INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

SERVICE LIFE PREDICTION OF FAÇADE PAINT COATINGS IN TRADITIONAL BUILDINGS

Methodology based on the inspection of in-use buildings

Mário Alexandre de Jesus Garrido

Civil Engineering Department, Instituto Superior Técnico, Universidade Técnica de Lisboa, Portugal

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Abstract

In the current conjuncture, the financial resources available for infrastructure maintenance and rehabilitation are very limited, creating a need for efficient resource management and for the ability to predict and plan maintenance actions throughout the infrastructure's service period. The existence of service life prediction methodologies of building materials and components is essential to such goals.

The research presented here proposes and tests a service life prediction methodology, based on the inspection of in-use buildings, applied to the service life prediction of façade paint coatings. This methodology comprises the quantification of defects, with the paint peeling defect quantification being considered. Additionally, the influence of five degradation factors was considered in the performance over time of the paint coatings. The result analysis was made through the use of degradation graphs and deterministic models.

Keywords: Service life, Service life prediction methodology; Building inspections, Façade paint coatings, Defect quantification, Paint peeling, Performance over time, Degradation factors, Degradation graphs, Deterministic models

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1. INTRODUCTION

In today's social and economical context there is a strong drive towards a more efficient use of resources in every sector of human activity. This is, in part, motivated by the goal of achieving and maintaining a *"sustainable development"*, which can be defined as *"development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs"* (Brundtland, 1987). The construction industry is one of the most determinant industries in this context, given the influence that the built environment has on the well being of populations and on the economical development of nations. Pearce (2003) produced a report concerning the specific contribution of the United Kingdom's construction industry in the pursuit of such a goal. This author highlights the significant influence of *inputs* given to the built environment in their design, construction and maintenance phases on the levels of economic activity housed therein and their respective productivity.

In order for adequate rehabilitation and maintenance strategies to be undertaken which can optimize the social and economic benefits of the built environment, and given the current context where the funds available for such actions are very limited, there has to be a way in which to plan and prioritize the necessary works. The planning of such works can be achieved by predicting the moments when the critical elements of the built assets reach degradation levels that exceed acceptable values. To be able to make such predictions, developments must be made concerning the methodologies for service life prediction of building materials and components.

The research presented here aims to contribute to such development, by exploring and testing a service life prediction methodology based on observation of long term degradation, achieved through inspection of in service buildings, and applied to the service life prediction of façade paint coatings. For this, the degradation in the form of the paint peeling defect in the inspected coatings was quantified, and the influence of five degradation factors on the coatings' the performances over time was assessed. As a result, degradation curves were obtained that model this performance over time, allowing for service life estimates to be made, as a function of any defined maximum acceptable degradation level.

2. STATE-OF-THE-ART

2.1. OVERVIEW OF THE SERVICE LIFE PREDICTION METHODOLOGIES

The development of service life prediction methodologies was greatly influenced by the work of various technical committees, associated with entities such as CIB[1] (CIB W80), RILEM[2] (RILEM 71-PSL, 100-TSL, 175-SLM) or ISO[3] (ISO TC 59 SC 14) (Lacasse et al., 2004). From the joint work of the CIB W80 and RILEM 71-PSL technical committees, resulted the reports by Masters and Brandt (Masters et al., 1987, Masters et al., 1989), where the authors present the outline of a general methodology for service life prediction of building materials and components, and identify some research needs in that domain.

Sjöström and Brandt (1991), as a result of the work developed in the CIB W80 and RILEM 100-TSL technical committees, presented a further contribution to the service life prediction problematic, in which the collection and use of in service exposure data in these methodologies was further explored.

The works of Martin et al. (1994) and Martin (1999) present a service life prediction methodology applied specifically to paint coating systems, where the use of reliability theory and reliability engineering is suggested, in order to improve the quality of the service life estimates.

The *Architectural Institute of Japan* (AIJ, 1993) proposed a methodology based on a factor method, which was later adopted by the *International Organization for Standardization* in the ISO 15686 standards (ISO, 2000).

2.2. GENERAL APPROACH

As a common feature in all the mentioned methodologies, there are three main stages that are structural in the approach to the service life prediction problem. These are the **problem definition** stage, the **data collection** stage and the **data analysis** stage.

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[1] CIB – International Council for Research and Innovation in Building and Construction;
[2] RILEM – International Union of Laboratories and Experts in Construction Materials, Systems and Structures;
[3] ISO – International Organization for Standardization;

The problem definition stage is where the scope of the research is established. In order to do so, one must define the materials under study, their characteristics, their application context, the environmental agents and other degradation factors that might have an influence on the material's performance over time, the possible defects that might cause the material to fail or degrade, the tests and methods that will be employed in the data collection phase, and the type of data analysis that will be undertaken.

