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Durability of current renderings: A probabilistic analysis

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ABSTRACT

The durability of constructions is essential to the quality of life in urban spaces. Recently there has been a growing concern of the construction stakeholders with the durability of the materials used and construction sustainability. In this study, using a multinomial logistic regression technique, a probabilistic analysis of the degradation condition of rendered facades, as a function of age and type of mortar, is performed. The probability of the rendered facades reaching the end of their service life, i.e. the moment after which they no longer comply with the minimum performance requirements, is also evaluated. To that purpose, a sample of 100 case studies located in Lisbon, whose degradation state is determined by in situ visual inspections, is used.

1. Introduction

The building stock represents more than 50% of the national wealth of the developed countries [21]. However, it is frequently very deteriorated since for many years a stance of "build and let it be" has been adopted [12]. Presently, the degradation of buildings and their components has become a complex problem from the economic, cultural and environmental points of view.

If no maintenance is performed, or if it is incorrectly planned, this will contribute to the loss of performance of buildings over time, until the minimum performance requirements cease to be complied with — end of the service life [13]. The definition of these requirements is quite subjective and depends on technical, economic and social issues [24]. An empirical study led by Aikivuori [1] shows that in only 17% of the cases did the decision makers define the maintenance actions as a function on the building's deterioration. The author states that the maintenance actions have been influenced by a subjective perception of the decision-makers, and that they rarely depend on technical or economic rational factors.

One way of optimizing the planning of the maintenance actions of buildings is to understand the way their elements degrade and the stage beyond which they must be intervened [30]. Without that information high costs are usually generated (associated to unrequired interventions or urgent repairs), which could be prevented.

Therefore there is a need for tools that evaluate the degradation of construction elements over time, allowing the estimation of the moment when action is needed. In this study a probabilistic analysis of the degradation condition of rendered facades as a function of time and mortar type is proposed. A sample of 100 case studies located in Lisbon is used, whose degradation state is determined through in situ visual inspections. The probability of the rendered facades reaching the end of their service life, i.e. the moment after which they no longer comply with the minimum performance requirements, is also studied. To that effect a logistic regression technique is used, a statistical technique frequently used in various areas of the scientific knowledge.

2. Background

In Portugal renders are the commonest coating type [7] and according to the 2011 Census [27] they represent around 62% of the universe of coatings. This preponderance is essentially due to its low cost and the relative lack of skill involved in its execution, compared with other coatings [8]. However this type of coating often displays high degradation levels that affect the built environment [29].

For renderings, as well as for other construction elements, it is found that the diagnosis of the causes or degradation factors is not easy, given the variability of the possible sources of each anomaly [11]. According to ISO 15686: 2000 [14], the factors that most significantly contribute to the durability of construction elements are: i) the materials quality; ii) the design level; iii) the execution level; iv) the environmental conditions; v) the in-service conditions; and vi) the maintenance level. Even though all of these factors are unquestionably relevant, the extent to which a rendering is affected by the degradation factors depends substantially on the mortar's properties [15].

In this study the degradation of 100 rendered facades is analysed based solely on in situ visual inspections. This type of data collection is

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an alternative to accelerated ageing laboratory tests that do not always provide a clear correspondence with the complex phenomena involved in the degradation process of construction elements, under real in-service conditions [18]. The exact composition of the renders in each case study was not determined here essentially due to the following reasons: i) amount of time and resources needed to perform lab tests in such a large sample; ii) these tests would imply the use of destructive techniques on the renderings analysed that are still in service; and iii) since the mortars' composition changes over time due to hydration and carbonation phenomena, their properties are usually improved during its service life and therefore data collected would not be fully representative [17].

Due to this limitation renderings were simply classified in four groups in terms of mortar type [10]:

i) Lime–cement renderings (Fig. 1a) — made of a mix of cement and lime, usually applied in several coats over the substrate; this rendering is more common in buildings from the first half of the XX century;
ii) Current cement renderings (Fig. 1b) — made essentially of cement, applied in several coats over the substrate, with a smooth or rough finish; they are the commonest rendering type [6];
iii) Renderings with crushed marble (Fig. 1c) — similar to current cement renderings, they contain coarser aggregates that confer a rough finishing; this rendering type was particularly trendy in the 50s and 60s of the XX century;
iv) Single-layer renderings (Fig. 1d) — rich in cement and usually manufactured premixed, they are applied in a single layer; this rendering type started being amply used since the 90s of the XX century.

For simplification purposes, in the sample analysed no historical buildings were included. The case studies are mostly composed of current cement renderings (60%), followed by lime–cement renderings (21%), single-layer renderings (13%) and renderings with crushed marble (6%).

The sample analysed are located in Portugal and are subjected to the following climatic conditions: i) no freeze–thaw cycles; ii) in Portugal, the most aggressive directions are usually north, because greater humidity is combined with fewer hours of sunshine, and west, because of strong solar exposure leading to temperatures that may affect the coatings [10]; iii) the sample analysed are subjected to annual temperatures between 15 and 17.5 ºC; iv) the areas studied correspond to levels of average annual rainfall between 400 mm and 600 mm; and v) most of the sample has an average relative humidity between 70% and 75%. Thus, at a macroclimatic level, it can be said that the cases analysed are located in a temperate climatic zone subjected to the influence of the proximity of the sea, with the classification "CSa" in the Köppen–Geiger system — updated with the climatic data for the second half of the 20th century [16].

Defects are thus characterized and classified according to a scale of discreet variables that range from "0" (no visible degradation) to "4" (generalized degradation leading to immediate corrective action). Each degradation condition is associated with a qualitative scale (based on the evaluation of the physical and visual conditions of the sample analysed) and a quantitative index that depicts the global performance of the facades. This quantitative index, proposed by Gaspar and de Brito [9] and Gaspar [10] is obtained as the ratio between the extent of the facade 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 facade in question, as seen in Eq. (1) [29].

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

where: S_w — weighted severity of degradation of the facade (%); 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 relative importance of each anomaly ($k_{a,n}\ \ R^+$) (if no further data are provided, it is assumed that $k_{a,n} = 1$); k — weighting factor equal to the highest degradation level in the facade; and A — total area of the cladding, in m^2.

Table 1 shows the correlation between the maximum level of degradation and the condition of the facades inspected.

3. Multinomial regression

There are different models that allow establishing an empirical relation between variables. To know the relationship between an independent qualitative variable and categorical (factors) or numerical (covariate) independent variables, one must use categorical regression [32]. This regression analysis has different definitions according to the dependent variable to be modelled. When the dependent variable is nominal (dichotomous) categorical regression is called logistic regression, a statistical technique used in the definition of prediction models [5]. Logistic regression can also be expanded into multinomial logistic regression, which is used when the dependent variable is nominal (polytomous). Unlike binary logistic models in which the dependent variable is a binary choice, normally the presence or absence of a given characteristic, in multinomial logistic regression there may be more than two choices (the dependent variable has more than two mutually exclusive classes) [34]. In short, this statistical technique describes the relationships between a categorical target variable (dependent or criterion variable) and the explanatory variables (independent or predictor variables) in terms of the probability of a given event [36].

The function used in the logistic regression to estimate the probability of a given realization j ($j = 1, \ldots, n$) of the dependent variable being a "success", $P[Y_j = 1] = \hat{\pi}_j$, is the logistic function whose generic form, for

Fig. 1. Examples of the types of mortar in the rendered facades analysed: (a) lime–cement mortar; (b) current cement mortar; (c) mortar with crushed marble; and (d) single-layer mortar.