Inspection and maintenance plan for roofs in current buildings

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EXTENDED ABSTRACT

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1. Introduction

The reactive culture existing in Portugal, associated to an almost non-existent legislation, constitutes an obstacle to the mobilization of appropriate means for the practice of maintenance. In an increasingly competitive society and in the current setting of international crisis, financial resources in Construction must be minimized through inspection and building maintenance plans.

External envelopes increasingly play an essential role, as they are linked to a set of factors that are crucial to the use of a building in a comfortable way and prove to be the elements that are most likely to be affected by weather factors. In fact, the implementation of inspection and maintenance plans for roofs is a key element for the control of systems performance service conditions, and also of deterioration factors, types of defects and their causes. A continuous and structured follow-up of maintenance source elements of a roof, associated with an appropriate planning, also enables taking all necessary actions for a proactive maintenance (cleaning, light interventions, deep interventions and replacement), making it possible to re-establish predefined performance levels, improve financial costs and satisfy the users.

2. Building maintenance

According to SILVA (1989), the concept of maintenance originates in product manufacturing associated to military industrial activity during World War II and, because of its importance, it was later applied to other sectors, such as the construction industry. In fact, maintenance is a combination of all technical and administrative actions that allow the building and its elements to play their corresponding roles during their service life (ISO 1586-1, 2005).

Maintenance is increasingly a critical, during a building’s lifecycle. According to FLORES-COLEN (2003), maintenance operations are actions that are carried out during the operation of a building, with the aim of guaranteeing minimum performance levels without any deterioration of the building’s elements and preserving the commercial value of the building and a sustainable use during its service life. These actions can be divided into two groups: proactive (preventive and predictive) and corrective / reactive.

According to ARDITI (1999), corrective maintenance consists in allowing a deterioration mechanism to develop in a building and, only later, taking action after failure. Associating this kind of strategy to unforeseeable defects leads to an escalation of costs, which shall increase with the increase of the deterioration of the areas where action is necessary. On the other hand, proactive maintenance consists in executing interventions before a defect is likely to occur, so as to reduce the probability of failure of any of the construction elements (SOUZA & RIPPER, 1998).

Maintenance plans must always take into account the implementation of appropriate and proactive maintenance strategies during the service life of all elements involved. When planning inspection and maintenance actions, one must follow a methodology that includes aspects such as decision, priority, frequency of interventions and other maintenance operations. Besides, the fact that maintenance plans follow an integrated and mixed methodology is an added value; in fact, they are currently designated as inspection and maintenance plans. In that respect, the most likely maintenance actions are planned (preventive maintenance), as well as inspections (predictive maintenance); it is also necessary to take into account corrective actions, associated to unforeseeable anomaly occurrences.

Maintenance Plans must include all building’s components which need maintenance care during their service life. In this research the entire process of implementation of an inspection and maintenance plan for building roofs was proposed and applied on real case studies.
3. Building horizontal envelope – Roofing system

By definition, a roof is the highest floor of a building. It can be pitched or flat and is a system that has a structural and cladding functions. The roof of a building is one of the elements of the envelope that most influence the performance of buildings. In fact, it can be considered as one of the most complex elements, and it needs quality constructive solutions that are certified by competent bodies, as well as an appropriate design and execution.

3.1. Roofs constructive technology

Flat roofs have significant functioning differences when compared to pitched roofs. From the structure itself that is resisting to the layer system used and materials applied, many are the aspects that differ in these two kinds of roofs. However, taking into account the requirements of each functional element, it is noted that there are many similarities in the two types of roofs.

3.1.1. Flat roofs

Flat roofs are characterized by flat surfaces or roofing plans. This type of system has a minimum slope, so as to allow drainage of rain-waters and to direct it according to the water drainage plan. So, by flat roof one means the system that has a slope ranging from -5° to 5° (NP EN 1991-1-4, 2010). Considering the importance that the influence of a layer might have on the other ones in terms of appropriate system performance, the main layers of a flat roof are summarized in Table 1. In many cases, flat roofs include a levelling layer and a solidarization layer.

