TÉCNICO LISBOA

Service life prediction of wood floorings

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Extended abstract

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1. Introduction

This study intends to develop a methodology for the service life prediction of wood floorings. This research follows the methodology proposed by Gaspar (2009) and Gaspar and Brito (2011) for the service life prediction of the elements of the buildings' envelope, which has been applied to several external façade claddings (Silva et al., 2011a,b; Emídio et al., 2014; Chai et al., 2015; Ximenes et al., 2015; Serralheiro et al., 2017; Marques et al., 2018). In this dissertation, this methodology is applied, for the first time, to predict the service life of an element in the interior of the building.

The methodology adopted is based on data collected by visual inspection, during a fieldwork survey, concerning the degradation condition of wood flooring systems. Subsequently, the data are analysed and transformed into a numerical indicator, which portrays the overall degradation condition of the wood floorings analysed, which allows the graphical description of the loss of performance of these components over time and according to their characteristics.

After this work, maintenance plans can be defined, to enhance the service life of wood floorings. By understanding the degradation mechanisms of the wood floors, the durability can be increased through the adoption of regular inspections and rehabilitation actions, thus promoting the sustainability of the solution and reducing its environmental impacts.

Wood floorings were selected as case study, in this dissertation, since they are one of the most common and attractive solutions for flooring, with a widespread use in Portugal and Worldwide.

2. Wood floorings

Main characterisation

Wood is a natural material and, consequently, its properties are subjected to a great variability caused by the physiology of the trees and by external factors that affect their growth, such as density, growth rate, forestry (specifically, if the recovery of certain forest areas is carried out using natural or artificial methods), genetic effects, the climate of the region, time of the year when the wood is cut, among others. Therefore, the characteristics of the wood may vary from tree to tree, and even in different parts of the same tree (Panshin and Zeeuw, 1980).

Therefore, the type of wood to be applied in each flooring must be selected according to its intended use. The characterization of wood is complex and different factors can be used to differentiate the different types of wood. In this dissertation, only the most common types of wood were analysed. According to Desch and Dinwoodie (1996), woods can be divided into two large botanical groups depending on their anatomical structure: softwoods and hardwoods.

There are several types of wood floorings; these can be divided into two main categories, solid wood, and composites. Both can be placed by gluing, nailing, or fitting on various substrate materials, such as screed, ceramic, wood, carpet, among others. In this study, in most cases, the substrate cannot be precisely identified, since the analysis of the case studies is performed based only on visual inspections, several years after installation (which makes it difficult to obtain reliable information about the execution conditions and materials applied).

Solid wood floors are noble and traditional. They are distinguished from other wood floorings by their stability, durability, and strength. Aesthetically, wood floorings are a timeless solution, having the attractiveness and nobility of a natural product. These floorings, besides having the advantage of application - the floor can be placed directly on the screed - are also recognized for an accessible maintenance, both in economic terms in the simplicity of the processes involved. Therefore, solid wood is still a preferential material in terms of floorings.

Wood floorings should be applied with a moisture content between 9.5% and 14% and should be exposed to the environmental conditions where it will be applied for about two weeks in advance, to ensure the adaptation of the elements to the interior environment.

Anomalies and their main causes

The degradation of wood elements arises as a result of the action of physical, chemical, mechanical or biological agents over time (Cruz, 2001).

The anomalies can be considered as the representation of these degradation factors, which may be the result of natural actions, human actions, inappropriate use or accidents.

Being a hygroscopic material, wood attempts to maintain the same relative humidity of the air that surrounds it, i.e. when the relative humidity of the air varies, the dimensions of wood also vary, which promotes the incidence of cracking of the wood (Cruz et al., 2015).

One of the main causes of anomalies in wood floorings is the contact with water or high humidity levels. Moisture increases the risk of degradation of this material by some biological agents, in the sense that they only attack the wood when its water content reaches certain values, as a general rule, above 20%. Specifically, when the wood remains in high moisture conditions for long periods, fungi or underground termites can attack the wood elements (Delgado, 2008). Fungi, insects, and marine xylophages are the three common types of biological agents that affect these materials.