In data collection phase, the objective is to collect information regarding the material's degradation mechanisms and defects, and the influence that the various relevant degradation factors have on the material's performance over time. For this, there are two main types of approaches: i) short term methodologies and ii) long term methodologies. Short term methodologies rely on the observation of degradation that occurs under exposure conditions designed to accelerate the effects of degradation agents. Long term methodologies, on the other hand, rely on the observation of long-term degradation that occurs under in-use conditions.

In the data analysis phase the collected data is used to build degradation models that allow conclusions to be withdrawn regarding the material's service life. Many approaches can be used in this stage, such as employing deterministic models, stochastic models, engineering models, factor methods or reliability theory.

3. METHODOLOGY

3.1. PROBLEM DEFINITION

The work presented here was developed as the application of a service life prediction methodology to the particular case of façade paint coatings, considering the performance over time regarding the paint peeling defect. The effect of five degradation factors was considered: *i) DF1: coating thickness*, *ii) DF2: paint binder*, *iii) DF3: paint surface texture*, *iv) DF4: substrate surface preparation* and *v) DF5:solar orientation*.

The data collection in the followed methodology was based on the observation of **long term degradation under in-use conditions**, achieved by the **inspection** of 100 in-service building façade coatings, and the **defect quantification** of the considered defects. The data analysis was performed using **degradation graphs** and **deterministic models**, with the use of three types of **degradation curves**: *i) Gompertz curves*, *ii) Potential curves* and *iii) Weibull curves*.

3.2. DATA COLLECTION

3.2.1. BUILDING INSPECTIONS

The façade coatings of 100 buildings were inspected in the city of Lisbon. The inspected buildings were built prior to 1940, corresponding to the *pre-pombaline*, *pombaline* and *gaioleiro* types of building (Paulo, 2009). In the choice of the inspected buildings, there was the concern to gather a sample of coatings with a full range of paint peeling extents, i.e. from coatings that presented no paint peeling to coatings that were almost completely peeled from their substrate.

The inspections were made with the following objectives: i) create a photographic registry of the façade, ii) collect paint samples from the coatings, iii) make measurements of the facades' dimensions, and iv) perform an *in situ* interpretation of the paint surface texture and substrate surface preparation. Additionally, the application date of the last coat of paint was determined by analysis of the municipal records, viewed at the *Arquivo Municipal de Lisboa*.

The photographic registries of the building façades consisted of partial façade images that were later stitched together and corrected for perspective distortion in order to produce a single image, similar to an elevation of the building façade. This process was made using specialized commercial image editing software. The process is illustrated in Figure 1.

Figure 1 – Stitching and perspective correction processes used to obtain and elevation type of façade image.

The measurement of façade dimensions was made using a *Stanley FatMax* laser measuring device. The width and height of the façades was measured, so that a scale could be associated to the façade image. In Figure 2 an example is presented of the measurements made for one of the inspected facades.

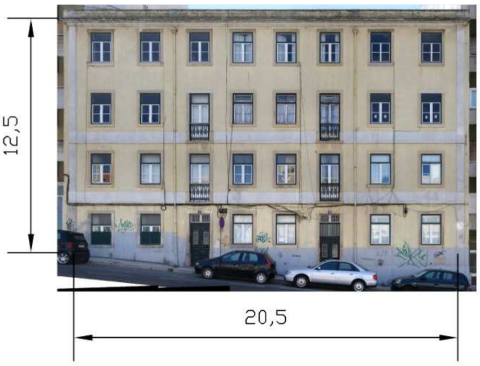

Figure 2 – Example of measured façade dimensions (width and height).

3.2.2. COATING THICKNESS MEASUREMENTS (DF1)

For the film thickness measurements, the paint samples collected during the building inspections were used. The samples were cleaned, so as to remove any pieces of mortar that might have been attached, and their thickness was measured using an *Elcometer 355 Coating Thickness Gauge*. Ten measurements were made for each paint sample, from which an average film thickness was calculated.

In cases where more than one layer of paint existed on the façade (i.e. layers from previous coatings that were not removed when the latest coating was applied) the coating for which the measurements were made was always the most recent one.

This method provides an estimate of the average film thickness. Yet, this estimate cannot be unequivocally assumed as being equal to the actual average coating thickness, since it is obtained from a punctual sampling of that coating. In order for this value to be representative of the real average coating thickness, several measurements would have to be made, at evenly distributed points throughout the whole coating. This would be highly unpractical, and would imply a far too great expenditure of resources, besides being too intrusive to the inhabitants of the buildings. As such, the adopted method was considered to be a good compromise between precision and expeditiousness.