Table 1 Composition of a flat roof system, according to LOPES (1994), CHUDLEY & GREENO (1997), HARRISON (1996) and ROCHA (2008)

<table>
<thead>
<tr>
<th>Flat roof system</th>
<th>Functional requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition of the system</td>
<td></td>
</tr>
<tr>
<td>Resistant structure</td>
<td>Support the different loads that occur in the roof</td>
</tr>
<tr>
<td>Drainage layer</td>
<td>Guarantee water drainage; create the roof slope</td>
</tr>
<tr>
<td>Vapour barrier</td>
<td>Create a barrier against the flow of water vapour coming from locations under thermal insulation layer and going to upper layers</td>
</tr>
<tr>
<td>Thermal insulation</td>
<td>Reduce temperature variation and thermal exchange between the interior and the exterior of the building</td>
</tr>
<tr>
<td>Waterproofing</td>
<td>Waterproof the roof; prevent water penetration into underlying layers</td>
</tr>
<tr>
<td>Protection layer</td>
<td>Protect the waterproofing layer from the effect of solar radiation and mechanical actions</td>
</tr>
</tbody>
</table>

3.1.2. Pitched roofs

Pitched roofs play an essential role in Portuguese architecture. In the case of common buildings, the most frequently applied cladding is undoubtedly ceramic roof tile, which can be considered as the traditional cladding for pitched roofs (BRITO & PAULO, 2001).

The configuration of pitched roofs has undergone many changes, due to the technical evolution of materials and constructive processes. According to BARROS (2008), the traditional pyramidal hip shape evolved to become nowadays a more asymmetric design with several compartments and several plans.

Similarly, the system of pitched roofs can be further divided into different constituent layers, namely: supporting structure; cladding thermal insulation; ventilation; insulation layer and lath work layer. All these components can be grouped in terms of structure, as shown in Table 2.
### 3.2. Deterioration of roofs

The deterioration of the elements of a roof is an issue that is still under development by researchers. Although there is an increasing concern in relation to the design of durable and quality buildings, a considerable number of defects in roofing systems still occur in Portugal.

The "Institut Technique du Bâtiment et des Travaux Publics" was a major pioneer in the study of defects affecting building elements. In 1982, a statistical study on 12,200 defects revealed that roofs showed a number of irregularities that was fairly higher than the majority of the remaining constructive elements, second only to the building’s façade. Subsequently, in Victoria (Australia), ILOZOR et al. (2004) conducted an similar study leading to the same conclusion, that roofs are the second most affected constructive element and with high number of defects.

#### 3.2.1. Deterioration factors

The premature deterioration of a roofing system is not only the result of an ineffective design and execution of its elements. According to GRIFFIN (1984), HODGES (1999) and PIRLA et al. (1999), the main deterioration factors of any kind of roof are related to the weather, such as water, high temperatures and variations, solar radiation, wind, chemical agents, pollution due to traffic, and improper use.

According to HODGES (1999), the premature and continuous deterioration of a roofing system causes a significant increase in its maintenance costs. In fact, each roofing system has a specific deterioration curve that can be summarized in Figure 1.

![Deterioration curve of a roof, adapted from HODGES (1999)](image)

#### 3.2.2. Characterization of defects in flat roofs

The analysis of defects in flat roofs is a topic that was developed by different authors as far as research is concerned. According to ROCHA (2008), the most frequent defects occur in the common surface and in individual points, followed by...
drainage systems. On the other hand, WALTER (2002) and CRUZ & AGUIAR (2009) demonstrated that, out of the different defects that can be identified in a flat roof and, especially, in the common area, the waterproofing layer represented the most affected component (Table 3).

