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Methodology for service life prediction of external paint finishes (on rendered facades)

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Extended abstract

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Extended abstract

1 Introduction

The main objective of this research is the development of a deterministic methodology for the service life prediction of external paint finishes on rendered facades. This study is based on field survey data of in-service conditions and the analysis is presented in the shape of degradation models through simple linear / non-linear regression and multiple linear regression.

Service life prediction assumes a primary role as it allows a more rational use of construction elements. This constitutes a useful tool in the definition of preventive maintenance plans providing an increase in performance.

In spite of the very broad use of paint as an external finish on rendered facades, many studies have shown that there is a great frequency of painting anomalies as this type of finish is very sensitive to degradation.

2 Framework of the proposed theme

The prediction of the service life of materials and construction components is a fairly recent concern, especially in studies connected to the construction industry. The awareness of the importance of durability only started to appear in developed countries in the sixties. The systematic approach of durability measurement, in order to obtain data that would allow the prediction of service life, gained relevance only in the eighties.

2.1 Service life concept

Service life is defined according to ISO 15686 as the period of time after construction during which buildings and their materials equal or exceed the minimum performance requirements. Its definition involves a prior definition of criteria of acceptance that varies in time, place, according to the measurer's point of view and, in fact, to all economic, political, aesthetic, environmental or normative contexts that frame judgment on construction [Gaspar, 2009].

The end of service life represents the point in time, in which the material or component can no longer ensure the activities they were developed for, by factors that are not always objective nor quantifiable. For simplicity sake, it is usually considered that the end of a building's service life occurs through functional obsolescence, lack of economic viability or physical wear of its keys materials [Ang e Wyatt, 1999], [Gaspar, 2001], [Gaspar e Brito, 2003c].

In this research, the chosen approach is based on the physical service life, in other words, the deterioration due to the action of degradation agents and the natural aging of the element. Degradation can still be split into aesthetical and functional categories, notably because in painted coatings the quality of the visual impact shown by the material is also an important factor when determining the end of service life. The unfulfilled criterion was deliberately left out of this work and instead degradation was regarded as a synergy of pathological events that lead to the end of the element's service life.

2.2 Maintenance and service life

According to Tekata et al. [2004], the necessity of maintenance is due both to the change of the building's conditions due to degradation - compromising the physical service life - and to the change of society's expectations and demands - compromising the functional service life.

The maintenance operations affect the behaviour of the elements in time changing the degradation models (rise in performance) and the values of service lives enabling an optimization of their life cycle durations. The role of maintenance is then crucial in order to intervene at the appropriate time avoiding the growth of existing anomalies, saving precious resources and minimizing the costs involved [Flores e Brito, 2003c].

3 Problem definition

Paint continues to have a leading role as an external finish in both national and international construction and, according to INE [2001], is the most used coating in Portugal.
Dependent on the design, application, drying process, environmental and exposure conditions, occasional anomalies or irreversible degradation processes may emerge that disrupt not only the aesthetic and visual quality of the facades but also compromise the protection coatings confer.

3.1 Anomalies characterization

The main anomalies affecting the paint were grouped in four categories:

- Stains \ chromatic anomalies;
- Cracking;
- Adherence loss (peeling and blistering);
- Cohesion loss (chalking).

According to experts, stains and chromatic alterations precede cracking, which may also precede blistering and detachments, showing a growing hierarchy of seriousness between the three aforementioned groups.

3.2 Degradation factors specification

The concept of a degradation factor used in this study includes any factor that might influence the durability of coatings, such as external (degradation agents) or internal (intrinsic characteristics of the material and its interaction with the surface) factors. The purpose of taking them into account is to point out the different behaviours and the interaction function with each other, working as filters that gather a set of buildings according to their mutual characteristics.
The specification of the degradation factors accounted for in this study relies on the adopted methodology being able to identify, estimate, quantify and specify; therefore the study focuses on the importance of the following factors, connected to the durability of paint:

- Exposure to humidity;
- Distance from the ocean;
- Wind/rain action;
- Distance from pollution sources;
- Facade orientation;
- Type of paint;
- Colour of the coating;
- Pellicle texture;
- Surface preparation.

4 Field data

The field work was performed on Lisbon’s building stock, on facades exposed to several degradation agents, regardless of their construction typology. Within this framework, 160 subjects were analysed, corresponding to 220 coatings.
The visual data resulting from the survey of the facades were registered on an inspection sheet created in order to systematically organize the recorded information. It contains the field variables needed to define, on a global scale, the facade degradation and the analysis of the degradation related to each considered factor, thus forming a database of in-service paint finishes. Each analysed facade has its own inspection sheet, where the input of the service life prediction method further developed is listed.

4.1 Definition of levels of degradation

According to several authors, field work results can provide a distorted image of reality by not taking into account some important aspects, e.g. the seriousness and intensity of the registered anomalies. In order to overcome this, levels or thresholds of degradation were defined for the registered defects according to their severity and the group of anomalies to which they belong.

