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**Application of the factor method to the prediction of the service
life of external paint finishes (on rendered facades)**

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Extended abstract

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1. Introduction

The main goal of this research is to predict the service life of external paint finishes by applying the factor method and it is intended to be a contribution on the subject of the durability of construction elements. The ISO standard 15686-1 defines durability as the capability of a building or its parts to perform their required function over a specified period of time under the influence of the agents anticipated in service, and defines service life as the period of time after installation during which a building or its parts meet or exceed the performance requirements.

Another important concept is obsolescence, which ISO 15686-1 defines as the loss of an item's ability to perform satisfactorily due to changes in performance requirements. As Gaspar (2002) stated, the end of service life of a construction material or element represents a point in time when it stops performing according to the requirements at a functional, technological or economical level. This subject has become increasingly relevant mostly for economic and environmental reasons (Hovde, 1998). The assessment of service life allows for the planning of when maintenance operations will be necessary and at what cost. The research in this field also increases the knowledge of how materials or construction elements perform under given conditions, which means that the prediction of service life can also be a tool for designers when making decisions.

The present dissertation is a follow up on the research that has been made at Instituto Superior Técnico by Gaspar (2002), Sousa (2008), Silva (2009), Chai (2011) and Ximenes (2012). It is important to acknowledge the work of Gaspar (2009), where the author predicts the service life of external cement-renders through degradation models and then applies the factor method. Emídio (2012) and Galbusera (2012) did the same for stone and ceramic claddings, respectively.

Regarding the methods to estimate the service life, there are three main ones (Cecconi, 2002; Gaspar, 2002 and Daniotti, 2003):

- Probabilistic methods, also called stochastic methods, based on probabilistic matrix calculations, which define the probability of change of the condition of the element under study, such as Markov chain models. These methods are very reliable; in spite of their complexity and the fact that a large amount of field data is needed;
- Deterministic methods, based on the study of degradation factors which affect the materials. Each of these factors is weighted and their action over time is represented by formulas, such as the Factor Method. These methods are easy and quick to apply; however, they don't take into account the variability associated with the degradation processes and several authors criticize them for over-simplifying when representing a complex reality;
- Engineering methods, which are used to analytically identify the loss of performance, allowing for a better control of the object's degradation process. These methods represent an intermediate level between the other two method types. An example is the failure mode and effects analysis method.

In this dissertation the factor method has been applied. The purpose of the factor method is to estimate the service life by multiplying the reference service life by factors which affect the durability of the building component under study. ISO 15586-1 (2000) presents the equation which allows the estimation of the service life:

$$VUE = VUR \cdot A \cdot B \cdot C \cdot D \cdot E \cdot F \cdot G \quad \text{Equation 1.1}$$

Where:

ESL - estimated service life;

RSL - reference service life;

A - factor related to the quality of materials;

B - factor related to the design level;

C - factor related to the execution level;

- D - factor related to the interior environmental conditions;
- E - factor related to the exterior environmental conditions;
- F - factor related to the in-use conditions;
- G - factor related to the level of maintenance.

These factors need to be characterized and quantified according to their effect on the performance of the materials or elements under study. In this research, the RSL was obtained based on data collected from onsite inspections. Several authors (Hovde, 1998; Marteinsson, 2003 and Gaspar, 2002) point out that the factor method has strengths and weaknesses. The factor method is criticized mostly for over simplifying reality and for the fact that factors are considered as absolute variables and are obtained empirically. On the other hand, the factor method is a straightforward and flexible approach, that allows for the recognition of the effect of combined deteriorating variables to date and it represents the only standardized method to obtain ESL from experimental data.

2. External paint finishes

The ISO standard 4618:2014 defines paint as a pigmented coating material which, when applied to a substrate, forms an opaque dried film with protective, decorative or specific technical properties, and coating as a layer formed from a single or multiple application of a coating material to a substrate. The components of paint are the binder (film-forming component), the solvent (its main function is to liquefy the binder, making the paint easy to apply), the pigments (granular solids to give properties like opacity, color, brightness, resistance and protection), the fillers (used to thicken the film, support its structure and increase the volume of the paint) and the additives (soluble, viscous or powder elements which are added to paints in small amounts to modify or enhance certain properties) (NP 41, 1982; Eusébio, 1985a; Amaro, 2007 and ISO 4618, 2006). The choice of the paint must take into account the external conditions and the support to be coated. The coating system can consist of a single layer of paint (single system) or a combination of several layers (multilayer system). The multilayer coating system may include one or more priming coats and finishes; it may also include intermediate layers.

2.1. Anomalies and causes

The anomalies affecting the paint finishes were grouped into four categories (Table 2.1).

Table 2.1 - Paint finishes anomalies

Groups of anomalies	Anomalies
Staining	Biological growth
	Humidity stains
	Change in color or brightness
	Dirtiness
	Efflorescence
Cracking	Mud cracking
Loss of adherence	Blistering
	Peeling
Loss of cohesion	Chalking

There are several deterioration causes related to the exterior conditions that interact with the paint finishes: exposure to humidity, wind or rain action, pollution, solar radiation, temperature extremes and variations, presence of water and others.