Table 3 Main defects in a flat roof system, adapted from PIRLA et al. (1999), WALTER (2002), ROCHA (2008) and ARAÚJO et al. (2008)

<table>
<thead>
<tr>
<th>Flat roof system</th>
<th>Common area</th>
<th>Individual points of the roof</th>
<th>Drainage system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracking of waterproofing or protection layer</td>
<td>Detachment of the waterproofing or heavy protection</td>
<td>Accumulation of surface dirt, debris and parasitic vegetation / biological colonization</td>
<td></td>
</tr>
<tr>
<td>Perforation of waterproofing</td>
<td>Blistering of waterproofing</td>
<td>Waterproofing detachment</td>
<td></td>
</tr>
<tr>
<td>Accumulation of water stains and corrosion</td>
<td>Formation of pleats or corrugations in the waterproofing</td>
<td>Efflorescences in the heavy protection layer</td>
<td></td>
</tr>
</tbody>
</table>

3.2.3. Characterization of defects in pitched roofs

The effective functioning of a pitched roof, similar to any other element in the outside envelope of the building essentially depends on the level of design and detail, on the quality of the materials, on the execution of the system and on its subsequent maintenance and use. As is the case in flat roofs, the importance of individual points in pitched roofs is well known for the occurrence of irregular situations. According to ROCHA (2008), the most frequent defects occur in individual points, followed by common area and drainage system (Table 4).

Table 4 Main defects in the system of pitched roofs, adapted from PIRLA et al. (1999), GARRAND (2001), ROCHA (2008) and LOPES (2009)

<table>
<thead>
<tr>
<th>Pitched roof system</th>
<th>Common area</th>
<th>Individual points</th>
<th>Drainage system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defects in the ventilation system and in the fixation elements</td>
<td>Misalignment of cladding elements</td>
<td>Looseing of cladding elements</td>
<td></td>
</tr>
<tr>
<td>Surface dirt, accumulation of debris and parasitic vegetation / biological colonization</td>
<td>Differences in colour tones</td>
<td>Peeling / disintegration</td>
<td></td>
</tr>
<tr>
<td>Cracking / fractures</td>
<td>Corrosion</td>
<td>Marked deformation of the cladding</td>
<td></td>
</tr>
<tr>
<td>Detachment of tail-ends</td>
<td>Fluidity of the tail-ends</td>
<td>Cracking / fractures</td>
<td></td>
</tr>
<tr>
<td>Surface dirt, accumulation of debris and parasitic vegetation / biological colonization</td>
<td>Blistering</td>
<td>Peeling / disintegration</td>
<td></td>
</tr>
<tr>
<td>Corrosion</td>
<td>Perforations</td>
<td>Loss of watertightness</td>
<td></td>
</tr>
<tr>
<td>Drainage system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cracking</td>
<td>Gutters breakage</td>
<td>Corrosion and water stains</td>
<td></td>
</tr>
<tr>
<td>Perforations</td>
<td>Lack of inlet drains and downpipes</td>
<td>Surface dirt, accumulation of debris, parasitic vegetation / biological colonization</td>
<td></td>
</tr>
</tbody>
</table>
The statistical study, conducted in 1982 by the “Institut Technique du Bâtiment et des Travaux Publics” concluded that 31% of defects corresponded to pitched roofs and 69% to flat roofs. Later, works developed by AQC (Agency Quality Construction) and published in “Sycodés 2007” registered 200 000 defects, leading to the conclusion that 37% of those defects occurred in flat roofs and that the remaining 63% corresponded to pitched roofs. With its research, ROCHA (2008) came to the conclusion that pitched roofs are more likely to suffer defects than flat roofs (54% of defects correspond to pitched roofs). These results are due, according to various researchers, to the improvement of the materials’ characteristics and waterproofing materials applied to flat roofs, to the evolution in terms of standards and certification of materials and to the fact that the construction of pitched roofs is carried out mainly by small builders.

4. Application methodology

In order to propose an inspection and maintenance plan for roof systems, one needs to include all aspects that are relevant to an efficient management of resources and costs. In fact, it is necessary to define various technical documents, such as the building’s identification sheet, the inspection sheet of each maintenance source element (MSE) and the scheduling of corresponding proactive maintenance activities.

The definition of intervention priorities, depending on the type of defect and related causes, is a process that must be integrated into the inspection and roof maintenance plan, as it allows a reduction of the costs of the entire maintenance system. Responding adequately to the needs, the definition of intervention priorities can also avoid dangerous situations. The planning of proactive maintenance actions for the different roof components includes predictive (inspections) and preventive actions (cleaning, light interventions, deep interventions and replacement) and their scheduling, keeping into account the different service lives and materials that are applied.