3.2.3. PAINT BINDER IDENTIFICATION (DF2)

To perform the paint binder identification, FTIR analyses were conducted on the collected paint samples. For this, a *Perkin Elmer 1600 Series FTIR* was used (Figure 3). This device allows for the analysis of substances through a solid potassium bromide (KBr) window.

In a first attempt to identify the paint binders, the FTIR analyses were conducted on samples of the raw paint film. This led to transmittance spectra that showed peaks associated to the usual paint binders, but that showed also the peaks associated with inorganic compounds that exist in paints, deriving from the pigments and fillers. As a result, the obtained spectra were not clear enough for binder identification.

Figure 3 – Perkin Elmer 1600 Series FTIR.

To overcome this difficulty, a new method was adopted which involved the extraction of the paint binder from the paint samples. This was done through the use of a solvent, methyl ethyl ketone (MEK), and allowed for the paint binders to be isolated, thus providing clear FTIR spectra which allowed for the identification of the binders (Figure 4).

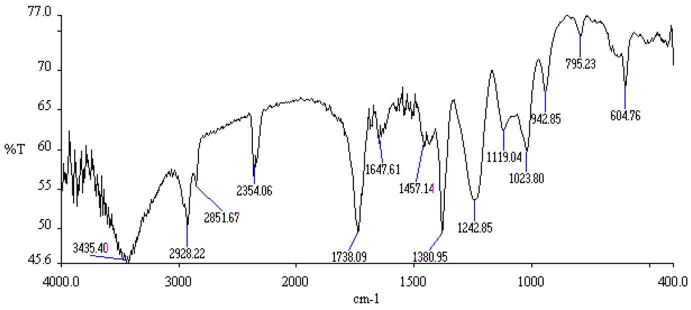

Figure 4 – Transmittance spectrum obtained from the FTIR analysis of a paint binder, polyvinyl acetate (PVA).

Through this method, four different types of binders were identified: *polyvinyl acetate (PVA)*, *acrylic resin*, *styrenated acrylic resin* and *oil-based*. The acrylic resin and styrenated acrylic resin binders were grouped generically for the data analysis as *acrylic resins*.

3.2.4. PAINT SURFACE TEXTURE DETERMINATION (DF3)

The identification of the paint surface texture was performed through visual inspection. Three types of surface textures were considered: *textured*, *smooth – plastic* and *smooth – oil*. Examples of these texture types can be found in Figure 5, Figure 6 and Figure 7, respectively.

Figure 5 – Example of a "textured" paint surface texture.

Figure 6 – Example of a "smooth – plastic" surface texture.

Figure 7 – Example of a "smooth – oil" surface texture.

3.2.5. IDENTIFICATION OF THE SUBSTRATE SURFACE PREPARATION (DF4)

Determining the exact conditions in which the paint coatings were applied, given that records concerning this subject aren't usually kept, or even if kept they aren't of public domain, is not an easily feasible task. This limits the capability to assess in a reliable way the cares taken during the application of the coatings. As such, simplifications to the analysis had to be made, in order to limit extensive assumptions that might reduce the quality of the data.

For this reason, the substrate preparation factor was approached from a very simplified standpoint, with two basic types of substrate surface preparation being considered: *repaint over paint* and *repaint removing paint*. These types of substrate preparation are illustrated in Figure 8 and Figure 9, respectively.

Figure 8 – Example of a "repaint over paint".

Figure 9 – Example of a "repaint removing paint".

The *repaint over paint* surface preparation comprises coatings that were applied as a repaint, without the removal of the previous paint coating. The *repaint removing paint* surface preparation includes both coatings applied after the full removal of any previous paint coatings, and coatings applied for the first time on the façade render that serves as a substrate.

3.2.6. DETERMINATION OF SOLAR ORIENTATION (DF5)

The solar orientation of the façades was determined using a compass, with four main solar orientations being considered: *North*, *South*, *East* and *West*. The grouping of façade headings into these main orientations was performed as illustrated in Figure 10.

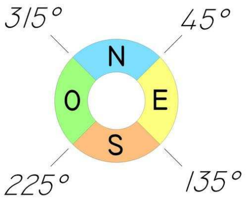

Figure 10 – Solar orientation system adopted.

3.2.7. PAINT PEELING DEFECT QUANTIFICATIONS

The defect quantifications were made using the *Photo Measure* application of the *BuildingsLife* platform (Paulo, 2009). This application allows areas and distances to be directly measured over images of building façades. The façade images obtained with the previously presented stitching and perspective correction processes were uploaded onto *BuildingsLife*, and scales were defined using the façade dimensions measured during the inspections.