As demonstrated in this investigation, an inadequate design (wrong choice of materials or unsuitable solutions) and poor execution can drastically reduce the service life of paint finishes. Other causes are natural ageing, inadequate use (vandalism) and accidental causes (floods, fires, collisions and others).

2.2. Degradation levels

The level of degradation is related to the degree of severity of an anomaly, i.e. how much it affects the element under study in terms of durability and service life. It is necessary to define degradation thresholds for each anomaly according to their characteristics. The NP EN ISO 4628 standard (2005) defines three parameters to quantify the degradation of the anomalies level: quantity, size and intensity of changes (Chai, 2011). Five levels of degradation were therefore defined from 0 to 4 depending on the degree of severity of each anomaly; the level 0 corresponds to absence of degradation - with a visual analysis - and level 4 to the presence of severe degradation. Table 2.2 shows the result of the degradation levels classification.

Table 2.2 - Degradation levels classification, through visual assessment

Anomalies	Level 1	Level 2	Level 3	Level 4
Biological growth	Considering the seriousness of this anomaly, levels below 3 were not considered	Considering the seriousness of this anomaly, levels below 3 were not considered	Easily visible stains due to biological growth	Very pronounced stains due to biological growth
Humidity stains	Barely noticeable stains from short distances of the façade. Degradation extension up to 50 cm from ground level	Noticeable stains from short distances of the façade. Degradation extension past 50 cm from ground level	Very noticeable stains even at a greater distance from the façade. Degradation extension past 100 cm from ground level	The most severe humidity stains generally correspond to biological growth. Therefore, level 4 humidity stains were not considered
Change in color or brightness	Perceptible loss of color at a very short distance from the facade or using equipment such as binoculars	More noticeable color change than level 1 at a short distance from the facade	Noticeable color change even at a greater distance from the facade	Very prominent color change and visible from a considerable distance from the facade
Dirt	Perceptible superficial dirt at a very short distance from the facade or using equipment such as binoculars	More noticeable superficial dirt than level 1 at a short distance from the facade	Dirt with some variation in color and noticeable even at a considerable distance from the facade	Dirt with visible continuous dark tones even further away from the facade
Efflorescence	-	Slight changes or barely perceptible	Moderate changes or very noticeable	-
Mud cracking	Low or very low number of cracks	Moderate number of cracks	Big number of cracks	Very high number of cracks
Blistering	Considering the seriousness of this anomaly, levels below 2 were not considered	Reduced number of blisters and size smaller than 3 cm	Reduced number of blisters and size between 3 and 5 cm. Considerable number of blisters and size smaller than 3 cm	Blisters with size greater than 5 cm. Very high number of blisters regardless of size. High number of blisters and size between 3 and 5 cm
Peeling	Considering the seriousness of this anomaly, levels below 3 were not considered	Considering the seriousness of this anomaly, levels below 3 were not considered	Reduced number of peelings and size smaller than 3 cm	Considerable number of peelings regardless of size. Considerable number of peelings and size greater than 5 cm
Chalking	Little cohesion loss	This level of degradation was not considered for this anomaly	Moderate cohesion loss	High cohesion loss leading to the total or localized disappearance of the paint film

3. Field work

The field work consists of three main stages: analysis of the sample previously selected by Chai (2011), field work preparation and on-site inspections. The sample from Chai (2011) was studied and described in order to determine its gaps and to estimate the minimum number of new cases required. The minimum number of cases required was calculated at 90 (Table 3.1), defined according to age groups and factors which affect the durability.

Table 3.1 - Minimum number of cases needed

Age	Distance to the sea	Humidity exposure	Wind / rain action	Orientation	Pollution exposure	Type of paint	Color	Finishing	Substrate	Total
0 to 2	5	0	10	10	5	10	0	0	20	20
3 to 6	0	0	5	0	5	5	10	0	15	15
7 to 10	0	0	5	0	5	0	5	0	5	5
11 to 14	15	0	10	15	5	15	15	5	20	20
15 to 18	20	10	15	30	5	20	20	5	15	30
Total	40	10	45	55	25	50	50	10	75	90

Before the on-site inspections, an inspection sheet was developed in order to register all necessary data for a complete characterization of the paint finishes observed. The inspection sheet includes fields about general information (address, volumetric configuration, etc.), environmental conditions, inherent characteristics of the paint finishes (type of paint, texture, color, etc.) and the anomalies, along with the percentage of the area affected. At this point, on-site inspections were carried out and 103 new elements were gathered. The paint finishes inspected were added to the sample from Chai (2011), yielding a total sample of 323 elements. The final sample was statistically analyzed and, overall, the purpose of filling the gaps of the initial sample was achieved for most of the variables. In conclusion, the sample obtained was able to provide a better foundation for service life prediction of the elements under study.