4.1. Detailed inspection and corrective maintenance

Inspection is a process by which it is possible to guarantee, by means of evaluation, that a given system or service in the building corresponds to an acceptable level of performance. These inspections enable a timely identification of unforeseeable defects and contribute to assess the maintenance plan and program new corrective actions. It is advisable to employ specialized technicians and equipment, so as to contribute to a reliable and effective diagnosis. In that respect, it is necessary to identify the building under study and its maintenance source elements that are to be analysed. The inspection sheet is crucial for this process and it is also necessary to classify defects and their causes, as well as the criteria underlying intervention priorities and maintenance actions that are to be subsequently carried out.

4.1.1. Characterization of the building and MSE

The building’s identification sheet is a crucial document for any inspection action. The document in question shows the name / location of the building, the year of construction, its function (commercial, housing, service or other) and the number of floors. The contacts made for the execution of the inspection, the existence of previous interventions and the identification of maintenance source elements, as well as their materials, are also crucial pieces of information that are to be included in the above mentioned sheets.

In terms of maintenance, a building and its elements are considered as a set of systems with specific maintenance needs, designated as maintenance source elements (MSE). Each element is characterized by a different deterioration mechanism and performance levels, and is usually independent from all other elements.

According to BRAND (1994), a building can be divided into six layers that are structured starting from the building’s envelope in contact with the outside, until the inside (structure, surrounding “skin”, services, interior space and furniture). Considering all the documents analysed, a proposal for classification of the existing MSE in a roofing system was developed (Table 5).
Table 5 Proposed structure of MSE for pitched roofs in buildings

<table>
<thead>
<tr>
<th>Pitched roofs</th>
<th>Flat roofs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladding</td>
<td>Drainage system</td>
</tr>
<tr>
<td>Supporting structure</td>
<td>Elements of anchorage and metalwork</td>
</tr>
<tr>
<td>Ventilation system</td>
<td>Roof skylights and windows</td>
</tr>
<tr>
<td>Tail-ends system</td>
<td>Masonry elements</td>
</tr>
<tr>
<td>Supporting structure</td>
<td>Drainage system</td>
</tr>
<tr>
<td>Waterproofing layer</td>
<td>Elements of anchorage and metalwork</td>
</tr>
<tr>
<td>Protection layer</td>
<td>Masonry elements</td>
</tr>
<tr>
<td>Tail-ends system</td>
<td></td>
</tr>
</tbody>
</table>

4.1.2. Inspection sheets

An inspection sheet enables the identification of defects in each MSE, as well as the most probable causes. The existence of parameters that are to be used for classifying maintenance priorities is an important aspect: that is why it has been decided to include the above mentioned classification in the inspection sheet.

In order to keep track of all fields in an inspection sheet, when filling in this document it is necessary to organize defects, their causes and classification criteria.

Based on Tables 4 and 5, it has been decided to classify defects taking into account each MSE that is to be analysed during inspections.

4.1.3. Criteria for the application of intervention priorities

The lack of technical documentation regarding intervention priorities in buildings’ roofs made necessary a bibliographic survey, not only of general priority criteria for a building, but also for other specific MSE, mainly façades. On the basis of the above mentioned references, it is now possible to draw up a proposal with intervention priorities for each MSE under analysis.

The classification of defects is based on four criteria, the environmental aggressiveness that surrounds the roof under analysis, the extent of the defect, the level of deterioration of the MSE to be analysed and the severity of the defect (MARTEISSON & JÓNSSON, 1999; BS ISO 1586-3, 2002; GASPAR, 2002 and FLORES-COLEN & BRITO, 2006). Subsequently, it has been decided to divide the adopted criteria into severity levels and multiplying factors, with the aim of identifying effective and realistic intervention priorities. In the case of environmental aggressiveness (multiplying factor 1) and extension of the defect (multiplying factor 2), it has been observed that it is essential to divide it into three severity levels: high (score 1), medium (score 2) and low (score 3), that correspond to a description of the state of the defect or MSE. On the other hand, for the state of deterioration of the MSE (multiplying factor 3), it has been decided to divide it into four classification levels: good (1); superficial deterioration (2); moderate deterioration (3); marked deterioration (4). Similarly, it has been decided to divide the severity of defects (multiplying factor 4) into five levels of severity: negative influence on the aesthetical aspect (1); considerable increase in costs of subsequent maintenance (2); decrease in the durability of the elements (3); functionality of the building affected (4); risk to the safety of users (5).