This allowed for the quantification of the coating areas affected by paint peeling, which were then converted into percentages of peeled coating after the additional measurement of the total coating areas.

3.3. DATA ANALYSIS

3.3.1. DEGRADATION GRAPHS

The data analysis was conducted with the support of **degradation graphs**. These graphs have an horizontal axel that represents the time elapsed since the last maintenance action, which in the present case is the application of the last paint coating, and a vertical axel that represents a measure of degradation. In the present work, this measure of degradation was the actual extension of the peeled coating area, expressed as a percentage of the total coating area.

3.3.2. DEGRADATION CURVES

The modeling was done with deterministic models, using degradation curves that attempt to mimic the performance over time of the paint coatings, regarding the paint peeling defect, by being fitted to the data in the degradation graphs. The curves used were of the Gompertz (Eq. 1), Potential (Eq. 2) and Weibull (Eq. 3) types.

$$D_G = e^{ae^{bt}} \tag{1}$$

$$D_P = at^b \tag{2}$$

$$D_W = 1 - e^{-(\frac{t}{\eta})^{\beta}} \tag{3}$$

In the expressions presented above, D_G D_P and D_W represent the extension of peeled coating, expressed as a percentage of the total coating area, t represents the time elapsed since application of the paint coating, and a b η and β are the parameters that were adjusted in the fitting of the curves to the data in the degradation graphs.

The fitting of the degradation curves was made through a process of mean squared error (MSE) minimization. The calculation of MSE values can take into account the errors determined either in the vertical or horizontal axis, i.e. given a coating age one can estimate the extent of degradation and compare that with the real degradation (vertical MSE, or MSE_D), or given a degradation extent one can determine the age at which the model will predict that degradation to occur and compare that with the real coating age (horizontal MSE, or MSE_t). The curves obtained by minimizing the horizontal MSE are usually significantly different from the curves obtained using a process of minimization of the vertical MSE. To find a compromise between these two methods, and achieve curves that will provide the best overall fit, an indicator was created, the *Combined Mean Squared Error* (CMSE), given by the expression presented in Eq. 4.

$$CMSE = MSE_t + MSE_D \times 10^3 \tag{4}$$

4. RESULTS AND DISCUSSION

4.1. GENERAL DEGRADATION GRAPH AND DEGRADATION CURVES

In Figure 11 the obtained general degradation graph is presented, along with the associated degradation curves that were fitted to it. The respective equations are shown in Table 1. It's evident that there is significant dispersion in the data shown. This dispersion was expectable considering that this graph plots together data from different types of coatings, which will present different performances over time. In fact, the dispersion in this type of data is essential, as it reflects and translates the different influences that the degradation factors have on the performance over time of paint coatings.

It is expectable that through the application of the degradation factors, which will act as data filters grouping together coatings with similar characteristics, this dispersion will be reduced and the different trends in performance over time may become more evident.

Table 1 – Equations for the obtained general degradation curves.

Gompertz	***Potential***	***Weibull***
$D_G = e^{-67{,}98536e^{-0{,}12081t}}$	$D_P = 1{,}54681E^{-6}t^{3{,}30210}$	$D_W = 1 - e^{-(\frac{t}{45{,}54301})^5}$

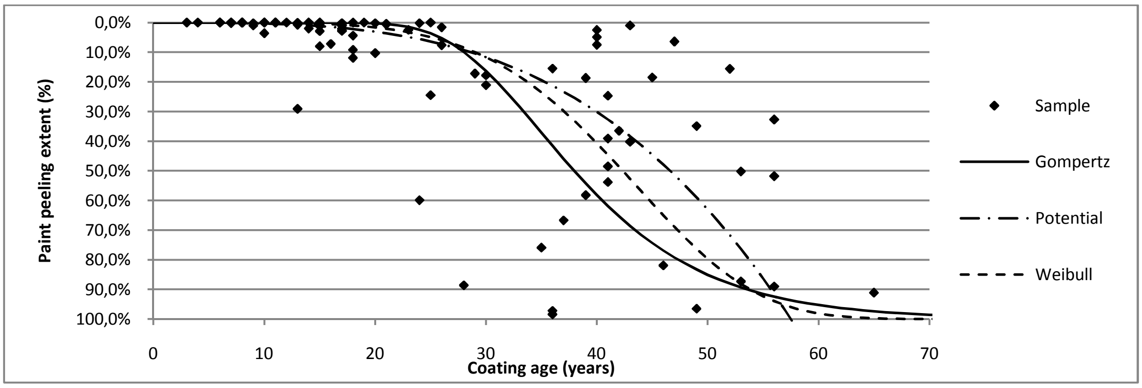

Figure 11 – General degradation graph and degradation curves.