Several authors developed scales of degradation, in order to build models of service life prediction of the building elements. Gaspar and Brito [2005], Bordalo [2008] and Silva [2009] determine the anomaly seriousness according to the anomaly type and affected area, by setting five levels of degradation (where 0 means no visible degradation and 4 indicates general degradation); Shohet and Paciuk [2004] established a physical and visual scale concerning external claddings that takes into account the affected area and the dimension of the anomalies, ranging from 0 to 100 (100 represents a flawless coating or with no signs of problems). Lastly, Gaspar [2009] creates a degradation atlas, which consists of a written and photographic information list referring to the several types of anomalies that affect renders, ranked according to their degradation level.

In the current analysis, the criterion used to define the degradation levels was seriousness, connected to the consequences, either in the protection given or in the visual perception. The range or area affected is a different concept, since it is another aspect that should be considered when assessing the global degradation level and therefore it is a very important definition in the field work.

Visual and physical scales to evaluate the detected degradation anomalies were created, based on the existing quantification norms ([NP EN ISO 4628-1:2005], [NP EN ISO 4628-2:2005], [NP EN ISO 4628-4:2005], [NP EN ISO 4628-5:2005], [NP EN ISO 4628-7:2005]). For each group of anomalies, a 0-4 degradation scale was set, where 0 represents no visible degradation and level 4 represents generalized degradation; the criteria adopted were the following:

- Quantity or density, for cracking (Table 1);
- Quantity, for chalking (Table 2);
- Hierarchy of the anomalies according to the severity and intensity of the alteration, for stains/colour changes (Table 3);
- Hierarchy of the anomalies according to the severity, density and dimension, for loss of adherence (Table 4).

Table 1 - Definition of degradation levels for cracking

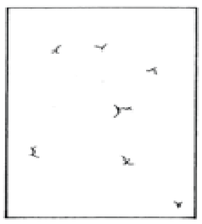
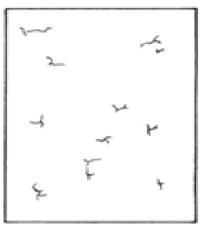
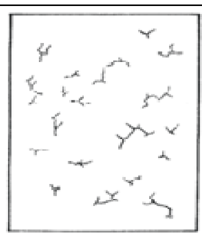
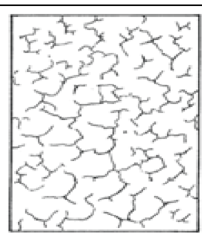
Degradation level	Level 0	Level 1 Good condition	Level 2 Slight degradation	Level 3 Moderate degradation	Level 4 Generalized degradation
Quantity	No visible degradation	Small number of cracks	Moderate number of cracks	Considerable number of cracks	High number of cracks
Visual scale [NP EN ISSO 4628-4, 2005					

Table 2 - Definition of degradation levels for chalking

Degradation level	**Quantity**
Level 0	No degradation visible
Level 1 - Good	Clearly perceptible
Level 3 - Moderate wear-and-tear	Quite perceptible
Level 4 - Generalized degradation	Very perceptible

Table 3 - Definition of degradation levels for stains / change in brightness and color

Level 0			
Intensity of the change	No degradation visible		
Defects characterization	Without visible defects		
Examples			
Description	No perceptible changes		
Level 1			
Intensity of the change	Slight or little perceptible changes		
Defects characterization	Uniform surface dirt Change in colour or brightness		
Examples			
Description	Little perceptible uniform surface dirt	Little perceptible change in colour	
Level 2			
Intensity of the change	Moderate or quite perceptible changes		
Defects characterization	Uniform surface dirt Change in colour or brightness		
Examples			
Description	Quite perceptible uniform surface dirt	Quite perceptible change in colour	
Intensity of the change	Slight or little perceptible changes		
Defects characterization	Localized surface dirt Humidity stains Efflorescences		
Examples			
Description	Light humidity stains		
Level 3			
Intensity of the change	Moderate or quite perceptible changes		
Defects characterization	Humidity stains Efflorescences Biological growth Localized surface dirt		

Examples			
Description	Quite perceptible humidity stains	Quite perceptible biological growth	
Examples			
Description	Quite perceptible localized surface dirt		Quite perceptible efflorescences
Intensity of the change	High or very perceptible changes		
Defects characterization	Uniform surface dirt Change in colour or brightness		
Examples			
Description	Very perceptible uniform surface dirt and change in colour	Very perceptible Localized surface dirt	Very perceptible change in colour (discoloration)
Level 4			
Intensity of the change	High or very perceptible changes		
Defects characterization	Biological growth		
Examples			
Description	Very perceptible biological growth		