The scaling indicator for each defect and MSE was determined based on the formula developed in the multicriteria analysis by FLORES-COLEN & BRITO (2006) and MADUREIRA (2011), keeping into account the weight of each defect with the worst scenario (maximum levels in each criterion adopted).
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\[
P_{\text{anomaly}} = 1 \times A + 2 \times E + 3 \times D + 4 \times S \quad (\text{Eq. 1})
\]

\[
P_{\text{intervention}} = \frac{P_{\text{anomaly}}}{\text{Max} \ (P_{\text{anomaly}})} \times 100 = \frac{1 \times A + 2 \times E + 3 \times D + 4 \times S}{41} \times 100 \quad (\text{Eq. 2})
\]

Where,

\( P_{\text{anomaly}} \) – weight of each defect in under analysis;

\( P_{\text{intervention}} \) – scaling indicator of the intervention’s priority;

A – environmental aggressiveness;

E – extent of the defect under analysis;

D – level of deterioration of the MSE;

S – severity of the defect under analysis.

The application of Equation 2 makes it possible to determine each intervention’s priority. In that respect, it has been decided to draw up a scale divided into four levels of intervention (Table 6). The percentages shown in Table 6 were determined based on various possible combinations for the value of \( P_{\text{intervention}} \), indicator, as an example, if all criteria under analysis have a minimum score, the intervention indicator has a value of only 24%; therefore, it is not necessary to analyse percentages below that value.

Table 6 Proposed classification of priorities of intervention in roof’s MSE

<table>
<thead>
<tr>
<th>Level</th>
<th>Intervention’s priority</th>
<th>( P_{\text{anomaly}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Non urgent actions</td>
<td>24% \leq P_{\text{anomaly}} \leq 40%</td>
</tr>
<tr>
<td>2</td>
<td>Medium term actions (2 to 5 years) that need further monitoring</td>
<td>41% \leq P_{\text{anomaly}} \leq 60%</td>
</tr>
<tr>
<td>3</td>
<td>Short term actions (1 to 2 years)</td>
<td>61% \leq P_{\text{anomaly}} \leq 80%</td>
</tr>
<tr>
<td>4</td>
<td>Actions with immediate priority (6 months)</td>
<td>P_{\text{anomaly}} \geq 81%</td>
</tr>
</tbody>
</table>

4.1.4. Corrective maintenance actions

A detailed inspection and the identification of the intervention’s priority of each defect make it possible to plan subsequent corrective maintenance actions. Depending on the severity of the defect, there are various actions that can be applied in a roofing system, as shown in Table 7.

Table 7 Proposal of corrective actions, depending on the type of defect identified

<table>
<thead>
<tr>
<th>Type of defect</th>
<th>Corrective actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetic</td>
<td>Cleaning</td>
</tr>
<tr>
<td>Loss of adhesion and fixation</td>
<td>Repair / replacement</td>
</tr>
<tr>
<td>Marked loss of functionality</td>
<td>Repair / replacement</td>
</tr>
<tr>
<td>Execution / design errors</td>
<td>Replacement</td>
</tr>
</tbody>
</table>

4.2. Planning of proactive maintenance actions

According to KYLER & KALINGER (1997), a roof submitted to an ineffective proactive plan might suffer a decrease of 18% to 20% in its service life. In fact, the characterization of this kind of actions is crucial to minimize the premature deterioration of the components of a roofing system.
4.2.1. Proposed estimate of service lives of roofs’ MSE

The definition of service life of an element represents a fundamental parameter for the reliability of any maintenance strategy. Therefore, based on BARBOSA (2009) and MADUREIRA (2011), it has been decided to devise a process of estimate of service life particularly generalized. In this respect, it has been deemed necessary to present the different values of service life, according to appropriate technical documents, as well as to evaluate their maximum and minimum values. Subsequently, their arithmetic mean has been determined and a proposed estimate of service life of the different MSE of a roofing system has been developed.