Atmospheric agents, such as UV radiation and rain, cause changes in colour and texture, which are translated into the greyish hue of "old" wood. Shoupe et al. (2008) refer that these changes, which consist of a chemical decomposition of wood compounds by action of ultraviolet radiation, eventually, alternated by washing of the degraded layer by the effect of rain, correspond to a purely superficial deterioration, with no other consequences than aesthetic.

The anomalies of mechanical origin may be caused by: alterations of the substrate, namely, movements of the structure due to shrinkage; variations of the initial support conditions; disregard of the construction joints; and absence of an adequate number of joints for the extension of the flooring, among others.

Currently, wood floorings are subjected to protective treatments, constituting a durable solution, with a high resistance to a wide range of chemical environments. In this sense, in the present dissertation, this degradation factor was not analysed in detail.

3. Fieldwork

The fieldwork survey is used to collect all the relevant information for the classification of the anomalies present in the cases studies analysed, in order to later develop a model for predicting the service life of wood floorings. This survey is crucial for the definition of the degradation curves and for evaluating the loss of performance of the wood flooring over time. For that purpose, 97 wood floorings, with different ages and various characteristics, were analysed, intending to obtain a degradation pattern for these floorings, through the comparison of the degradation state of different examples.

Regardless of the accuracy achieved during fieldwork, the visual inspections present some limitations, such as:

- The high susceptibility of this type of floorings to execution errors, which are not easily detectable when the flooring is already installed, such as environmental conditions at the time of application, among others;
- The difficulty in obtaining information regarding the maintenance and interventions to which the floor has been subjected, as well as the respective dates;
- The subjectivity of the inspections, which depends on the expertise and accuracy of the inspector. In fact, several inspectors may have slightly different analyses, regardless of the adoption of the same initial assumptions. In this sense, the inspection and diagnosis form proposed intends to standardise the inspection criteria, thus mitigating the occurrence of potential inspection errors.

Definition of the degradation levels

Different levels of degradation have been defined for each group of anomalies and, in some cases, for each specific anomaly. The degradation levels of each anomaly take into account the type of anomaly and the quantity/size of its defects. Consequently, to distinguish the severity of the anomalies, percentages of their extent have been defined on the surfaces to be analysed. These percentages and the proposed degradation levels for each of the groups of anomalies are presented in Tables 1 to 3.

4. Degradation model

Service life definition

The concept of service life is not unequivocal, and different authors present slightly different approaches to this concept. According to Masters and Brandt (1987), the service life of a building component is equal to the period of time during which all the essential requirements are met or exceed, assuming that the component is subjected to periodic maintenance. Whether these actions are implemented or not can play a crucial role in the buildings life cycle, since the performance of a building element over time can be influenced by the occurrence of maintenance actions, changing the values of the elements' service life and the related intervention costs (Flores, 2002).

Table 1: Degradation levels of aesthetics anomalies

Aesthetics		
Anomalies	% affected	Degradation level
Colour change	0 a 20	1
	20 a 60	2
	60 a 90	3
	90 a 100	4
Cigarette marks	0 a 20	3
	20 a 100	4
Scratches or wrinkles	0 a 20	1
	20 a 60	2
	60 a 90	3
	90 a 100	4
Wearing or detachment of the finishing layer	0 a 20	1
	20 a 60	2
	60 a 90	3
	90 a 100	4
Stains	0 a 10	1
	10 a 20	2
	20 a 60	3
	60 a 100	4
Inadequate maintenance	0 a 20	1
	20 a 60	2
	60 a 90	3
	90 a 100	4
Wear	0 a 10	1
	10 a 50	2
	50 a 90	3
	90 a 100	4

Table 2: Degradation levels of functional anomalies

Functional		
Anomalies	% affected	Degradation level
Warping, swelling or other flatness deficiencies	0 a 10	1
	10 a 30	2
	30 a 90	3
	90 a 100	4
Cracking of elements and/or joints	0 a 10	1
	10 a 40	2
	40 a 90	3
	90 a 100	4
Broken or splintered elements	0 a 5	1
	5 a 10	2
	10 a 50	3
	50 a 100	4
Rot	0 a 5	1
	5 a 10	2
	10 a 50	3
	50 a 100	4
Moisture	0 a 5	1
	5 a 20	2
	20 a 50	3
	50 a 100	4
Disaggregation	0 a 10	1
	10 a 40	2
	40 a 90	3
	90 a 100	4
Pulverulence	0 a 10	1
	10 a 30	2
	30 a 90	3
	90 a 100	4
Xylophage attack	0 a 30	3
	30 a 100	4
Crumbling	0 a 5	2
	5 a 20	3
	20 a 100	4