4.2. INFLUENCE OF THE DEGRADATION FACTORS

Applying the degradation factors in order to filter the data makes it possible to observe the effect that those factors have on the performance over time of the paint coatings. This was done with each one of the factors listed previously, either individually or in combination of more than one factor. Degradation curves, of the Gompertz, Potential and Weibull types, were fitted to the obtained degradation graphs.

The following degradation graphs and curves are presented as examples of the type of results that can be achieved with the application of this methodology, since it would be impossible to present here all the results given the significant amount of information that was obtained.

4.2.1. COATING THICKNESS (DF1)

For the analysis of the *coating thickness* degradation factor, the sample was divided according to thickness intervals. The results shown here correspond to a division of the data in two thickness levels, defined as follows:

- Level 1 – film thickness under 400 μm;
- Level 2 – film thickness greater than or equal to 400 μm.

The Gompertz degradation curves obtained are shown in Figure 12, and the equations for all the types of degradation curves are presented in Table 2.

It becomes evident that the coatings in the Level 2 of thickness show a better performance over time (regarding the paint peeling defect) when compared to the Level 1 coatings. This is translated by significantly different values of paint peeling when comparing coatings that present the same age.

Nonetheless, the dispersion shown in the data is still significant, which indicates that even though film thickness is a very relevant factor in the performance over time of paint coatings, there are still other factors that influence the rate at which coatings degrade over time.

Table 2 – Equations for the degradation curves obtained by application of the "DF1: coating thickness" degradation factor.

	Gompertz	***Potential***	***Weibull***
Level 1	$D_G = e^{-74{,}57801e^{-0{,}14159t}}$	$D_P = 2{,}69105E^{-6}t^{3{,}24404}$	$D_W = 1 - e^{-(\frac{t}{40{,}22679})^5}$
Level 2	$D_G = e^{-68{,}84021e^{-0{,}11481t}}$	$D_P = 1{,}71693E^{-6}t^{3{,}24404}$	$D_W = 1 - e^{-(\frac{t}{48{,}75654})^5}$

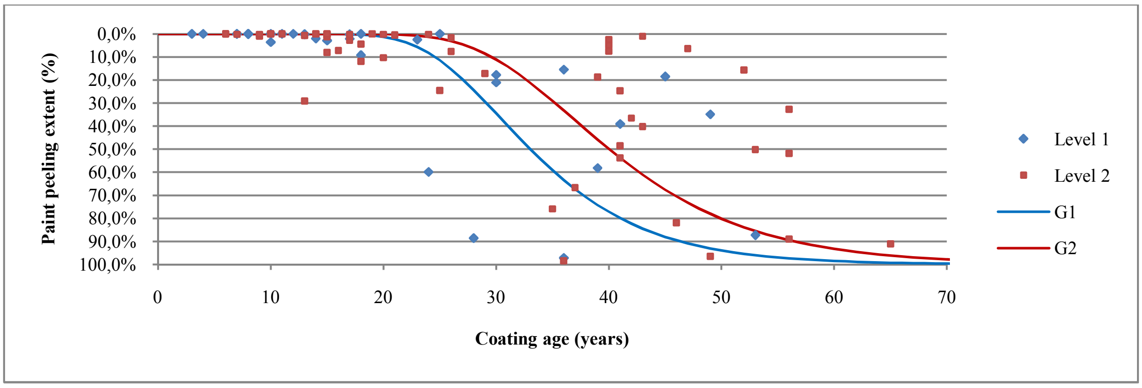

Figure 12 - Degradation curves obtained by application of the "DF1: coating thickness" degradation factor (Gompertz curves).

4.2.2. PAINT BINDER (DF2)

In the paint binder degradation factor analysis, three categories of binders were considered: PVA, acrylic resins and oil-based. The acrylic resins category groups together the acrylic resin binder and the styrenated acrylic resin binder.

The Potential degradation curves obtained in this analysis are shown in Figure 13, and the equations for all the types of degradation curves are presented in Table 3.

The results seem to show that coatings with the acrylic resins binder have the best performance in the initial part of the degradation curves. Given the relatively low dispersion in the corresponding data, especially if we disregard the coating with the highest peeling extent, there is some indication that the general development of the obtained curve might be close to what it should be if there were more coatings in the sample with this type of binder. However, there are very few points presenting a high paint peeling extent, which is a factor that should be considered in the interpretation of this degradation curve.

Table 3 – Equations for the degradation curves obtained by application of the "DF2: paint binder" degradation factor.