4.2.2. Proposed frequency of proactive maintenance actions

Proactive actions are applied to existing buildings and new ones alike. When planning maintenance interventions, one must distinguish all different operations that are necessary, such as inspection, protection treatments, repairs, replacements or localized replacements, repairs in specific areas or full replacement, at the end of the service life.

i) Planning of predictive actions

The application of predictive maintenance is based on inspections with predefined frequency, depending on the MSE to be analysed. Taking into account various bibliographic references, it was possible to establish an appropriate inspection frequency. In fact, a prevalence of MSE that underwent inspection actions every six months and once a year has been observed. In sporadic cases, such as claddings with micro concrete tile and supporting structure, the necessary frequency is considerably higher (6 years, every five /three years, respectively). This is particularly due to the durability, resistance and likelihood of deterioration of these elements.

In the methodology employed, it has been decided not to specify the frequency of inspection according to the type of material to be applied. Therefore, the suggested values might suffer slight variations, depending on the criterion applied by the inspector or competent authority.

ii) Planning of preventive actions

Preventive maintenance actions are based on cleaning, surface treatments, light and deep interventions and full replacement of the MSE at the end of its service life. The bibliographic investigation carried out proved the existence of different cleaning techniques, depending on the element under analysis. The MSE of a roofing system must undergo cleaning actions every six months or once a year, with the exception of the supporting structures, since their exposition the above mentioned factors is not significant.

Regarding the frequency of light and deep interventions, a considerable variation has been observed. As an example, the claddings in ceramic tile must undergo light interventions every 5 years; however, whenever necessary (during inspection), this kind of intervention must be carried out in the waterproofing layer and protection layer. The same elements must undergo deep maintenance actions every 25 years and every 20 years, respectively.

If the operations of light intervention overlap with or are near the operations of deep intervention or replacement, it is suggested that the former are skipped, because heavier actions can already include some of those operations. The same is valid for substitution / replacement at the end of the service life that overlaps with light and deep interventions.
5. Implementation of the inspection and maintenance plan for roofs

The inspection and maintenance plan for a building’s roof proposed in this dissertation was calibrated by means of a field work, which consisted of the inspection of 60 roofs (total surface of 45662 m²) in the district of Lisbon and Setúbal, during the months of April, May and July 2011.

Of all case studies analysed, a prevalence of pitched roofs (57%) was observed; the remaining 43% correspond to flat roofs. During field work, no inspection of mixed roof was carried out. Figures 2 and 3 illustrate two types of systems that were inspected.

By selecting different case studies, it was possible to analyse areas with different levels of aggressiveness (rural, urban and coast environment), type of use (housing and service), number of floors (2 to 14 floors), age of construction (prevalence of buildings less than 30 years old) and types. Although the type of use of the inspected buildings is mainly housing (90.6%), and the remaining 9.4 % correspond to service buildings, the latter represent 50% of the roofs that underwent an inspection and therefore a surface of 19562 m². In fact, the significant weight of service buildings in the study carried out was demonstrated. It was not possible to inspect the remaining types of use, due to various difficulties encountered.

In relation to pitched roofs, a prevalence of artificial stone claddings in the inspections carried out was observed. This is due to a higher presence of this kind of cladding in Portugal, which was transposed to the sample obtained, in such a way that the data and conclusions drawn are closer to reality. As to the other materials that can be applied to claddings of pitched roofs, an effort was made to obtain a significant sample of each one of them. However, that was not possible for natural and mixed stone claddings. However, when the MSE of flat roofs were considered, a prevalence of use of waterproofing layer as a system of self-protection was observed, followed by heavy rigid protection.

The validation of the classification system for defects in pitched roofs was carried out considering 322 defects identified in 34 inspected roofs and a global surface of 24000 m². Regarding the 26 inspected flat roofs, 296 defects were identified in a global area of 21662 m².

