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Statistical models applied to service life prediction of rendered façades

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ABSTRACT

An approach to the evaluation of the service life of rendered façades applying statistical tools is described. Using multiple linear regression analysis and artificial neural networks, mathematical models are established to estimate the degradation of this type of coating. To devise the models proposed, a sample of 100 rendered façades was subjected to meticulous field work to determine their condition. Some statistical parameters are used to evaluate the validity and efficacy of the models proposed. The service life of the sample of rendered façades is also evaluated, as estimated by the various models, and the result is expressed in histograms. The usefulness of these models to evaluate complex problems, such as the degradation phenomena of rendered façades, is thus demonstrated.

1. Introduction

External coatings play a fundamental role in buildings' performance. They increase the structure's durability, protect it from environmental agents and are very important in terms of aesthetics. Factors that must be taken into account when choosing which coating to use include quality/cost criteria and the conditions it will be subjected to throughout its service life [16].

In Portugal renders are the most common coating type [6] and according to the 2011 Census [18] they represent around 62% of existing solutions. This preponderance is essentially due to its low cost and the relative lack of skill involved in its execution, compared with other coatings [11]. The low investment in this solution, however, often implies unacceptable degradation levels of the façades [9].

Studies related to the durability and service life prediction of this coating type are therefore needed. In this study multiple linear regression (MLR) analysis and artificial neural networks (ANNs) are used to understand in detail the variables that contribute to explaining the degradation phenomena of rendered façades. Mathematical models are then established to describe façade degradation. To that effect a sample composed of 100 rendered façades (with distinct characteristics and degradation levels) was analysed.

2. Background

The service life of a construction element is directly related to the environmental conditions it is subjected to, the quality of the materials used, the workmanship, the service conditions and the maintenance planning [17,19]. An efficient evaluation of the service life must bear in mind these factors and enable the optimisation of inspection and maintenance plans and the implementation of a more rational management of the resources spent on constructions during their service life [25].

Several service life prediction methods have been put forward in recent years. Conspicuous among them are the empirical methods that try to define the degradation condition of coatings over time in real service conditions by resorting to field work [29,31]. Regardless of the sample's size, after the field work is completed a graphical and statistical analysis is performed to define degradation paths which relate the loss of performance of the elements to their age [7,30].

The service life prediction model proposed by Gaspar and de Brito [12] and Gaspar [13] contains a quantitative index that depicts the global performance of any construction element. This degradation severity index is obtained as the ratio between the extent of the façade degradation, weighted as a function of the degradation level and the severity of the anomalies, and a reference area, equivalent to the maximum theoretical extent of the degradation for the façade in question, as seen in expression (1).

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

where: S_w — normalised severity of de gradation of the façade, as a percentage; A_n — area of coating affected by an anomaly, in m^2; k_n — anomaly's “n” multiplying factor, as a function of its condition (between 0 and 4); $k_{a,n}$ — weighting coefficient corresponding to the

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relative importance of each anomaly ($k_{a,n}$ R^{+}) (if no instructions are provided, it is assumed $k_{a,n}=1$); k — weighting factor equal to the highest degradation level in the façade; A — total area of the cladding, in m^2.

Therefore this indicator takes into account both the degraded area of the coating, affected by the various anomalies, and the severity level of the anomalies, also referred to as 'condition'. The anomalies are classified in terms of condition through a weighting factor (k_n) using a discrete scale of values from the best condition (level 0 — absence of visible degradation) to the worst (level 4 — extensive degradation or loss of functionality).

Gaspar and de Brito [14] used the current market cost of repair techniques associated with the various anomalies as a ratio of the cost of executing a new render in order to obtain different weights for the anomalies. These are presented in Table 1, where it is clear that the anomalies' repair costs match their gravity, as found empirically.

The Gaspar model [13] was used as a general framework for the service life prediction methodology for façade coatings. This approach was later applied to adhered ceramic cladding [2] and stone cladding [32].

2.1. Field work

100 current external renders were analysed. The data on façade degradation was collected during field work. Complementary information (location, drawings, documentation from Town Halls, and other relevant data) was collected in advance to put each case study into better perspective. Furthermore, an inspection and diagnosis file was produced where data were grouped into categories: façade condition, and additional durability-related data.