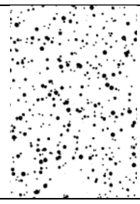
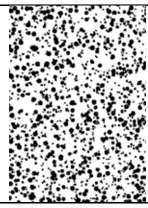
4.2 Characterization of the sample studied

Based on survey information and having set the classification criteria of the different variables, it is possible to characterize the samples (160 buildings and 220 facades) in the following way:

- The majority are housing units (67%), from which 81% have a compact structure and 43% low height;
- 20% are less than 1 km from the sea, 32% between 1 and 5 km and 48% more than 5 km;
- 47% have recurring exposure to humidity while 53% have negligible exposure;
- 22% are slightly exposed to wind/rain, 45% moderately exposed and 33% severely exposed;
- The parameter that shows the greatest heterogeneity is “distance from pollution sources”; only 21% lack exposure;
- The average age of the last painting is 6 years; 29% are less than 4 year olds, 27% between 4 and 8 years, 29% between 8 and 12 years and 16% more than 12 years;
- The distribution of the facades regarding their orientation is fairly regular for all quadrants;

- 40% are plain paint, 38% are elastic membranes and 22% are textured paint;
- Within the 40% plain paints, 63% are traditional plain paint, 27% are non-traditional plain paint and 10% are paints made with silicates and silicone;
- The majority of the buildings (50%) have colours between yellow, orange and light pink and 27% are white; dark colours have little relevance;
- 56% of the buildings have smooth finishing and 44% have rough finishing.

Table 4 - Definition of degradation levels for peeling and blistering

<table>
<tr><td colspan="7">Level 0</td></tr>
<tr><td>Defect characterization</td><td colspan="5">No degradation visible</td><td></td></tr>
<tr><td colspan="7">Level 2</td></tr>
<tr><td>Defect characterization</td><td colspan="6">Blistering</td></tr>
<tr><td>Quantity and size</td><td colspan="6">Small amount and size up to 3 cm</td></tr>
<tr><td>Visual scale [NP EN ISO 4628-2, 2005 e NP EN ISO 4628-5, 2005]</td><td colspan="6"></td></tr>
<tr><td colspan="7">Level 3</td></tr>
<tr><td>Defect characterization</td><td colspan="6">Blistering</td></tr>
<tr><td>Quantity and size</td><td colspan="3">Small amount and size between 3 - 5 cm</td><td colspan="3">Moderate amount and smaller than 3 cm</td></tr>
<tr><td>Visual scale [NP EN ISO 4628-2, 2005 e NP EN ISO 4628-5, 2005]</td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>Defect characterization</td><td colspan="6">Peeling</td></tr>
<tr><td>Quantity and size</td><td colspan="6">Small amount (area affected up to 1%) e size up to 3 cm</td></tr>
<tr><td>Visual scale [NP EN ISO 4628-2, 2005 e NP EN ISO 4628-5, 2005]</td><td colspan="6"></td></tr>
<tr><td colspan="7">Level 4</td></tr>
<tr><td>Defect characterization</td><td colspan="6">Blistering</td></tr>
<tr><td>Quantity and size</td><td colspan="2">Larger than 5 cm, regardless of the amount</td><td colspan="2">Dense pattern regardless of the size</td><td colspan="2">Moderate amount e and dimension between 3 - 5 cm</td></tr>
<tr><td>Visual scale [NP EN ISO 4628-2, 2005 e NP EN ISO 4628-5, 2005]</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Defect characterization</td><td colspan="6">Peeling</td></tr>
<tr><td>Quantity and size</td><td colspan="3">Dense and moderate pattern (affected area higher than 1%) regardless of the size</td><td colspan="3">Small amount and larger than 5 cm</td></tr>
<tr><td>Visual scale [NP EN ISO 4628-2, 2005 e NP EN ISO 4628-5, 2005]</td><td colspan="3"></td><td colspan="3"></td></tr>
</table>

5 Data analysis

The analysis methodology can be divided in four different steps: definition of the minimum level of acceptance in paint finishes, quantification of degradation as one parameter that can translate the global level

of facade degradation, definition of the relationship between this parameter and the condition, application of the graphical method (degradation models) and identification of a reference service life.
Conceptually, it is considered that degradation means loss of performance, and thus its progression provides an understanding of the loss of performance during the service life of coatings.

5.1 Minimum performance level

In this study, the definition of the minimum performance level follows the same criterion as Gaspar [2002], Bordalo [2008] and Silva [2009], considering that the minimum performance level is equal to level 3 (moderate degradation). After this limit, it is considered that the coatings reach the end of their life cycle and are not fit to perform the function for which they were designed, leading to a generalized repair in order to re-establish the characteristics essential to its proper performance.
The advantage of this method is to be able to adopt different criteria for coating acceptance, according to several profile analysis. In each situation, the decision maker should identify criteria to focus on, adjust the threshold level of their demand - which may be higher or lower than that considered - and obtain the remaining lifetime for the case study.