	Gompertz	***Potential***	***Weibull***
PVA	$D_G = e^{-15{,}13874e^{-0{,}06690t}}$	$D_P = 2{,}74796E^{-6}t^{3{,}09277}$	$D_W = 1 - e^{-(\frac{t}{56{,}42599})^3}$
Acrylic resins	$D_G = e^{-1086{,}07431e^{-0{,}15705t}}$	$D_P = 1{,}23358E^{-6}t^{3{,}15195}$	$D_W = 1 - e^{-(\frac{t}{49{,}4831})^{11}}$
Oil-based	$D_G = e^{-742{,}13802e^{-0{,}18346t}}$	$D_P = 4{,}62851E^{-7}t^{3{,}61984}$	$D_W = 1 - e^{-(\frac{t}{42{,}24520})^5}$

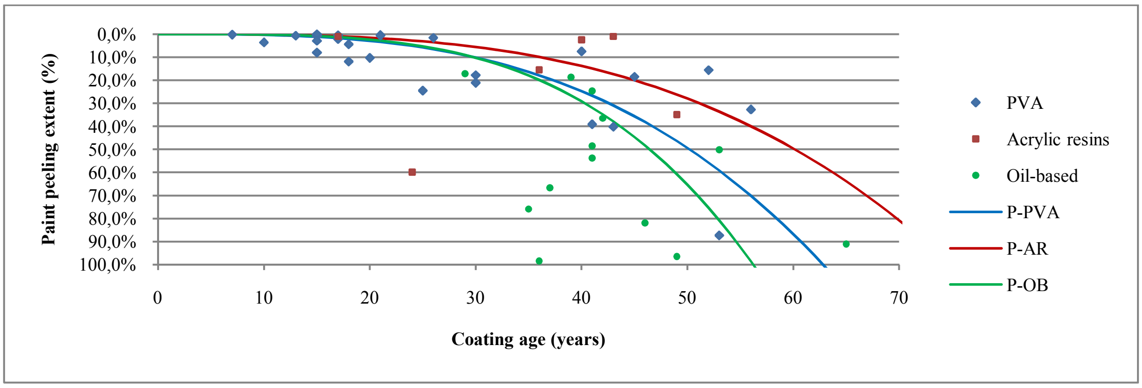

Figure 13 - Degradation curves obtained by application of the "DF2: paint binder" degradation factor (Potential curves).

It's possible to observe that this reduction in the dispersion of the data is common to the other two binder categories. This indicates that this factor is very relevant in its influence to the performance over time of the paint coatings. The results obtained with respect to this, indicate that the PVA binder provides a better performance over time to the coatings when compared to the oil-based binders. The acrylic resins seem to have the best performance, but as was said, the number of coatings in the study sample with this type of binder should be higher in order to confirm this result.

4.2.3. PAINT SURFACE TEXTURE (DF3)

The analysis of the influence of the *paint surface texture* degradation factor led to the degradation graph and curves presented in Figure 14. The equations for these degradation curves are shown in Table 4.

Table 4 – Equations for the degradation curves obtained by application of the "DF3: paint surface texture" degradation factor.

	Gompertz	***Potential***	***Weibull***
Textured	$D_G = e^{-37{,}59611e^{-0{,}08874t}}$	$D_P = 1{,}52406E^{-5}t^{2{,}60016}$	$D_W = 1 - e^{-\left(\frac{t}{51{,}78084}\right)^5}$
Smooth – plastic	$D_G = e^{-62{,}65949e^{-0{,}12391t}}$	$D_P = 2{,}94523E^{-6}t^{3{,}13458}$	$D_W = 1 - e^{-\left(\frac{t}{45{,}13661}\right)^5}$
Smooth – oil	$D_G = e^{-742{,}13802e^{-0{,}18346t}}$	$D_P = 4{,}62851E^{-7}t^{3{,}61984}$	$D_W = 1 - e^{-\left(\frac{t}{42{,}24520}\right)^5}$

The *textured* paint films seem to present the best performance over time of the three texture types. This was an expectable result, since this type of coating is usually considered to have higher resistance to degradation agents and, as a result, improved durability over other *smooth – plastic* paint films. Additionally, if we consider that the average film thickness in *textured* paints is usually higher than the average film thickness of *smooth – plastic* or *smooth – oil* paints, and given the results found concerning the influence of film thickness on the performance over time of coatings, the result presented here is once again what would be expectable.

The *smooth – oil* paint films show the quickest degradation, or the worst performance over time, which justifies the fact that this solution has been practically abandoned in the construction industry.