Table 3: Degradation level of joint anomalies

Joints		
Anomalies	% affected	Degradation level
Colour change	0 a 20	1
	20 a 50	2
	50 a 90	3
	90 a 100	4
Detachment or loss of the filling material of the joints	0 a 20	1
	20 a 50	2
	50 a 90	3
	90 a 100	4
Change of joint size	0 a 20	1
	20 a 50	2
	50 a 90	3
	90 a 100	4

Gaspar (2009) refers that the end of a building service life may occur due to functional obsolescence, loss of economic performance, and physical degradation of its key materials. Moser (1999) states that the end of service life is dependent on safety, functional or aesthetic criteria, in which the last criterion constitutes a parameter of difficult evaluation, since the definition of a minimum performance level is associated with the stakeholder's point of view and expectations.

To standardise this concept, ISO 15686-1: 2000 was created, and later updated in 2011; this standard is currently considered the most relevant reference for service life prediction of buildings and components. This standard defines service life as the period of time, after construction, in which the building and its elements meet or exceed the minimum performance requirements.

Methodology applied

The methodology used is a deterministic or an empirical method. This method intends to evaluate the loss of performance (or the evolution of degradation over time) of wood floorings in real service conditions and in different phases of their service life.

In this study, the service life prediction method initially proposed by Gaspar and Brito (2008) and Gaspar (2009) is used. This method is based on data collected from visual inspections and the respective identification and classification of observed anomalies, which are grouped according to their nature and severity. Gaspar (2009) includes in the model the value of the areas affected by each type of anomaly, in order to assess the extent of degradation and in parallel proceed to the respective weighting in relation to the level of severity of each one.

In this study, the characterisation of the degradation condition of wood floorings is done through the adoption of the qualitative levels of degradation presented in Tables 1 to 3. These degradation levels are converted into quantitative information, i.e. a numerical index which establishes the overall degradation condition of the flooring, called severity of degradation (S_w). This numerical index is given by the ratio of the weighted degraded area to a reference area, equivalent to the whole flooring with the highest possible degradation level - Equation (1).

$$S_{w,wf} = \frac{\sum(A_e \cdot k_n \cdot k_{a,n}) + \sum(A_f \cdot k_n \cdot k_{a,n}) + \sum(A_j \cdot k_n \cdot k_{a,n})}{A \cdot \sum(k_{máx})} \quad (1)$$

The parameters that are taken into account in the equation that is associated with the model used are: $S_{w,wf}$ - severity of degradation of the wood floorings, in %; A - flooring area (m^2); A_e - area of aesthetic anomalies (m^2); A_f - functional anomalies area (m^2); A_j - joint anomalies area (m^2); k_n - multiplication factor for anomaly *n*, as a function of its degradation level (*k* varies between 0 and 4); $k_{a,n}$ - weighting coefficient corresponding to the relative weight of the detected anomaly; $\sum(k_{máx})$ - sum of the weighing constants, corresponding to the highest possible level of degradation (4+4+4);

Therefore, after collecting fieldwork information on the degradation condition of the various wood floorings analysed, their service life is predicted using graphic and statistical analysis of the evolution of their severity of degradation index over time.

To estimate the severity of degradation index, the weighting coefficients presented in Tables 4 to 6 are used. These coefficients allow obtaining values closer to the reality, i.e. values that reflect, in a more adequate way, the reality observed during the inspections carried out on the floorings. The weighting coefficients are defined considering the repair costs of each anomaly, as well as the propensity of the anomaly to cause new anomalies or increase the propagation rate of the existing ones, and the effects of the anomaly in decreasing the capacity of the flooring to fulfil the minimum requirements.

