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Methodology for the service life prediction of ceramic claddings in pitched roofs

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HIGHLIGHTS

- The service life prediction of pitched roofs' ceramic claddings is modelled.
- The methodology is validated based on a visual inspection campaign.
- 85 buildings and 146 claddings are analysed, with a total area of 43,991.6 m^2.
- The evolution of the degradation condition of pitched roofs is quantified.
- Various degradation patterns are established based on the roofs' characteristics.

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ABSTRACT

Currently, the built heritage presents clear signs of degradation, requiring in some situations an urgent intervention. The majority of defects can be avoided or mitigated at the design and execution stages, but the designers and stakeholders often neglect the maintainability of the buildings and components, thus compromising their performance and durability. It is thus necessary to adopt an integrated approach during the buildings life cycle, evaluating their performance over time, the influence of the degradation agents and mechanisms on their durability and service life, and the adoption of cost-effective maintenance strategies. In this sense, it is crucial to use quantitative information related with the performance of building components over time. This study intends to respond to this need by proposing a methodology for the service life prediction of pitched roofs' ceramic claddings, which are the most common type of roofing system adopted in Portugal and in many countries around the world. These elements are one of the most vulnerable in a building, more exposed to the degradation agents, and with a higher incidence of defects. The method proposed is validated based on a visual inspection campaign, performed in 85 buildings and 146 claddings located in Portugal, with a total area of 43,991.6 m^2. Various degradation patterns are established based on the roofs' characteristics, evaluating their influence on the roof claddings' service life. The proposed methodology allows obtaining coherent results, providing relevant information regarding the pitched roofs ceramic claddings' service life, aiding the adoption of rational and integrated maintenance strategies.

1. Introduction

The loss of performance of buildings and components occurs gradually over time, leading inevitably to the occurrence of defects and failures and, consequently, to the inability of buildings to fulfil the uses and requirements for which they were designed. Currently, many European cities present clear signs of deterioration, requiring, in some situations, an urgent intervention. The current deteriorating condition of the built stock is a direct consequence of a "build and let decay" approach, which was adopted during the last decades [1]. The inexistence of proper maintenance strategies and policies created an enormous economic, cultural and environmental problem [39].

Therefore, it is crucial to establish and implement serious and effective maintenance policies to promote the rehabilitation and

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revitalization of European building stock and infrastructures [23]. Typically, maintenance actions are carried out based on previous experience or put forward as "reasonable", without comparing different maintenance strategies [32]. This approach does not necessarily lead to the most cost-effective solution or to a satisfactory long-term performance of buildings and components [25]. It is thus necessary to adopt and implement a more rational planning of maintenance actions, as a consequence of a need for intervention conditioned by scarce financial resources, compelled by social and environmental concerns [38].

Service life prediction is the most adequate procedure to estimate the maintenance, repair, and replacement needs of a building component over its life cycle [20,69]. The predicted service life of buildings and components is a high-valued piece of information to support decisions in property management; moreover, it is a key element in appraising different maintenance alternatives based on their long-term costs [41,50]. In fact, the optimization of maintenance plans and the informed evaluation of the most advantageous solution requires a reliable knowledge regarding the performance of the component under analysis over time, and the dynamic interaction between them and the surrounding environment, identifying the relevant degradation agents [68].

In this sense, the availability of service life prediction methodologies, based on the deterioration patterns of building components over time and according to the relevant degradation factors, it is fundamental for the definition of any maintenance programme [54,73,43]. Murta et al. [51] refer that in several situations, the buildings' deterioration present similar patterns and evolution, usually starting from the buildings' roof. In fact, the roof is the most vulnerable element of a building, since it is more exposed to the deterioration agents, thus presenting a higher incidence of defects [28,75]. Nevertheless, there is a lack of standardized approaches to service life prediction of roofing systems, essentially due to the lack of reliable methods to model the degradation mechanisms affecting the roofing systems [44].

