaly in a certain element that can only be verified in another type of construction elements.
With the developed methodology there was also an intention of organizing and systematizing the existing information and creating the bases for future projects on rehabilitation of buildings and structures. The intention of making the structure of the databases flexible in order to allow the introduction of new data requires a special care over the way they are grouped. The flexibility of that structure is required in order to follow the development of the knowledge on existing materials and/or of the new materials to be introduced into construction, so that it can allow the modernization of rehabilitation works due to technological evolution, besides allowing a simple and effective search of the data, among other reasons.
The software mentioned earlier facilitates the practical and effective implementation of the presented methodology.

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