4. Degradation models

The next step of the research is the application of a degradation model to characterize the degradation of paint finishes over time, based on models developed by Gaspar (2002; 2009). A degradation model is a mathematical function which translates the qualitative data obtained through on-site inspections into a quantitative index that reflects the global degradation state of the element under study. Equation 4.1 shows how to obtain the numerical index mentioned, called severity of degradation (S_w).

$$S_w = \frac{\sum(A_n \cdot k_n \cdot k_{a,n})}{A \cdot k} = \frac{E_w}{k} \quad \text{Equation 4.1}$$

Where:

A - exposed painted area, in square meters;

A_n - painted area affected by defect n, in square meters;

k_n - degradation level for defect n, with $k_n \in \{1, 2, 3, 4\}$;

$k_{a,n}$ - relative importance of the defects detected; if no specification exists, $k_{a,n} = 1$;

E_w - extent of the painted area's weighed degradation, obtained by the ratio between the weighted affected area and the total painted area;

S_w - severity of degradation of the painted area obtained by the ratio between the extent of the painted area's weighed degradation and the maximum degradation level (k), expressed in percentage.

Regarding the anomalies' weighing coefficients, in this research were considered the relative weights that showed better results in the investigation of Gaspar (2009), which were also adopted by Chai (2011).

The C1 scenario assumes that all defects contribute with the same degree of importance to the degradation and the C2 scenario assumes that the anomalies of adhesion failure are more severe than cracking and chalking, which, in turn, are more severe than staining (Table 4.1).

Table 4.1 - Weighing coefficients of the anomalies (Chai, 2011)

Group of anomalies	Staining		Cracking		Adhesion failure		Chalking	
	C1	C2	C1	C2	C1	C2	C1	C2
Scenario								
Weighing coefficients ($k_{a,n}$)	1.00	0.25	1.00	1.00	1.00	1.50	1.00	1.00

4.1. Evolution of the paint finishes' degradation

After obtaining the severity index for each case of the sample and knowing the age of the paint finishes, it was possible to draw a chart containing the overall results (Figure 4.1). Through simple regression techniques, a degradation curve that best adjusted to the points was drawn; this curve is a 3rd order polynomial curve and represents the average performance loss of the paintings over time. The R-squared value indicates the accuracy of the statistical model used, the higher this value is, the more suited the model is. Considering the R-squared value obtained (0.75), the curve is well adjusted to the points of the sample.

In this study, an estimated service life of 6 years was obtained for coatings characterized by poor execution, which is almost half the service life of the coatings with adequate level of execution and shows the high impact of poor execution on the life expectancy.

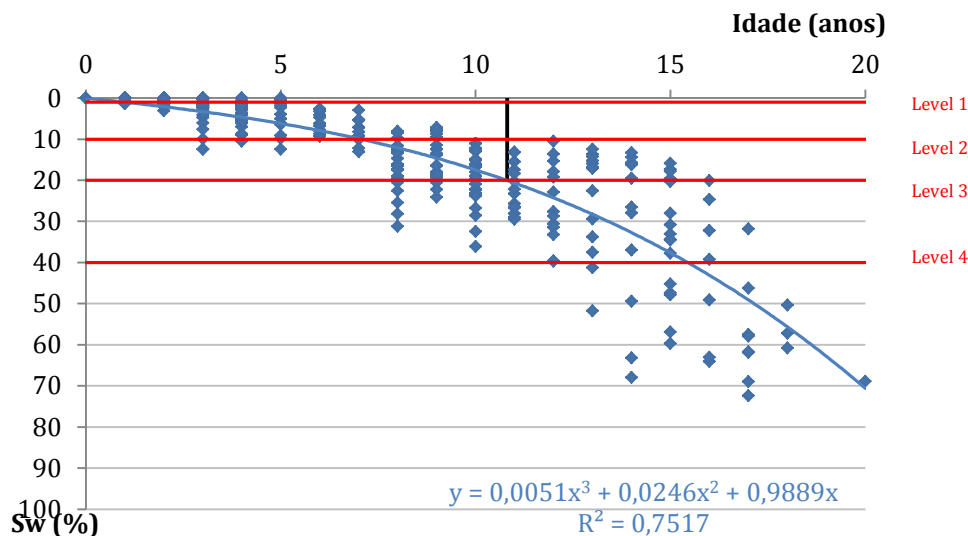


Figure 4.1 - Service life prediction for external paintings

In chapter 2, five levels of degradation were defined, from 0 to 4, depending on the degree of severity of each anomaly. Level 3 was set as the limit state of service life, which corresponds to a loss of performance of 20%. When the end of the service life is reached, an intervention needs to be considered. At this point, levels previously defined were related to ranges of values of severity of the degradation (Table 4.2).

In Figure 4.1, the intersection between the degradation curve and the severity equal to 20% was used to identify that the average service life expected for the paint finishes is approximately equal to 10.8 years.

Table 4.2 - Correspondence between the degradation indicators (Chai, 2011)

Severity	Degradation levels
$S_w \leq 1\%$	0
$1\% < S_w \leq 10\%$	1
$10\% < S_w \leq 20\%$	2
$20\% < S_w \leq 40\%$	3
$S_w \geq 40\%$	4

After this, the final sample was analyzed according to the different factors that influence the durability of the paint finishes. As it will be shown further, these factors are the basis for the factor method calculation.

Relevant results were obtained for most of the variables considered (some examples are shown in Figures 4.2 to 4.5). The reliability of the results is supported by the R-squared values.

