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Methodology for service life prediction of architectural concrete facades

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HIGHLIGHTS

- The service life of architectural concrete facades is evaluated based on visual inspections.
- 174 facades were analysed as well the factors that influence their degradation.
- Concrete facades with high exposure to damp and near from the sea are less durable.
- Light-coloured facades, protected from rain and with varnishing are more durable.
- The information provided is crucial to establish rational maintenance plans.

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ABSTRACT

In this study, a methodology for the service life prediction of architectural concrete facades is proposed, following a research line previously developed for other types of claddings, to evaluate their durability. The methodology developed is based on the collection of data in visual inspections. In this study, 174 facades were analysed, during the fieldwork phase, through a survey of the different degradation phenomena. This information is used to define degradation curves, which graphically express the loss of performance of architectural concrete facades over time, evaluating the influence of the degradation agents, allowing estimating a reference service life for this type of coating. The model proposed in this study leads to acceptable and consistent results, adequately translating the degradation observed in reality. However, for some characteristics of architectural concrete facades, it is not possible to obtain unequivocal conclusions, which reveals the high susceptibility of these coatings to the aggressive environmental agents, e.g. sea salts, which act simultaneously on the facade, hindering the determination of the separate influence of these characteristics on the degradation found. This study intends to give a contribution to the service life prediction of exterior facades, allowing defining rational maintenance plans and reducing the costs associated to the buildings refurbishment during their life cycle.

1. Introduction

Concrete is the most common type of processed material used in construction [1]. In the last decades, concrete's durability has gained special relevance within the scientific community. Several studies have concerned concrete's durability, mostly about steel corrosion, alkali-aggregate reaction, sulphate attack, freeze-thaw and its durability in marine environment and all other environmental factors [2]. However, there is a lack of knowledge regarding the analysis of the degradation phenomena of architectural concrete when applied as an envelope solution.

Therefore, this study addresses the durability and service life of concrete facades in service conditions, analysing different types of solutions in which reinforced concrete is used as a coating element, with different surface treatments, such as polish or painting. The types of solutions analysed comprise: prefabricated concrete panels; cast *in situ* concrete elements; and a concrete layer applied over the substrate.

Concrete facades are widely used as a surface finishing solution due to the protection it offers to the building's structure against aggressive agents (environmental, physical, chemical and mechanical) [3]. This type of surface also offers a high aesthetical potential since it allows many finishing options [4,5]. In fact, architectural concrete can be seen as a durable solution, requiring low maintenance efforts during its life cycle [6]. Furthermore, this type of surface must be capable of fulfilling the target mechanical, physical, durability, and visual requirements [5], also presenting good

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thermal, acoustic and fire-resistant properties. According to Freedman [4], architectural concrete as cladding solution also reduces the propensity for differential settlement as it stiffens the perimeter foundations of the building. Furthermore, this solution is the most adequate to blast-resistant buildings, due to its ductility and capacity to dissipate energy [7].

However, concrete is a material that, as many others, degrades over time, as soon as is put into use. Some anomalies (e.g. efflorescence, discolouration) occur due to a weathering process, induced by environmental agents, such as temperature, solar radiation and rain, among others. In other cases, degradation can occur due to mechanical or physical actions (e.g. cracking). Also, the degradation of architectural concrete can occur due to an inadequate choice of materials or to design/execution errors. Consequently, architectural concrete must be prescribed adequately, considering the factors that most influence its degradation, to prevent its premature deterioration [8]. Often, execution errors, due to unskilled workmanship, can negatively influence its degradation, especially when these errors leave voids on the surface (e.g. honeycombing), due to an incorrect vibration, allowing the penetration of aggressive agents into the concrete's matrix.

In fact, there are several factors that influence the deterioration of concrete surfaces. Therefore, the service life of architectural concrete facades varies significantly according to its characteristics, thus leading to different plans of maintenance and repair of the surface [9]. It is thus important to understand the architectural concrete facade's degradation phenomena, which allows defining maintenance plans, to fulfil the performance requirements during its service life, intending to reduce repair costs and to decrease waste generation [10].