Therefore, this study intends to develop a methodology to predict the service life of pitched roofs with ceramic tiles as external cladding. The service life method proposed in this study is validated through a visual inspection campaign, performed in 85 buildings and 146 claddings located in Portugal, with a total area of 43,991.6 m^2. The methodology encompasses three main stages: i) the combination of the information collected during the fieldwork, related with the defects observed, into a numerical index that reflects the overall degradation condition of the element under analysis, which allows identifying a degradation pattern of the pitched roofs with ceramic claddings over time; ii) the specification of the minimum acceptable degradation level; and iii) the determination of the estimated service life of pitched roofs' ceramic claddings according to their characteristics. This methodology allows obtaining coherent results, providing very relevant information to aid the adoption of adequate maintenance programs, allowing optimizing human and financial resources during the buildings life cycle.

2. Background

The roofing system is the most vulnerable and critical element of a building [57]. During its life cycle, the building's roof and, in particular, its cladding system, is subjected to severe environmental factors such as the direct incidence of solar radiation, with extreme and variable temperatures in the roof's cladding surface, the incidence of wind, rain and, in some situations, snow, and the action of biological and chemical agents [27,51]. In addition to aggressive environmental agents, inadequate design, choice of materials, use conditions and lack of maintenance are also responsible for the extensive deterioration of roofing systems, as well as the occurrence of premature defects and early failures [43].

According to the American Association of Roofing Contractors [55], the building's roof (and in particular, its cladding system) represents one of the most important and largest investments in buildings, given the need to be durable, ensuring a watertightness and thermal insulation function under the specific conditions it is subjected during its service life. However, in some situations, the roofs are considered as an unsightly part of the building, and since they are not always visible, the investment made during the construction phase and in the implementation of adequate and periodic maintenance policies is scarce, leading to serious problems, compromising the structural integrity of the buildings and the users' safety [35]. Consequently, the collapse of roofing systems still occurs worldwide [9,11], thus revealing a need for reliable tools to understand the deterioration mechanisms and causes, translated into numerical models to portray the degradation of roofing systems over time and to predict their estimated service life according to their specific characteristics, thus allowing adopting technical solutions to mitigate the risk of failure of roofing systems [58].

Therefore, as the most exposed "skin" of buildings it is then crucial to understand the deterioration of the roofing systems' claddings. In this sense, this study proposes a methodology to predict the service life of pitched roofs' ceramic claddings, through the analysis of their evolution of degradation over time and according to their characteristics. Pitched roofs are the most common type of roofing systems in the residential building stock, which justify some efforts in the definition of adequate maintenance policies, which requires knowledge regarding the durability and service life of these roofing systems [71]. Moreover, ceramic tile claddings are the most frequent pitched roofs cladding solution in Portugal [15], as well as all Latin countries, which explains the selection of pitched roofs' ceramic claddings as the aim of this study. The preference for adopting ceramic tiles as a cladding solution for pitched roofs is based on their advantages, compared to other cladding systems, namely: different architectural styles due to the diversity of shapes and accessory parts; the quality and high durability of ceramic tiles; good performance against the actions of atmospheric agents; and raw material at a reduced cost. The Portuguese market has a large variety of ceramic roof tiles, with several options in terms of shape, colour and texture. They are distinguished mainly by their coupling system and geometry. The most common types are Portuguese (or *lusa*), Marseille, cap, roman and flat roof tiles, integrating the pitched roofs of most traditional buildings, residential and commercial current buildings, former industrial buildings, churches and pavilions.

3. Dataset collection

3.1. Description of the sample

In this study, a sample of 85 buildings and 146 claddings is analysed, with a total area of 43,991.6 m^2. The dataset is located in Portugal, in centre and south regions of the country, and the buildings analysed are owned by the Portuguese Air Force. 40.4% of the sample corresponds to claddings in service buildings, 38.4% to claddings in residential buildings, 10.3% to claddings in buildings with other uses (e.g. warehouses or workshops), 6.2% to buildings that are both services and residential and 4.8% to churches.

To model the service life of ceramic claddings of pitched roofs, a heterogeneous sample is selected, in terms of the age of the claddings. The effect of maintenance actions is not encompassed in the proposed service life prediction model and, therefore, the age