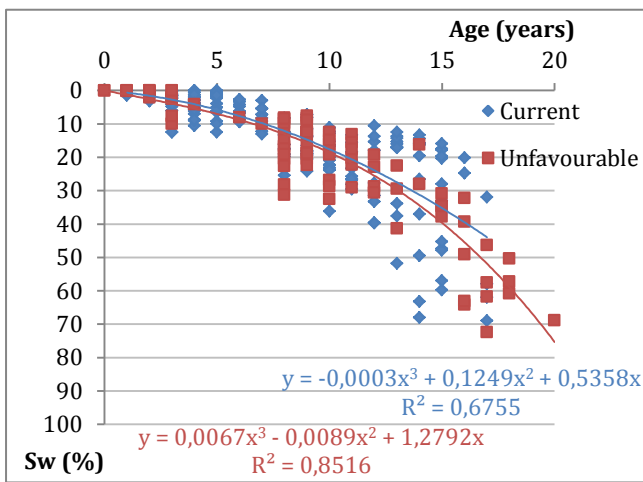


Figure 4.2 - Degradation curve according to pollution exposure

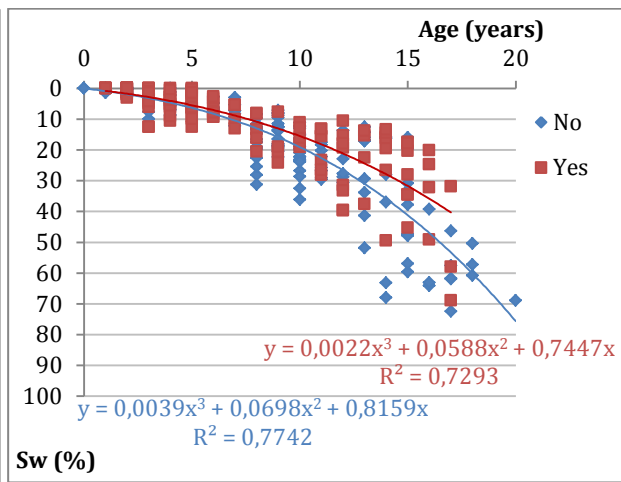


Figure 4.3 - Degradation curve according to ease of inspection

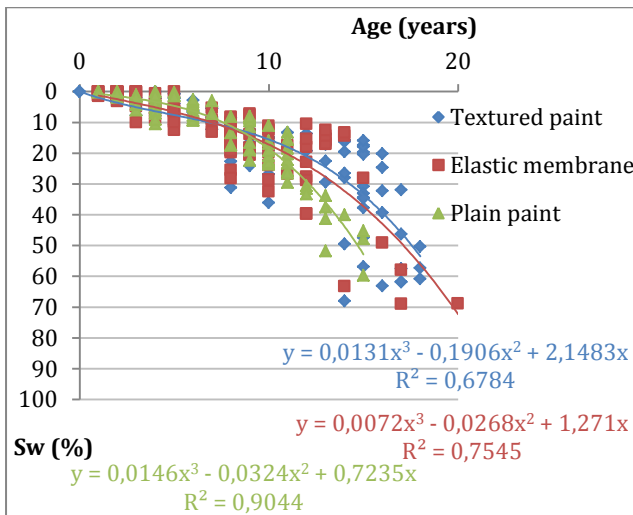


Figure 4.4 - Degradation curve according to type of paint

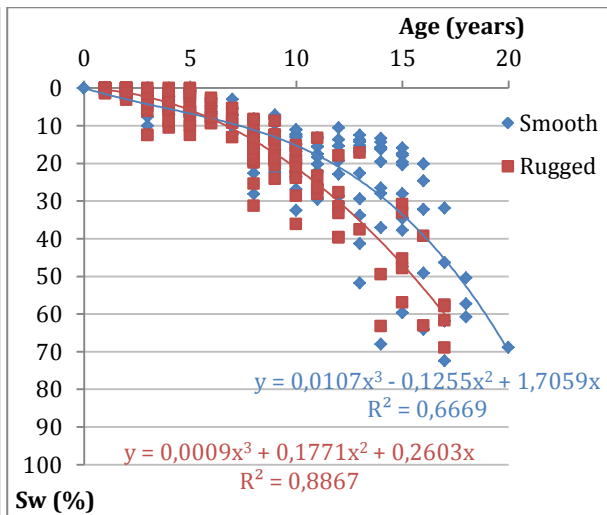


Figure 4.5 - Degradation curve according to texture

5. Factor method

At this point a deterministic methodology for the prediction of service life of the paint finishes based on the factor method is proposed.

5.1. Extrapolation of the degradation curve for each point

Gaspar (2002) developed a methodology to evaluate the expected service life for each case within the sample which was applied in the present study. It is called the method of conversion factor to the value of ordinates. In this method a k factor is evaluated and equals the ratio between the severity of the degradation calculated through the equation 4.1 and the corresponding severity value of the average curve for the same age. After calculating the k values, the f' function (equation 5.1) is obtained by multiplying f (average degradation curve function) and k .

$$f' = k \cdot f = k \cdot a \cdot x^3 + k \cdot b \cdot x^2 + k \cdot c \cdot x \quad \text{Equation 5.1}$$

Where:

f - average degradation curve function;

f' - degradation curve for each dot function;

k - conversion factor;

a , b and c - constants of the 3rd-order polynomial average curve.