Table 4: Weighting factor according to the functional anomalies

Functional	
Anomalies	Weighting factor
Warping, swelling or other flatness deficiencies	1.2
Cracking of elements and/or joints	1.2
Broken or splintered elements	1.2
Rot	1.2
Moisture	1.2
Disaggregation	1.2
Pulverulence	1.2
Xylophage attack	1.2
Crumbling	1.2

Table 5: Weighting factor according to aesthetics anomalies

Aesthetics	
Anomalies	Weighting factor
Colour change	0.6
Cigarette marks	0.6
Scratches or wrinkles	0.6
Wearing or detachment of the finishing layer	0.6
Stains	0.6
Improper maintenance	0.6
Wear	0.6

Table 6: Weighting factor according to joint anomalies

Joints	
Anomalies	Weighting factor
Colour change	0.6
Detachment or loss of the filling material of the joints	1
Change of joint size	1

Degradation curves

The degradation curve is a graphical representation of the evolution of the degradation condition of wood floorings over time. This curve (Figure 1) is obtained through a regression analysis between the numerical index that expresses the degradation of wood floorings (S_w) and their age, considering the sample analysed in the fieldwork survey, i.e. a third-degree polynomial was adjusted to the cloud of points corresponding to the sample analysed.

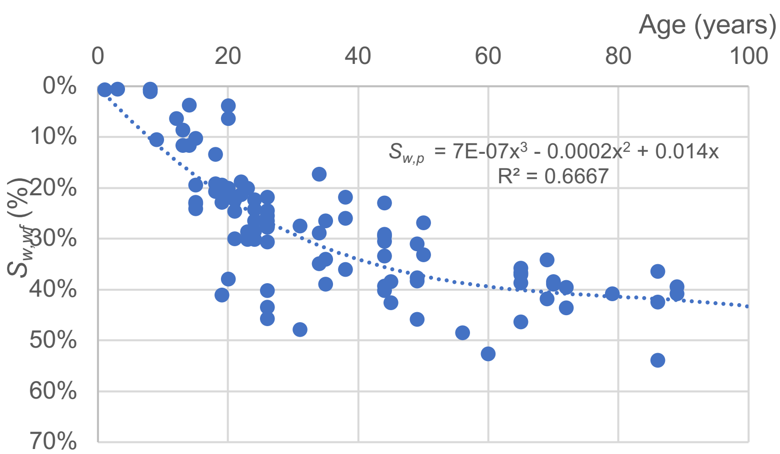

Figure 1: Overall degradation curve (97 case studies)

The curve obtained is an "S-shaped" curve, comprising three distinct phases, initiation (the occurrence of premature anomalies), maturation and a terminal phase (Gaspar and Brito, 2005). Wood floorings present an accelerated loss of performance in the initiation period, followed by a stabilization/maturation period, in which the degradation phenomena are felt in a cumulative but slow way, and finally, the terminal phase, a senescence period, in which the degradation is felt in a more accelerated way, due to an intensification of the degradation actions and synergy between them (Serralheiro et al., 2017).

5. Results and conclusions

In this study, and through the adoption of the proposed model, the evolution of the degradation condition of wood floorings over time could be characterised, revealing that these floors tend to suffer from anomalies at early stages of their service life, mainly due to in-use conditions.

The evolution of the degradation condition of wood floorings was also analysed as a function of the different characteristics of these floors, e.g. considering the hardness of wood (Figure 2) or the exposure to moisture, in areas next to kitchens or sanitary facilities (Figure 3). The sample analysed is small, from a statistical point of view; nevertheless, some statistically significant values were obtained. The results obtained revealed, as expected, that the wide range of characteristics of wood floorings influence their behaviour over time, affecting their durability.