5.2 Quantification of global deterioration

The quantification of global degradation of the facade considers the definition of the severity level of degradation normalized (S_w) that takes into account three basic factors: extent of each anomaly, condition level and relative weighting between anomalies through this expression [Gaspar, 2009]:

$$S_{w,p} = \frac{\Sigma\left(A_n \times k_n \times k_{a,n}\right)}{A \times k} \qquad (1)$$

where,
S_w - degradation severity of coating, expressed as a percentage;
k_n - multiplying factor of n anomaly, depending on its level of degradation, varying as k = {0, 1, 2, 3, 4};
$k_{a,n}$ - weighting coefficient corresponding to the relative weight of the detected anomaly; $k_{a,n} \in R^+$; $k_{a,n} = 1$ if there is no specification;
A_n - area of a facade affected by an anomaly, in m^2;
A - area of the facade in m^2;
k - constant according to the value of the worst condition of a coating with an area A (k = 4).
The extent of the anomalies and their level of severity (rated 0-4) consist of data collected in the fieldwork. Regarding the balance between anomalies, several scenarios were studied for the indicators S_w, based on a hierarchical relationship between the four distinct groups of anomalies (stains/change in brightness and colour, cracking, chalking and loss of adherence) like in the researches of Silvestre [2005] and Gaspar [2009].
In each scenario, different relative weights were tested for these groups of anomalies and the results were analyzed regarding their ability to translate the physical reality registered. Table 5 represents the weighting coefficients that achieved the best results by reducing the weighting of stains/colour changes anomalies and increasing the weighting of the loss of adherence.

Table 5 - Weighting coefficients

Anomalies	Stains\Colour changes	Cracking	Peeling and blistering	Chalking
Weighting coefficient	0.25	1.00	1.50	1.00

5.3 Relationship between severity and condition

The weighted normalized severity is an indicator of global degradation of coatings that varies from 0 to 100%. In order to make it operational, it is necessary to establish the relationship between severity, expressed as a percentage, and condition, on a scale of 0 to 4.

The ratio between level of degradation and severity, expressed in level of condition, was based on the model of Gaspar [2009], already adopted by Silva [2009]. There is a consistency between the observed degradation in the case studies and degradation level assigned to them by the severity of their value. The correspondence table adopted is presented in Table 6.

Table 6 - Correspondence between the degradations indicators

Severity	Degradation levels
$S_{w,p} \leq 1\%$	0
$1\% < S_{w,p} \leq 10\%$	1
$10\% < S_{w,p} \leq 20\%$	2
$20\% < S_{w,p} \leq 40\%$	3
$S_{w,p} \geq 40\%$	4

After defining the relationship between severity and condition, it is possible to divide the sample into five intervals, depending on the values obtained for the weighted normalized severity (Figure 1) and thus analyze the distribution of case studies according to this indicator and overall levels of degradation (Figure 2).

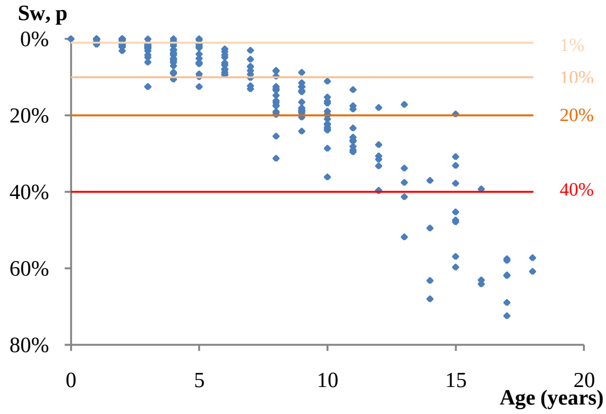


Figure 1 - Distribution of degradation in 220 case studies in the five different degradation levels 0, 1, 2, 3 and 4