The function above allowed for the calculation of the expected service life (ESL) for each case study and the results were used to plot another graph which shows the service life distribution over time (Figure 5.1). The trend line represents the average value of the graph dots and the expected service life average evaluated with the method of conversion factor is 11.5 years.

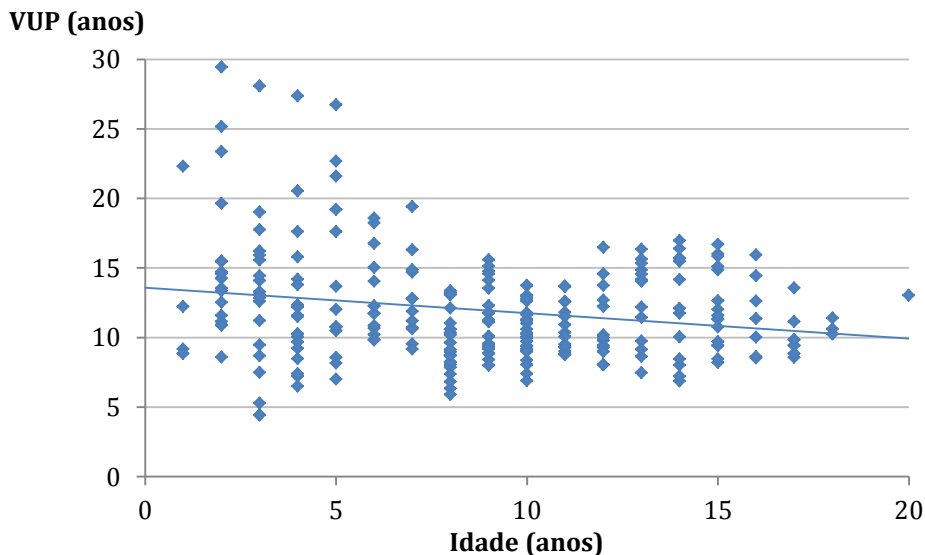


Figure 5.1 - Estimated service life distribution *versus* age

After this, new graphs concerning the service life distribution over time according to different factors that influence the durability were plotted and most of them gave results which support the previous ones (some examples are shown in Figures 5.2 to 5.5).