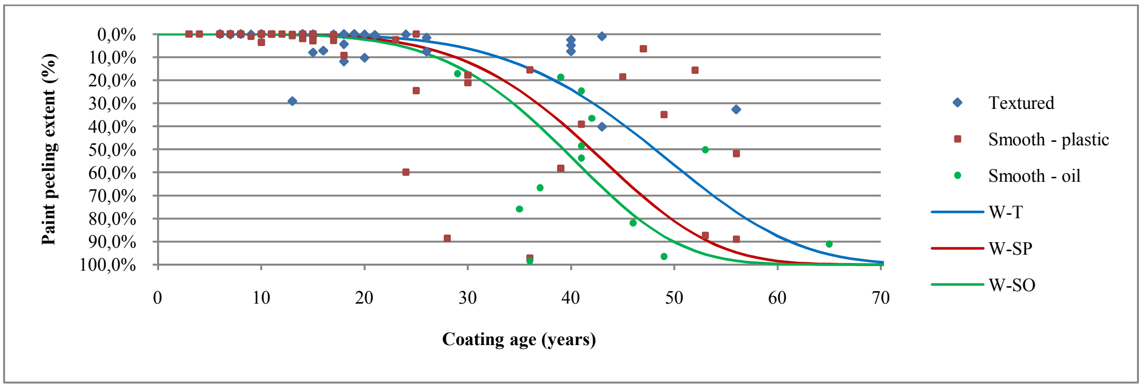

Figure 14 - Degradation curves obtained by application of the "DF3: paint surface texture" degradation factor (Weibull curves).

4.2.4. SUBSTRATE SURFACE PREPARATION (DF4)

The equations for the degradation curves obtained with this factor are shown in Table 5. The curves did not show significant differences in performance over time between the "repaint removing paint" and the "repaint over paint" solutions. The results were affected by a level of dispersion that suggests that the individual application of this factor is not enough to reveal different trends in performance over time of paint coatings, meaning that this factor should be combined with additional degradation factors. This was made, and an example of the results can be seen in 4.2.6.

Table 5 – Equations for the degradation curves obtained by application of the "DF4: substrate surface preparation" degradation factor.

	Gompertz	***Potencial***	***Weibull***
Repaint removing paint	$D_G = e^{-59{,}84923e^{-0{,}12106t}}$	$D_P = 5{,}14940E^{-7}t^{3{,}55740}$	$D_W = 1 - e^{-(\frac{t}{45{,}75069})^5}$
Repaint over paint	$D_G = e^{-81{,}68746e^{-0{,}12152t}}$	$D_P = 4{,}06752E^{-7}t^{3{,}69601}$	$D_W = 1 - e^{-(\frac{t}{45{,}32578})^5}$

4.2.5. SOLAR ORIENTATION (DF5)

The application of this factor revealed that coatings in façades facing North have the best performance over time, whereas coatings in façades facing West have the worst performance over time, followed by coatings in façades facing South. This is a result that is consistent with the levels of average solar exposure in each orientation. The equations for the degradation curves obtained are presented in Table 6.

Table 6 – Equations for the degradation curves obtained by application of the "DF5: solar orientation" degradation factor.

	Gompertz	***Potencial***	***Weibull***
North	$D_G = e^{-13{,}29133e^{-0{,}05828t}}$	$D_P = 1{,}74841E^{-6}t^{3{,}21128}$	$D_W = 1 - e^{-(\frac{t}{50{,}68526})^5}$
South	$D_G = e^{-52{,}04740e^{-0{,}11698t}}$	$D_P = 1{,}91062E^{-4}t^{2{,}10118}$	$D_W = 1 - e^{-(\frac{t}{43{,}33733})^5}$

East	$D_G = e^{-57,32268e^{-0,11399t}}$	$D_P = 3,52976E^{-7}t^{3,62094}$	$D_W = 1 - e^{-(\frac{t}{47,37767})^5}$
West	$D_G = e^{-130,73159e^{-0,16008t}}$	$D_P = 2,97340E^{-7}t^{3,74628}$	$D_W = 1 - e^{-(\frac{t}{41,22525})^5}$

4.2.6. COMBINATION OF DEGRADATION FACTORS

Filtering the data through the simultaneous use of various degradation factors allows for better data segmentation, grouping the paint coatings according to their respective common characteristics, thus providing degradation curves that are better adjusted to each specific coating, given its inherent characteristics, application conditions and degradation agents.

With the current study sample of 100 buildings, the simultaneous application of more than two degradation factors would mean that each data segment would not contain enough buildings for the obtained results to be representative. For this reason, the combination of degradation factors was performed with a maximum of two simultaneous factors.

As an example of the type of analysis performed, and of the results it yields, the combination of the *paint surface texture: smooth – plastic* factor and the *substrate surface preparation* factor is presented. The obtained degradation graphs and curves are shown in Figure 15, with the respective equations being presented in Table 7.