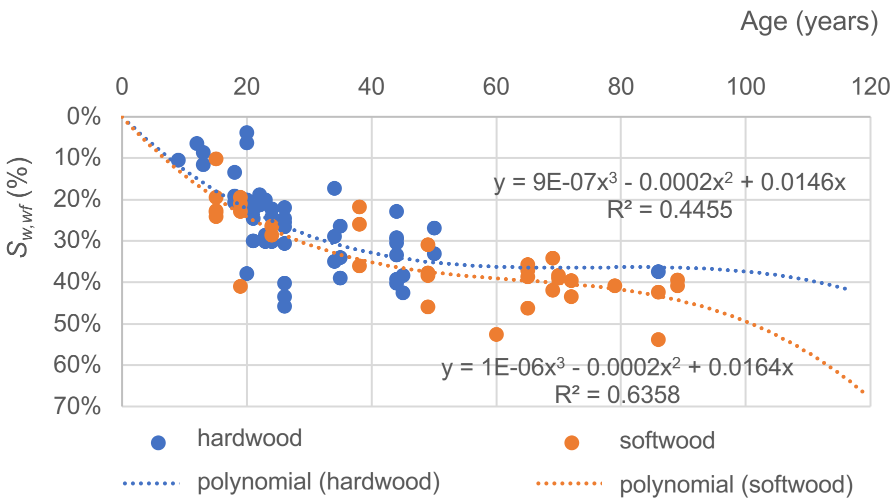

Figure 2: Degradation curve of wood floorings according to the hardness of the wood

Finally, the reference service life of the wood floorings was determined. A maximum degradation limit of 30% was adopted to establish the end of service life of these floorings. Based on this assumption, a reference service life of 32 years was obtained. This value is in accordance with the existing literature on the durability of this type of flooring.

From the analysis of the degradation curves of the wood floorings analysed according to their characteristics, an estimated service was obtained for each one of the characteristics analysed. Regarding the type of flooring and the type of finishing, these characteristics do not lead to a truly relevant estimated lifetime variation, with a variation of 3 years between the most and less favourable characteristics. These results could mean that all types of finishes and all types of flooring are efficient and durable if they are applied in a correct manner and in a space suitable for those characteristics.

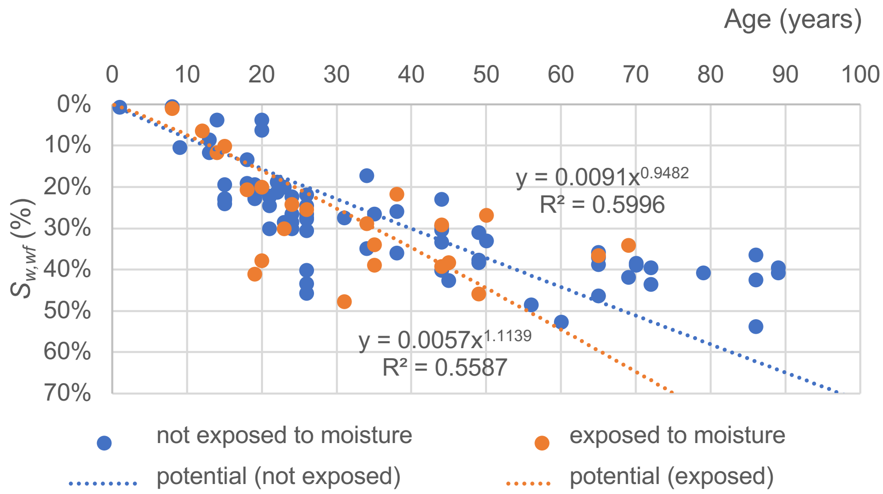

Figure 3: Degradation curve of wood floorings according to the proximity to moisture sources

The type of wood, the proximity to a moisture source, and the periodicity of maintenance show a variation in the estimated service life of 9, 4 and 7 years, respectively. The results show, as expected, that these characteristics lead to some variability in the estimated service life of wood floorings.

Other characteristics, such as the type of use, the level of use and the degradation condition of the window frames in the room in which the flooring is located, show a very significant impact on the estimated service life, i.e. a variation of 15, 17 and 13 years, respectively, was obtained for these characteristics. Therefore, these characteristics significantly influence the durability and service life of wood floorings, considering the high variation obtained for the estimated service life for these characteristics, considering that the reference service life of the overall sample is 32 years. This study thus allows quantifying the impact of the various characteristics considered. Moreover, the results obtained reveal the higher importance of the level of use of spaces (with a variation on the estimated service life around 17 years) in comparison with the type of flooring used (where the variation between the available options leads to an estimated service life variation of only 3 years).

The results obtained in this study allow quantifying that variability, leading to an estimation in years, which is the first step to adopt more sustainable solutions during the design stage, as well as for the optimisation of maintenance actions, which allow increasing the durability and service life of the wood floorings.

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