Currently, there are several studies related with the service life prediction of coatings and other elements of the building's envelope [11–13], namely exterior natural stone cladding, current renderings, adhesive ceramic tiling systems, painted surfaces and external thermal insulation composite systems (ETICS). Therefore, it also seems relevant to analyse the durability of architectural concrete when applied as a finishing surface, since this type of coating is becoming increasingly used internationally and there is a lack of knowledge regarding its durability, its pathology and the influence of degradation agents on its physical and visual deterioration. In this study, a service life prediction model for architectural concrete facades is proposed, based on visual inspections to 174 architectural concrete surfaces located in Portugal, considering their degradation condition, their characteristics, exposure and use conditions. Based on this information it is possible to estimate the service life of architectural concrete facades, interpreting the various weathering factors that influence the degradation of this type of coating over time. By evaluating these weathering factors, it is possible to extend the durability of architectural concrete facades, since the degradation mechanisms are already understood and their impacts can be reduced with regular inspections and rehabilitation actions. Furthermore, the information provided by this study is extremely relevant to establish the periodicity and scheduling of maintenance actions, reducing unnecessary costs.

2. Background

Despite being a complex issue, predicting the service life of buildings is a very interesting and changeling task. Presently, many authors have studied and proposed inspection and maintenance plans [10,14,15] for building's components, allowing reducing repairs' costs, optimizing the use of scarce resources. To elaborate these types of plans, it is necessary to understand the degradation's phenomena, in which way the loss of performance of the buildings occurs over time, and which the most relevant parameters to promote the degradation of their elements are.

The end of service life is not an unequivocal concept, e.g. ASTM E362-82 [16] defines the service life of a building or an element as the period of time, after installation, during which all its properties exceed the minimum acceptable requirements, assuming regular maintenance procedures. The Architectural Institute of Japan [17] refers that this concept can be defined as the period of time, in years, until a building or its elements, equipment or parts reach a certain level of degradation, in regular circumstances of design, construction, using and exposure to environmental elements.

Therefore, to standardize this concept, ISO 15686-1: 2000 [18] was developed and it is nowadays the most important reference on service life prediction [19]. This standard defines that service life planning is a process developed during the design of a building, which tries to ensure that a building's service life equals or exceeds the designed service life, considering the service life costs of that same building.

The service life can be predicted according to deterministic methods (e.g. factor method and graphical method), probabilistic/stochastic methods (e.g. Markov chains) and engineering methods (e.g. Failure modes effects analysis – *FMEA*, Failure mode effects and criticality analysis – *FMECA*, and Performance limits methods – *PLM*) [11,20–23].

The deterministic methods are based on the construction elements' degradation factors and on their acting mechanisms. A given weight is assigned to each of these factors, posteriorly incorporated in formulas that express these mechanisms' actions over time.

Among the deterministic methodologies, the factor method, initially developed by the Architectural Institute of Japan (in 1993) and described in ISO 15686-1: 2000 [18], is the most widely used and accepted method, being considered as a general framework for service life estimation of building components. According to this standard, it is possible to estimate the service life (*ESLC*) of a building or its elements, based on a reference service life (*RSLC*), usually the expected service life under normal conditions of use, and on several factors related to the in-use conditions. The factors used in this method are: *A* (components' quality); *B* (design level); *C* (work execution level); *D* (indoor environment); *E* (outdoor environment); *F* (in-use conditions); and *G* (maintenance level). Each one of these factors, or a combination of them, can affect the building's service life. This method can be expressed by a mathematical formula – Eq. (1). Thus, the factor method allows estimating the service life of a building, based on the previous knowledge of its reference service life [20,24].

$$ESLC = RSLC \times factor\ A \times factor\ B \times factor\ C \times factor\ D \times factor\ E \times factor\ F \times factor\ G \quad (1)$$

Despite being widely used in the construction sector, this method has been criticized by several authors, who describe the following limitations [20,22,24,25–27]: (i) this method only gives an empirical estimation of the service life, since it depends on the available information, not providing any information regarding the accuracy of the estimation of the service life of the element under analysis (not providing any dispersion measures or the error of estimation of the model); (iii) it is not expected that the designers have all the necessary information to decide which factors have more influence on the building's service life; (iv) this method strongly depends on the values adopted for the durability factors, since it has a high sensitivity when there are subtle variations of the data; (v) this method does not provide a definition of the factors that should be included in the model, or how these factors could be quantified; and (vi) it is an overly simple method to describe the complex degradation's phenomena.