Table 7 – Equations for the degradation curves obtained by application of the "paint surface texture: smooth – plastic" and "substrate surface preparation" degradation factors.

		Gompertz	***Potential***	***Weibull***
Smooth – plastic	***Repaint removing paint***	$D_G = e^{-49,48653e^{-0,10702t}}$	$D_P = 2,22050E^{-6}t^{3,18686}$	$D_W = 1 - e^{-(\frac{t}{48,69103})^5}$
	Repaint over paint	$D_G = e^{-91,85606e^{-0,14933t}}$	$D_P = 4,12906E^{-6}t^{3,15158}$	$D_W = 1 - e^{-(\frac{t}{38,89351})^5}$

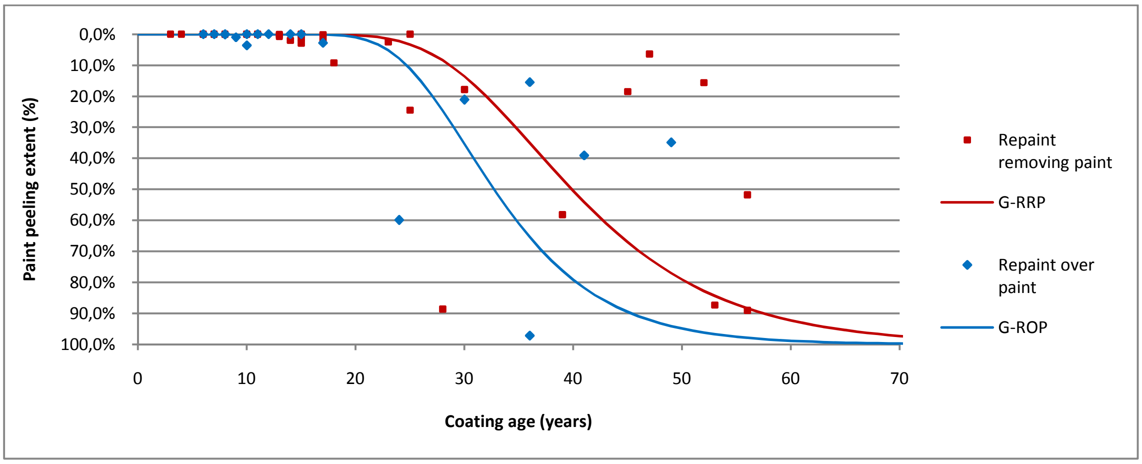

Figure 15 - Degradation curves obtained by application of the "FD3: paint surface texture: smooth – plastic" and "FD4: substrate surface preparation" degradation factors (Gompertz curves).

In the degradation graph shown in Figure 15, it is evident that the surface substrate preparation has a real influence on the performance over time of paint coatings presenting a smooth – plastic texture. In fact, this suggests that these coatings are significantly vulnerable to the lack of care taken in properly preparing the substrate prior to their application. This result is made evident by the improved performance over time of coatings applied directly over the façade render (repaint removing paint), when compared to the coatings applied over previous paint layers (repaint over paint).

5. CONCLUSIONS AND FURTHER DEVELOPMENT NEEDS

A general methodology for the service life prediction of façade paint coatings was presented and tested through its application to a sample of 100 buildings, one coating defect and five degradation factors. This methodology proved to be very effective in providing analytical tools that can be used to make service life prediction for façade paint coatings. These tools consist of the various degradation graphs and degradation curves, which allow for deterministic service life estimates to be made, given that a maximum acceptable degradation level is defined. With these degradation curves it was possible to observe the influence of the five degradation factors considered in the performance over time of paint coatings.

During the course of the research, it was possible to observe that the degradation curves that were most consistent in presenting lower CMSE values were the Gompertz curves. For this reason, Gompertz curves are considered to be the most adequate for the modeling of the performance over time of façade paint coatings, regarding the paint peeling defect, using the presented methodology.

The general methodology presented here can be developed and applied further. It would be very interesting to apply this methodology using coating defects other than paint peeling, such as loss of color, chalking or cracking. This way, it would be possible to perform service life estimates which took into account more than one failure mode, in order to ascertain which would be the determining failure mode in each scenario. The extension of the methodology to include the analysis of more degradation factors would as well be of great interest, given that it would allow a better understanding of the factors that significantly influence the performance over time of paint coatings. In this context, it would be interesting to assess the influence of other external degradation agents, such as pollution levels, façade humidity or driving rain. Finally, a basic way in which this methodology can yield better results is through its application to bigger building samples, so that it becomes possible to perform the data analysis using combinations of three or more degradation factors. This would have the advantage of allowing better data segmentation according to similar coating characteristics, which would provide degradation curves that are better adapted to each type of coating in each type of application context.

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