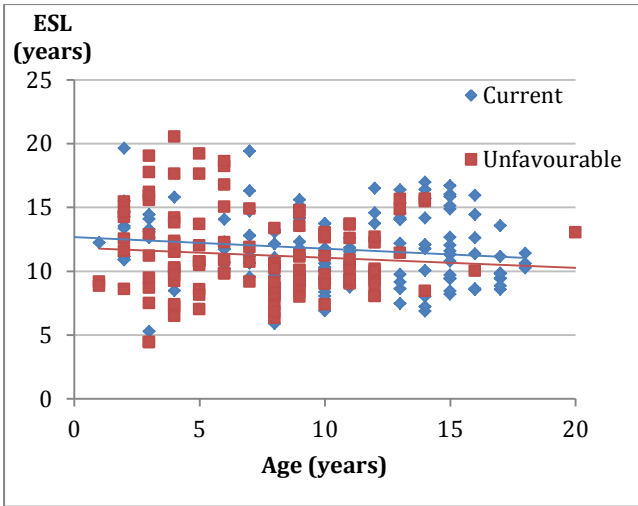


Figure 5.2 - Estimated service life according to humidity exposure

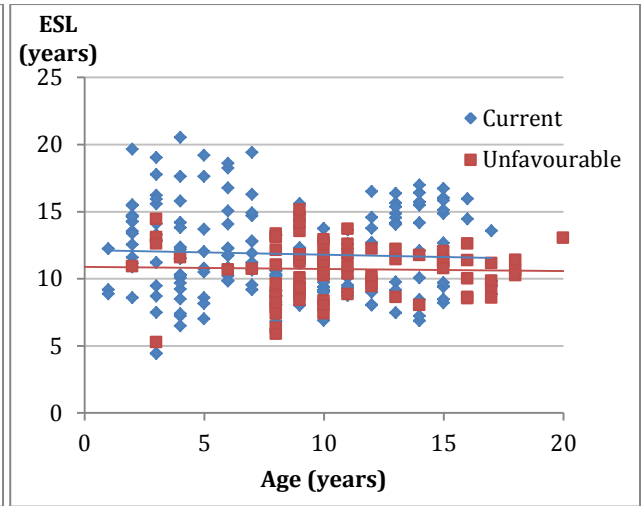


Figure 5.3 - Estimated service life according to pollution exposure

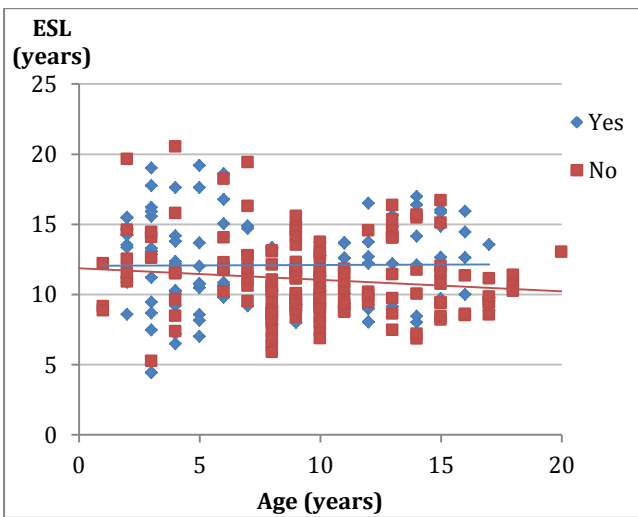


Figure 5.4 - Estimated service life according to ease of inspection

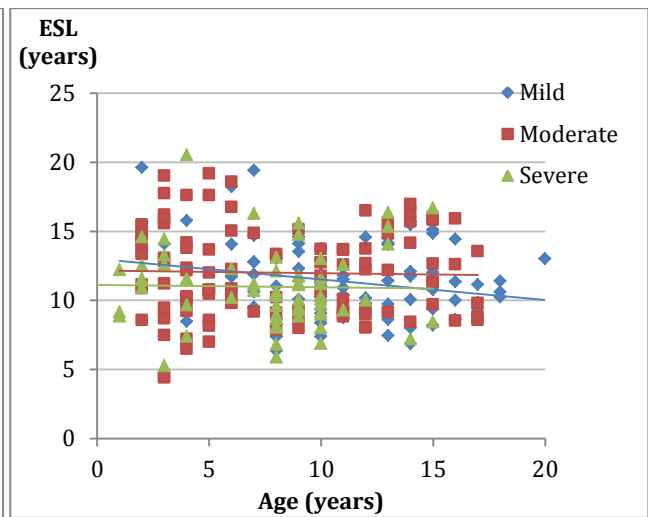


Figure 5.5 - Estimated service life according to wind/rain action

5.2. Calculation of the reference service life (RSL)

In the previous sections two average service life values were obtained: 10.8 and 11.5 years. In this sub-chapter, another methodology was explored in order to define a final RSL value to be applied in the factor method. This methodology tries to identify the reference service life that best expresses the conditions of the sample around the average results obtained. Therefore, it was cases were selected with a variation in severity less than or equal to 5% compared to the average curve of degradation; 19 cases were gathered in these conditions. At this point, the factor method is applied for the first time in reverse order according to equation 5.2 to calculate the RSL for each of the 19 selected cases (Table 5.2). The calculation has been carried out based on the recommendations of the ISO 15686-1 (2000) standard: therefore, the values assigned are 0.8 (unfavorable), 1 (current), and 1.2 (favorable), depending on the condition considered.

$$VUR = \frac{VUE}{0.8^x * 1.2^y}$$

Equation 5.2

Where:

ESL - estimated service life;

VUR - reference service life;

x - number of occurrences of 0.8;

y - number of occurrences of 1.2.

The sub-factors considered so far in the degradation models were classified according to the multiplication factors in the equation 1.1. Each one of the factors include sub-factors which in turn include several variables that describe the data concerning the paint finishes collected a during field work (Table 5.1).

The factors related to the indoor environmental conditions (these do not affect the external coatings) and to the in-use conditions were excluded.

Table 5.1 - Categorization of variables according to the factor method

A - Material properties		E - Outdoor environmental conditions	
A1 - Type of paint	k1 - Textured paint	E1 - Distance from the sea	k1 - < 1 km
	k2 - Elastic membrane		k2 - > 1 and < 5 km
	k3 - Plain paint		k3 - > 5 km
A2 - Color	k1 - White	E2 - Humidity exposure	k1 - Current
	k2 - Light colors		k2 - Unfavorable
	k3 - Dark colors	E3 - Wind/rain action	k1 - Severe
A3 - Surface	k1 - Rugged		k2 - Moderate
	k2 - Smooth	k3 - Mild	
B - Characteristic of the design		E4 - Orientation	k1 - N
B1 - Substrate	k1 - Render		k2 - S
	k2 - Existing paint		k3 - E
C - Characteristic of execution on-site		E5 - Pollution exposure	k4 - O
C1 - Level of execution	k1 - Adequate		k1 - Current
	k2 - Inadequate	k2 - Unfavorable	
D - Indoor environmental conditions (excluded)		F - In-use conditions (excluded)	
G - Level of maintenance			
G1 - Maintenance	k1 - Yes	G2 - Ease of inspection	k1 - Yes
	k2 - No		k2 - No

Subsequently, each one of the variables listed in Table 5.1 was attributed a multiplicative coefficient, in order to weigh their influence on the loss of performance of the paint finishes.

The value obtained as a possible RSL value is the average of the results obtained (Table 5.2) and is equal to 11.9 years.

At this stage of the investigation, three values for defining the reference service life were obtained (Table 5.3) with little variation between them.

These remarks led to the reference service life for paint finishes to be set at 11 years, corresponding to the integer number closest to the average of the three values just listed.