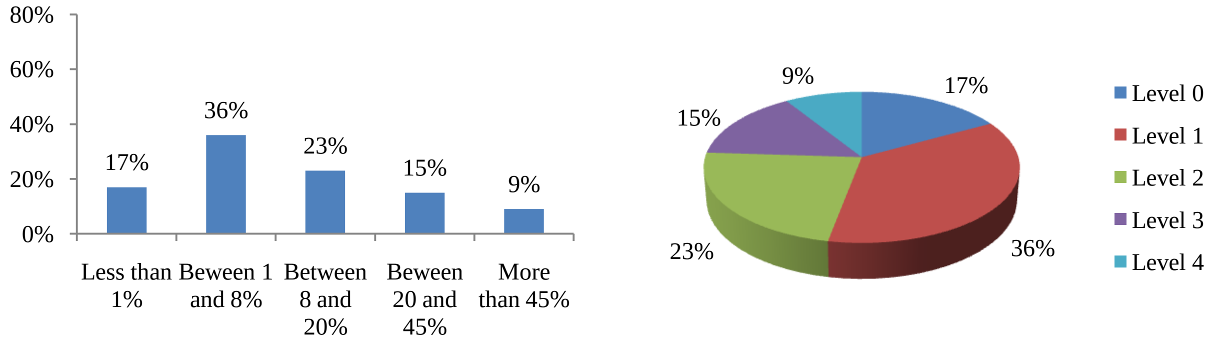


Figure 2 - Sample distribution according to severity and degradation levels

5.4 Degradation models through simple linear / non-linear regression

After the degradation severity was defined and the age of the coating for each case study was known, it was possible to build a graph containing the overall sample. Using statistical techniques, linear and polynomial decay curves were adjusted to the points, representing the performance loss of the paintings over time (Figure 3).

The configuration obtained for the polynomial curve shows a convex development, expressing a trend of paint coatings to slowly decay, but whose effects are felt cumulatively. As shown in Figure 3, up to five years, the rate of deterioration is low, followed by an accelerating trend of the degradation potential.

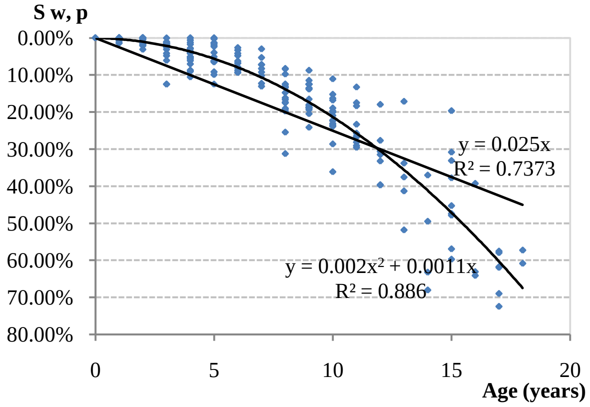


Figure 3 - Degradation curves (linear and polynomial) obtained from the 220 cases analyzed in the fieldwork

In the analysis of conditioning factors in degradation a list of the parameters proposed in the factorial method was used as a reference, associating each subfactor analyzed to the corrective factors of the method developed by the Architectural Institute of Japan [AIJ, 1993]. Their classification is shown in Table 7.

Thus, the sample was split according to these different variables in order to obtain independent regression curves, enabling the development of degradation models associated with each factor. The greater the distance between the curves, the greater the distinction between the service lives associated with each factor, in other words, the greater its influence.

Table 7 - Sub-factors and categories analysed

Factor	Sub-factors	Categories analysed			
Factor A - factor related to material quality	Type of paint	Plain paint	Textured paint	Elastic membranes	
	Texture	Smooth finishing	Rugged finishing		
	Colour	White	Yellow, orange and light pink	Light green, light blue and dark pink	
Factor C - factor related to execution	Surface preparation	Repainting over existing paint	Paint over render		
Factor E - factor related to exposure conditions	Exposure to humidity	Negligible	Current		
	Distance from the sea	Less than 1 km	Between 1 and 5 km	More than 5 km	
	Distance from pollution sources	Negligible	Current		
	Wind/rain action	Slight	Moderate	Severe	
	Facade orientation	North	South	East	West

Results are shown in Figures 4-13. Its analysis shows that they were, in general, consistent with what would be expected and can be interpreted as a first approach to the factor method. The most influential factors, within those considered, were wind / rain action, distance from the sea, facade orientation and texture.

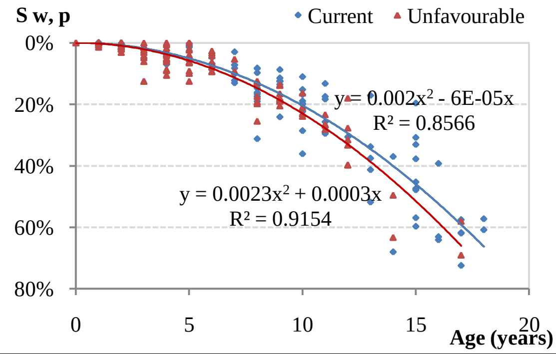
Degradation curves	**Interpretation**
	Improved performance of coatings with current exposure to moisture, compared with those with severe exposure.

Figure 4 - Degradation curves according to the exposure to humidity

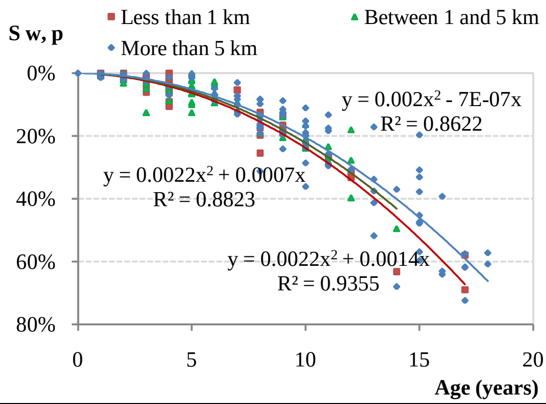
Degradation curves	Interpretation
	Improved performance of the coatings more than 5 km from the sea, followed by those between 1 and 5 km, and finally those less than 1 km.