After the analysis of the data gathered during the inspections, a prevalence of defects in claddings of pitched roofs (32.3%) was observed, followed by drainage system (18.9%) and tail-ends(14.6%). These elements are particularly likely to suffer a premature deterioration if regular and effective inspections and preventive maintenance actions are not carried out. Similarly, a prevalence of defects in the waterproofing layer of flat roofs (23.6%) was registered, followed by drainage system (21.3%) and tail-ends (16.2%). The material applied in the waterproofing layers and tail-ends system, does not have a noticeable resistance to environmental deterioration factors and therefore causes various defects in the remaining elements of the roofing system (Figures 4 and 5).
Extended abstract

On the other hand, a prevalence of aesthetic defects in the inspection of both roofing systems was registered. In terms of type of defects involved, a significant relative frequency of surface dirt, accumulation of debris and parasitic vegetation / biological colonization was observed in the different MSE analysed.

The occurrence of this kind of defects is particularly associated to insufficient maintenance. However, poor slope of the cladding and drainage system, constant circulation of people, incorrect execution of the elements and environmental actions (strong winds, biological action and atmospheric pollution) might subsequently cause the various aesthetic defects already mentioned.

The existence of defects of loss of adhesion and fixation is significant in the sample under analysis, especially cracking and blistering of the different MSE of both types of roofing systems that were inspected. Figures 6, 7 and 8 illustrate the prevalent defects in the sample under analysis.

In terms of priority of intervention of the defects identified in pitched roofs, a prevalence of medium term actions (2 to 5 years) that need further monitoring (priority of intervention 2) was registered, followed by short term actions (1 to 2 years), that is, priority of intervention 3. Similarly, for the inspected flat roofs, urgent intervention is needed, prevalently of level 3 (short term actions).

The prevalence of levels 2 and 3 in urgency of intervention is essentially due to the considerable frequency of defects of loss of adhesion and fixation. On the other hand, due to the age of the roofs analysed and to the clear lack of maintenance planning, various aesthetic defects show a considerable extension (≥ 21%) and, as a result, also high levels of deterioration and severity, resulting in intervention levels higher than 1. Figures 9 and 10 illustrate the distribution of intervention urgency in the MSE of both roofing systems analysed.
Corrective maintenance measures are specific procedures that eliminate probable causes of the defects identified in the inspections; its main objective is to re-establish appropriate levels of quality and performance in order to subsequently implement planning of proactive maintenance. So as to categorize corrective actions, it was necessary to analyse the defects, causes and corresponding intervention priorities of all the maintenance source elements of the roofing system and only later suggest the necessary actions.

According to the analysis carried out, in case of high deterioration levels it might be necessary to partially replace (light intervention) or fully replace (deep intervention) the failed maintenance source element. In various cases it was also observed that the total replacement of the element is not only more viable in terms of costs, but it also guarantees the re-establishment of appropriate levels of performance.

As an example, it was observed that, regardless of the element under analysis and of the level of priority, in the presence of surface dirt, accumulation of debris or parasitic vegetation / biological colonization, it is necessary to clean, in order to eliminate any defect involved – the only difference being the products that are to be applied. In relation to the biological deterioration of the wooden supporting structures, it was observed that if the level of intervention is 4, the replacement of the element is the most effective solution. On the other hand, if the level of intervention is 3, the application of thermoplastic products and, subsequently, of fungicide and termite pesticides proves to be sufficient in order to eliminate the defect involved. In both cases, appropriate ventilation must be guaranteed.

In case studies, a planning validation was carried out by means of analysis of the needs of maintenance that each maintenance source element had. In that respect, it was necessary to study all the defects identified in the inspections, the priority of intervention, the age of the roofs inspected and possible maintenance actions during their service life.

On the basis of the data supplied by users, by people in charge of property management and building maintenance, it was observed that 80% of inspected pitched roofs underwent cleaning actions, surface treatments and light interventions in the last ten to fifteen years. However, the information made available in several cases was only verbal and there is no other specific information on the interventions carried out. In sporadic cases, it was not possible to obtain any information whatsoever on the maintenance actions carried out, but it was possible to observe that they were inexistent due to the level of deterioration of the identified defects.