Data on façade condition implied:

- A detailed survey of the façade's size;
- A list and description of the anomalies detected, their extent within the façade and their location;
- The analysis of the probable causes of each anomaly;
- A list of the diagnosis means and inspection techniques used to collect data;
- The definition of the gravity of the anomalies detected to be used later in the degradation models.

Additional data to study façade durability included:

- Identification number of the case study;
- Location of the building (distance from the sea or roadways);
- Date and nature of the last intervention on the façade;
- Construction size, the colour and texture of the surface;
- Potential critical points in the façade (balconies, protruding elements, flowerbeds, sills);
- Orientation and degree of exposure of the façade surfaces;
- Materials' characteristics (render type);
- Design factors (protection of the render at the façade's top and near the ground, copings and window drips);
- Level of detailing and execution;
- Climatic characteristics (wind/rain combination, exposure to damp, temperature);
- Type and frequency of use (items such as the ownership: private companies — commercial or institutional, individual citizens, mixed ownership or dwelling for rental).

Besides the data collected through visual observations, the users and owners of the buildings inspected were also surveyed.

When statistical tools such as MLR or ANN are used to describe complex phenomena, the size of the sample is of major importance. In this study these statistical tools were applied to a sample of 100 façades. Even though the sample may be small from a statistics standpoint, in reality it is considered very significant given the complexity and length of time spent on each façade.

3. Use of multiple linear regression in the service life prediction of coatings

Regression analysis is one of the methods most frequently used to study the behaviour of a dependent or endogenous variable, relative to other variables (predictors), which are responsible for the way the first performs. Regression analysis is not always needed for prediction or explanatory models; sometimes the intention is only to adjust a regression equation to available data. In fact King [20] argues that the objective of a regression analysis is simply to measure the effects of predictors on the dependent variable.

MLR analysis can be a very useful tool in service life prediction models for façade coatings. It can determine which factors influence the service life. A Silva et al. [33] analyses service life prediction of stone cladding with this tool. Similarly, in this study MLR is used to determine the predictors that most significantly contribute to explain the degradation of rendered façades. SPSS software (Statistical Package for Social Sciences) was used.

The MLR analysis included in the model 15 predictors relating to the characteristics of the coatings under analysis, namely: render age, render type, façade colour, building height, building volume, detailing/design level, eaves' protection, platband copings, balcony copings, ground floor protection (socle), façade orientation, distance from the sea, exposure to damp, distance from pollution sources, and façade protection level. The dependent variable (S_w), the façade's degradation severity, is given by Eq. (1).

To perform this regression analysis it was necessary to quantify the qualitative variables. Table 2 presents the choices made, which resulted from the analyses of the case studies. These factors were initially obtained through the relationship between the overall degradation path (from which the reference service life for the whole sample was defined) and the degradation paths associated with each specific characteristic of the façades, from which the estimated service life for each characteristic is obtained. The factors considered are then adjusted through an iterative process (function of statistical acceptance criteria), aiming at the scenario that best portrays the cases analysed in the field work.

The Stepwise method was used to select and build the regression model, including only the statistically significant predictors. The basic hypotheses behind the regression analysis were revised and their statistical significance was ensured, thus eliminating the multicollinearity effects which occur when predictors explain each other, jeopardising the whole multiple regression analysis [23].

Table 1
Relative weights of the anomalies in rendered façades ($k_{a,n}$).

Degradation level	Stain		Cracking		Loss of adherence	
1	$k_{a,n}=0.12$	2.50€/m^2	$k_{a,n}=0.95$	20.50€/m^2	$k_{a,n}=1.53$	33.00€/m^2
2	$k_{a,n}=0.53$	11.50€/m^2	$k_{a,n}=0.95$	20.50€/m^2	$k_{a,n}=1.53$	33.00€/m^2
3	$k_{a,n}=0.53$	11.50€/m^2	$k_{a,n}=1.12$	24.00€/m^2	$k_{a,n}=1.53$	33.00€/m^2
4	$k_{a,n}=0.53$	11.50€/m^2	$k_{a,n}=1.53$	33.00€/m^2	$k_{a,n}=1.53$	33.00€/m^2