Table 5.2 - RSL evaluation for 19 elements of the sample

ID	Age	Number of occurrences 0.8	Number of occurrences 1.2	RSL (years)
L008	18	4	4	12.5
L009	15	4	4	12.7
L013.2	6	1	3	7.7
L026	7	2	4	8.0
L028	10	3	3	12.5
L065	2	5	2	23.1
L101	6	1	3	7.9
L121.2	2	1	2	9.4
L132.1	8	4	2	18.0
L132.3	8	4	2	18.0
L138.1	5	1	3	7.8
L139.3	5	1	3	7.8
L140	5	1	3	7.8
ID 8	7	2	5	6.7
ID 14	10	3	4	10.0
ID 29	8	3	2	15.0
ID 30	20	3	2	17.7
ID 45	13	3	5	9.0
ID 56	11	4	3	15.4

Table 5.3 - Values for defining the RSL

Method	RSL (years)
Degradation curve (Figure 4.1)	10.8
Graphic model (Figure 5.1)	11.5
Average of the RSL values for the 19 cases	11.9

5.3. Factor's quantification

The weighting coefficients earlier assigned to each variable to calculate the RSL value for the 19 cases were not definitive and needed to be confirmed. For this purpose, following the methodology used by Gaspar (2009), Emídio (2012) and Galbusera (2012), several scenarios were studied with the aim to quantify new weighting coefficients in order to maximize the reliability of the estimated ESL values. The benchmarking of the results was done by comparing the results obtained by applying the factor method (FM) with the reference values, corresponding to the field work results - graphical method (GM).

Thus, the following acceptance criteria were defined:

- the average of the ratios between the results of the factor method and the graphical method must have a maximum variation of 5% from 1.00 ($FM/GM \leq 1.05$);
- the amplitude of ESL results evaluated through the factor method has to be less than, or equal to, those obtained by the graphical method ($FM_{max} - FM_{min} \leq GM_{max} - GM_{min}$);
- the outcomes of the application of the factor method need to be credible. For this reason, these have to be less than twice the average service life evaluated with the graphical method and higher than 25% that ($2.75 \text{ years} \leq FM \leq 22 \text{ years}$);

- the cumulative frequency of the ratio FM/GM has to maximize the results around 1.00 (acceptance of 15%) and minimize the results above 1.50. In particular, $FM/GM \geq 0.85$ at least in 50% of the sample and $FM/GM \leq 1.05$ at most in 10% of the sample;
- the aim of the iterations is to maximize the number of cases falling within the following range: $0.85 \leq FM/GM \leq 1.15$.

The model proposed for the formula to calculate the estimated service life of paint finishes is based on Equation 1.1 and is presented through the equation 5.3.

$$ESL = RSL \cdot A1 \cdot A2 \cdot B1 \cdot C1 \cdot C2 \cdot E1 \cdot E2 \cdot E3 \cdot E4 \cdot E5 \cdot G1 \cdot G2 \quad \text{Equation 5.3}$$

Sendo que:

- ESL – estimated service life;
- VUR – reference service life;
- A1 – type of paint;
- A2 - color;
- B1 – surface;
- C1 – execution level;
- C2 - substrate;
- E1 – distance from the sea;
- E2 – humidity exposure;
- E3 – wind / rain action;
- E4 - orientation;
- E5 – pollution exposure;
- G1 - maintenance;
- G2 – ease of inspection.

The factor method was therefore applied seven times using a different set of weighting coefficients. Each scenario is described in Table 5.4. The statistical results obtained after the factor method application are resumed in Table 5.5.

Table 5.4 - Scenarios' characterization

Scenarios	Description
Scenario 1	It takes into account the average service life value obtained from Figure 5.1 (11.5 years). A difference of 0.05 from 1.00 has been assigned for every year of difference between the service life of each variable and the average
Scenario 2	It takes into account the average service life value obtained from Figure 4.1 (10.8 years). A difference of 0.05 from 1.00 has been assigned for every year of difference between the service life of each variable and the average
Scenario 3	A weighting value equal to 1.00 has been conferred to all the sub-factors
Scenario 4	The values assigned are 0.80; 1.00 and 1.20, based on ISO 15686, taking into account if the influence of the variables is unfavorable, current or favorable to the performance of the elements under study (respectively)
Scenario 5	The values assigned are 0.90; 1.00 and 1.10, taking into account if the influence of the variables is unfavorable, current or favorable to the performance of the elements under study (respectively)
Scenario 6	Weighting values (k) were obtained for each one of the variables in order to get the best possible result
Scenario 7	The weighting coefficients were obtained by the ration between the service life value obtained for each variable and the average service life value obtained from Figure 5.1 (11.5 years). This is a mathematic scenario like the scenarios 1 and 2, so the physical meaning of the variables wasn't taken into account.

Table 5.5 - Statistical analysis of the scenarios results

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	
FM / GM average (≤ 1.050)	1.050	1.074	1.014	1.072	1.065	1.000	1.076	
Standard deviation FM/GM	0.260	0.289	0.268	0.372	0.296	0.266	0.261	
Amplitude of results (years)	FM (\leq MGmax - GM min)	3.00	7.12	0.00	13.06	6.64	9.36	5.40
	GM	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Extremes values FM (years)	Max. (≤ 22 years)	13.14	16.21	11.00	18.25	14.495	16.265	14.92
	Min. (≥ 2.75 years)	10.13	9.09	11.00	5.19	7.86	6.91	9.51
FM / GM ≥ 0.85 ($> 50\%$)	78.26%	77.17%	69.57%	71.74%	78.26%	80.43%	79.35%	
FM / GM ≥ 1.50 ($< 10\%$)	5.43%	8.70%	4.35%	10.87%	8.70%	6.52%	5.43%	
$0.85 \leq$ FM / GM ≤ 1.15	47.83%	43.48%	40.22%	29.35%	43.48%	55.43%	46.74%	

Generally speaking, the outcomes were satisfactory taking into account that the cumulative frequency of the ratio FM/GM is over 69% for all scenarios. Only scenarios 2, 4 and 5 did not fulfill one or two criteria.