Similarly to the analysis of pitched roofs, it was possible to obtain some information on the different interventions carried out on flat roofs until the date of the inspection. Regarding cleaning actions and light interventions, it was observed that the inspected roofs underwent this type of intervention in the last decade. However, the information on deep interventions and the replacement of the maintenance source elements was very ambiguous, and only in sporadic cases was it possible to obtain credible and effective information for the analysis.

Figures 11 e 12 show maintenance needs, depending on the MSE and on the roofing system under analysis.
On the basis of the analysis presented, it was possible to observe that in sporadic cases, maintenance actions need to be anticipated or delayed compared to what was theoretically stipulated, especially in pitched roofs, so as to allow an appropriate performance of the entire roofing system during its service life.

As an example, regarding micro-cement claddings, it was realised that it is prudent to anticipate light intervention actions; in fact, it is suggested that take place every ten years. Similarly, it was decided to establish a frequency of intervention every three years for the finishing elements system in the case of pitched roofs, especially due to their resistance to the main deterioration factors. Keeping in mind the level of deterioration of roof skylights, windows and other fixation and metalwork elements, as well as their likelihood of being damaged by weather deterioration factors, it was decided to anticipate light interventions, suggesting that they take place every three years.

6. Conclusions

Considering the scope of the dissertation, it was carried out a thorough research in order to standardize three key documents for the implementation of inspection and maintenance plan for roofs: identification and characterization sheet of roofs; sheet inspection and planning proactive actions.

During the study conducted the existence of a large variety of constructive types and materials in roofs (pitched and flat) was observed. The appropriate choice of type to be applied is quite arbitrary, since each one of them has advantages and disadvantages, but it was possible to illustrate their main functionalities. The deterioration of a roof's elements is an issue that is still under development by researchers. However, it was observed that the defects that occur in roofs represent quite a high percentage when compared to the total number of defects in a building.

The sample showed only 9% of service buildings, but during the analysis of data collected, this has proved to be a very significant in relation to the total area surveyed (43%). Thus, it was possible to measure a inspection and maintenance plan at the residential and service buildings. For service buildings, there has been a major concern in performing periodic action, although in many cases ineffective.

The field work showed that roofs included in the coastal environment have higher levels of degradation, particularly anchorage and metalwork elements, which showed considerable corrosion rates. From the analysis, it was found that cladding is the pitched roof element with more frequent anomalies, followed by drainage system and tail-ends. Similarly, it was found that the waterproofing layer is the flat roof element with more frequent anomalies.

For the type of anomaly, it was demonstrated that aesthetic defects, particularly surface dirt, accumulation of debris and parasitic vegetation / biological colonization, are most frequent in the elements analysed, explaining the fact that they are the first manifestations of degradation, caused by lack of maintenance by the users and entities responsible for the management of the building.
Taking into account the analysis of anomalies and intervention priorities, it was possible to propose a corrective actions. Thus, regardless of the element being analysed and the priority degree, it was concluded that, in the presence of surface dirt, accumulation of debris and parasitic vegetation / biological colonization, cleaning is the most efficient action. In view of loss of adhesion anomalies, it was concluded that the partial replacement or total element, is the most advantageous and economical action. The anomalies of functionality loss can be eliminated by strengthening the element or partial / total replacement. Depending on the priority and analysed element, it should be considerate the most economically solution.

The field work showed that, in sporadic cases, maintenance actions need to be anticipated or delayed compared to what was theoretically stipulated, especially in pitched roofs. However, in flat roofs the frequency of maintenance actions remained the same compared to theoretical planning.

In short, an effort was made to summarize the main factors underlying a proactive approach to maintenance based on the following information:

- knowledge of the constructive process of maintenance source elements (MSE) of a roofing system;
- description of deterioration agents, defects and their causes;
- description of the values of service life of the components of a roof system;
- main maintenance actions on the constructive elements under analysis.

After finishing up this dissertation, it is concluded that it can contribute to disseminate the usefulness of the topic, especially because it suggests effective and organized procedures and subsequent testing of their validity and practical applicability. The maintenance strategy presented should be disseminated and implemented at the different hierarchic levels of construction, so as to allow a full understanding of its importance and enhancement of quality levels of roof’s components.

7. Bibliography