Figure 5 - Degradation curves according to the distance from the sea

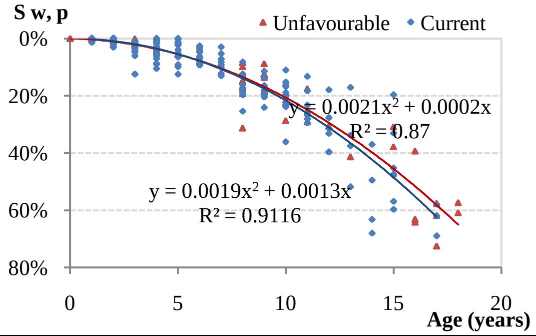
Degradation curves	Interpretation
	Inconclusive (results inconsistent with those expected)

Figure 6 - Degradation curves according to the distance from pollution sources

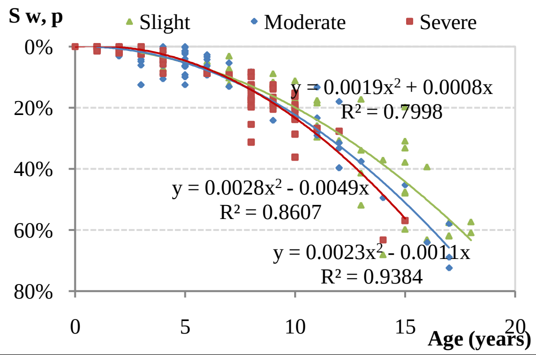
Degradation curves	Interpretation
	Improved performance of the facades slightly exposed to wind/rain action, followed by those moderately exposed, and finally those severely exposed

Figure 7 - Degradation curves according to wind / rain action

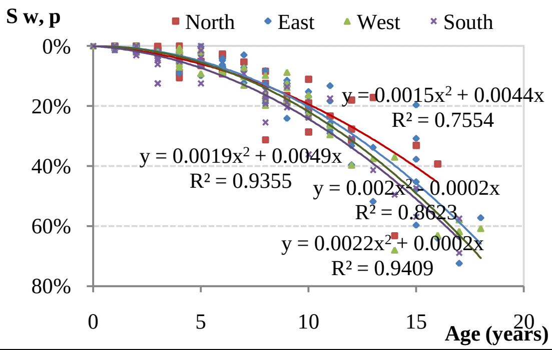
Degradation curves	Interpretation
	Improved performance of facades facing North and East Faster degradation in the facades facing South and West

Figure 8 - Degradation curves according to the orientation of the facade

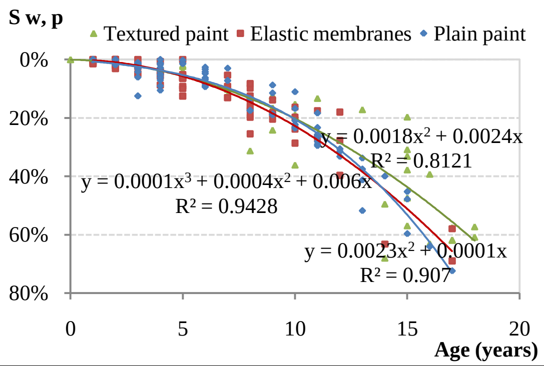
<table>
<tr><th>Degradation curves</th><th>Interpretation</th></tr>
<tr><td>
</td><td>Short term: inconclusive (overlapping curves)
Long term: improved performance of textured paints, followed by membranes and, finally, smooth paints</td></tr>
</table>

Figure 9 - Degradation curves according to the type of paint

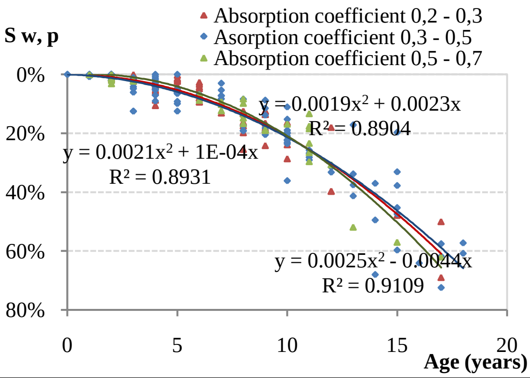
<table>
<tr><th>Degradation curves</th><th>Interpretation</th></tr>
<tr><td>
</td><td>Inconclusive (overlapping curves)</td></tr>
</table>