Scenario 1 yielded slightly better results compared to the scenario 2, which may be due to the fact that differences between the mean values of expected lifetime for each variable k in the second iteration were obtained from the value 10.8 years and are bigger in module than in the first scenario, which consequently generates k values more unequal among variables and therefore can produce worse results.

Regarding the percentage of cases in which FM / GM is between 0.85 and 1.15, scenario 4 showed the worst results, that is, the lowest percentage (29.4%), followed by scenario 3 (40.2%) and finally, the fifth scenario showed the best result (43.5%) of all three. Such outcomes show that the best results can't be obtained considering k values equal to 1 or considering k values far from 1 (equal to 1.2 or 0.8), this means it is necessary a balanced solution among these values, which is what scenario 5 achieves. Emídio (2012) and Galbusera (2012) also achieved the best results with scenario 6, as would be expected.

In the current work, scenario 3 has the second worst percentage of cases in which FM / GM is between 0.85 and 1.15 and for Galbusera (2012) the third iteration has the third worst percentage. Regarding Emídio (2012), scenario 3 is the second scenario with the better results, but fails one of the acceptance criteria. These outcomes show that a differentiation of the variables which affect the durability of exterior paint finishes is necessary, which is precisely one of the main goals of this research.

The seventh iteration did not fulfill the FM / GM average criteria, however has the third highest percentage of cases in which FM / GM is between 0.85 and 1.15. This scenario presents weighting values close to 1 and a smaller difference between them, compared to scenario 6, which supports the conclusion that a very small difference between the weighting coefficients or values close to 1 do not lead to better results.

Scenario 6 achieved the best outcomes of all seven: the weighting values obtained achieved the bigger percentage of cases in which the ratio FM / GM is close to 1 (55.4%). In Table 5.6 the weighting values obtained in the sixth simulation are presented.

Table 5.6 - Values obtained in scenario 6

Sub-factors	Variables	Final k values	Sub-factors	Variables	Final k values
A1 - Type of paint	k1 - Textured paint	1.15	E2 - Humidity exposure	k1 - Current	1.00
	k2 - Elastic membrane	1.10		k2 - Unfavorable	0.90
	k3 - Plain paint	0.95		k1 - Severe	0.95
A2 - Color	k1 - White	1.00	E3 - Wind / rain action	k2 - Moderate	1.10
	k2 - Light colors	1.00		k3 - Mild	1.15
	k3 - Dark colors	1.00		k1 - N	1.15
B1 - Surface	k1 - Rugged	1.05	E4 - Orientation	k2 - S	0.90
	k2 - Smooth	1.00		k3 - E	1.00
C1 - Level of execution	k1 - Adequate	1.00		k4 - O	1.00
	k2 - Inadequate	0.85		E5 - Pollution exposure	k1 - Current
C2 - Substrate	k1 - Render	1.00	k2 - Unfavorable		0.80
	k2 - Existing paint	1.00	G1 - Maintenance	k1 - Yes	1.00
E1 - Distance from the sea	k1 - < 1 km	0.95		k2 - No	0.80
	k2 - > 1 and < 5 km	1.10	G2 - Ease of inspection	k1 - Yes	1.15
	k3 - > 5 km	1.10		k2 - No	0.95

As with the work of Galbusera (2012), the factor method proved to be practical and efficient for estimating the life of construction elements, in this case external paint finishes.

6. Conclusion

Overall, the outcomes of the current research were satisfactory and the goals set in the beginning were achieved. The sample collected by Chai (2011) was analyzed and completed through new inspections; the final sample yields 323 elements.

After the final sample was statistically analyzed, a degradation model was applied to characterize the degradation of paint finishes over time, based on the work of Gaspar (2002; 2009), and the average life expectancy for external paint finishes was quantified at 10.8 years. In the present study, an important outcome was reached: the estimated service life for the coatings characterized by poor execution is equal to 6 years, which represents nearly half of the service life of the coatings with adequate level of execution and shows how grossly poor execution results in a significant reduction of life expectancy.

The reference service life (RSL) for external paint finishes was set at 11 years, obtained through the average results of distinct methodologies. This result is considered to be an acceptable value taking into account the values indicated by several entities or researchers.

The final stage of the research consisted in the analysis of seven scenarios or iterations in order to improve the accuracy of the weighting multiplying factors which influence the durability of the elements under study. An important conclusion that has been reached is that it is necessary to differentiate how the various variables considered affect the service life. A final set of the factor method's weighting values was proposed in order to estimate the service life of the external paint finishes. The statistical indicators achieved in the sixth scenario prove the reliability of the factor method, which despite the inherent limits, has proven to be an effective and simple to use.

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