Figure 10 - Degradation curves according to the colour of the paint

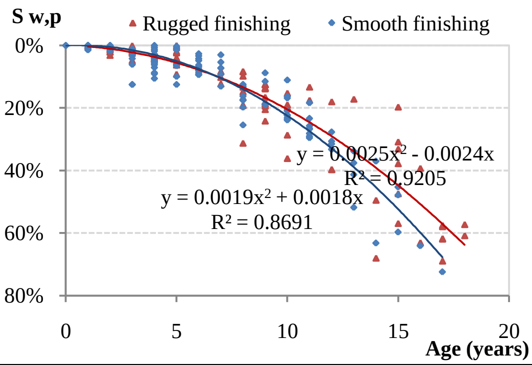
<table>
<tr><th>Degradation curves</th><th>Interpretation</th></tr>
<tr><td>
</td><td>Improved performance of coatings with rough finish</td></tr>
</table>

Figure 11 - Degradation curves according to the finishing of the paint

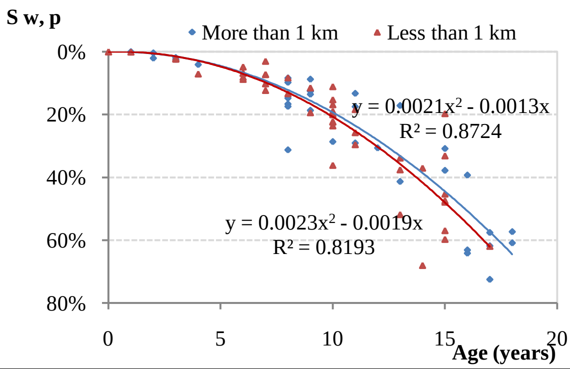
<table>
<tr><th>Degradation curves</th><th>Interpretation</th></tr>
<tr><td>
</td><td>Improved performance of facades located more than 1 km from the river compared with those located within 1 km</td></tr>
</table>

Figure 12 - Degradation curves according to the distance from the river (buildings located in Lisbon)

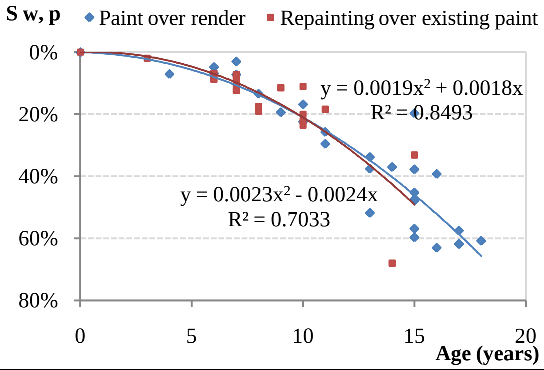
Degradation curves	Interpretation
	Improved performance of paints applied directly on render (results with little statistical validity due to the small number of cases - 46 facades)

Figure 13 - Degradation curves according to the surface preparation (46 paints)

5.5 Degradation models through multiple linear regression

The degradation is defined by a number of factors that together contribute to the deterioration of paint finishes thus ending their service life. This sub-chapter focuses on analyzing the simultaneous effect of the considered parameters, allowing ranking their influence on degradation. This can be accomplished through a regression analysis where the relationship, called the regression function, between one variable y, called the dependent variable, and several others x_i, called the independent variables, is studied.
The degradation model through multiple linear regression is given by the equation (2):

$$y = b_0 + b_1.x_1 + b_2.x_2 + ... + b_p.x_p + \varepsilon = b_0 + \sum_{i=1}^{p} b_i x_i + \varepsilon \quad (2)$$

where: y - dependent variable predicted by a regression model; p - number of independent variables (number of coefficients); x_i - independent variable (i=1, 2, …. p); b_0 - constant; b_i - coefficient corresponding to independent variable x_i (i=1, 2, …. p); ε - random errors of the model.

In the performed analysis, software SPSS (Statistical Package for Social Sciences) was used and the Stepwise method was chosen. In this method, the independent variables that are not significant, i.e. representative of the dependent variable, are excluded. Moreover, the effects of multicollinearity are eliminated [Silva et al., 2011, citing Leung et al., 2001].
When developing the model, the qualitative ranks of each degradation factor were replaced by figures, using numerical values. These were calculated as the ratio between the predicted service life (found through the interception between the horizontal line at S_w = 20% and the corresponding degradation curve) and the reference service life (9.75 years). The model that allows the best results takes into account three different independent variables: age, distance from the sea and orientation of the facade, while $b_0 \neq 0$.
The significance of the model is analyzed in two different ways: the first consists on a significance test of all the coefficients in the regression model while the second considers the significance of the individual coefficients, both performed through hypothesis tests (Table 8).

Table 8 - Hypothesis tests reflecting regression model significance

	Null hypothesis (H_0):	Alternative hypothesis (H_1):
Significance test of all coefficients in the regression model	H_0: $b_0 = b_1 = \ldots = 0$	H_1: ϵ ∃ i: $b_i \neq 0$ (i.e. there is at least one coefficient different than zero).
Significance test of the individual coefficients	H_0: $b_i = 0$	H_1: $b_i \neq 0$

The probability that the null hypothesis is rejected when true is designated by the term α, and the level of significance; (1- α) represents the level of reliability. In this work a significance level of 10% is used which corresponds to a standard value.
The significance of the sum of all the coefficients in the regression model can be analyzed through the results in the Anova table (part 1) in Table 9. In fact, through these results the null hypothesis can be tested by the

so called F test, which represents the ratio between the variance explained by the model and the variance not explained by the model (Snedecor's distribution).

Table 9 - Table Anova (Part 1): Significance test of all coefficients in the regression model

	gl	*SQ*	*MQ*	*F*	*Significance F (p)*
Regression	3	5.321106633	1.773702211	354.300939	4.10632^{-83}
Residual (error)	216	1.081339718	0.005006202		
Total	219	6.402446351			

The probability p = P (F > F_{model}) defines the probability of the lowest level of significance leading to rejection of H_0. Since $p = 4.10632\times 10^{-83} < \alpha = 0.10$, H_0 is rejected at a level of 10%, i.e. at least one of the coefficients b_i and the corresponding variable x_i in the regression model are significant.
The significance of the individual coefficients x_i included in a multiple linear regression model with p independent variables can be tested by performing a significance test on the parameter $b_i/\ S(b_i)$ with a Student's t-test. Like in the F test, here the value of p is compared to the significance level α, for each of the coefficients. Table 10 presents the obtained results.

Table 10 - Table Anova (Part 2): Significance test of the individual coefficients

Variables	Coefficients (b_i)	Standard error ($S(b_i)$)	t Stat	p value
Constant (b_0)	0.4734	0.1715	2.7602	0.0063
Age (x_1)	0.0353	0.0011	31.1710	6.802^{-82}
Distance from the sea (x_2)	-0.2618	0.1438	-1.8207	0.0700
Orientation of the facade (x_3)	-0.3175	0.0906	-3.5028	0.0006

Table 10 shows that for all variables, $p < \alpha = 0.10$ and therefore they are all representative of the severity.
Once the significance of the sum of all the coefficients and the significance of the individual coefficient are verified, the regression statistics output can be analyzed (Table 11).

Table 11 - Regression statistics output

Multiple R (R)	0.9116
R Square (R^2)	0.8311
Adjusted R Square ($R^2_{ajusted}$)	0.8288
Standard error (σ)	0.0708
Observations (n)	220

This analysis reveals a strong correlation (R = 0.91) within the set of coefficients and that 83% of the variability of the severity is explained by age, solar orientation and distance from the sea ($R^2_{adjusted} = 0.83$) while the remaining 17% is due to external factors, not considered in this study.
However, the model relies in the validity of some assumptions which have to be verified (residuals analysis and analysis of existence of multicollinearity). After verifying that the residuals (e_j) follow a Normal distribution ($e_j \sim N(0, \sigma^2)$), $E(e_j) = 0$, $Var(e_j) = \sigma^2$, and that the independent variables do not exhibit a linear correlation, it is concluded that the severity of the degradation can be explained through the three independent variables: age, distance from the sea and solar orientation, using the following equation (3):

$$\text{Severity} = 0.4734 + 0.0353\ \text{Age} - 0.2618\ \text{Distance from the sea} - 0.3175\ \text{Solar orientation} \quad (3)$$

6 Discussion of results

After the minimum performance level of 20% has been established, the reference service life (RSL) is defined by the two following degradation models:

- The degradation model through simple non-linear regression, where the RSL is obtained graphically by intercepting the degradation curve and the horizontal line corresponding to the minimum level of performance;
- The degradation model through multiple linear regression, where the average RSL is obtained numerically by solving the equation of the regression curve x_1 (age) for y = 0.20.

Results are shown in Table 12 as well as the values of service lives defined in other studies.

Table 12 - Service life values according to the present investigation and others studies

Paint finish		
Source		Reference service life (years)
Current analysis	Degradation model through simple non-linear regression	9.7
	Degradation model through multiple linear regression (average)	8.5
Flores-Colen [2002]		5
Japanese Guide [AIJ, 1993]		More than 10
Guarantee of paint products (average)		5
Decree No. 24/2011		8
Cementitious renders		
Source		Reference service life (years)
Gaspar [2009]		21

The results are well within the expected range, according to research in this area and addressing the perception among technicians about what durability of paintings concerns. These results can be interpreted as a sign of the ability of the proposed methodology to describe the degradation.

The adopted methods proved to be a precise system within the prediction of service live of facade paintings, allowing the identification of the main variables for the development of prediction methodologies: average curves of degradation and reference service lives. This method has the advantage of allowing more information to be added over time, and therefore, as knowledge develops, it is suggested that more factors of degradation ought to be considered and the results transposed to the factorial method.

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