Green Energy and Technology

Ana Silva
Jorge de Brito
Pedro Lima Gaspar

Methodologies for Service Life Prediction of Buildings

With a Focus on Façade Claddings

Springer

Green Energy and Technology

More information about this series at http://www.springer.com/series/8059

Ana Silva · Jorge de Brito
Pedro Lima Gaspar

Methodologies for Service Life Prediction of Buildings

With a Focus on Façade Claddings

Springer

Ana Silva
Instituto Superior Técnico
Universidade de Lisboa
Lisbon
Portugal

Pedro Lima Gaspar
Faculty of Architecture
Universidade de Lisboa
Lisbon
Portugal

Jorge de Brito
Instituto Superior Técnico
Universidade de Lisboa
Lisbon
Portugal

ISSN 1865-3529 ISSN 1865-3537 (electronic)
Green Energy and Technology
ISBN 978-3-319-33288-8 ISBN 978-3-319-33290-1 (eBook)
DOI 10.1007/978-3-319-33290-1

Library of Congress Control Number: 2016937506

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

Contents

Chapter 1
Introduction

1.1 Introduction

Buildings are complex systems composed of several elements, which are assembled to respond to a number of needs—functional and symbolic—according to set of legal and environmental requirements and to potentially accommodate users with different levels of demand (Kyle 2001). In fact, many expectations are created around constructions; according to Allen (1995), buildings have to fulfil safety requirements, protecting users from the exterior environment, providing privacy and security to people, connecting them to the outside world through doors and windows. Furthermore, construction elements are designed to be used for a certain period of time (their service life), performing all the functions for which they were designed without excessive maintenance costs. However, buildings and their components initiate an inevitable degradation process as soon as they are put into use and progressively lose their performance capacity over time.

For a long period of time, the construction industry was only concerned with minimizing the initial costs and there were no practical and reliable methods for service life prediction or for management of the maintenance of buildings throughout their life cycle (Lounis et al. 1998). Currently, due to the progressive degradation of the built heritage and the high costs associated with their construction, maintenance and repair, the study of the durability of buildings and their elements has been assuming an increasingly important role (Beer et al. 2011). This growing interest is due to several factors, including: (a) the interest shown by the owners to establish requirements for the service life of structures during the design stage; (b) awareness of the stakeholders in the construction sector that the quality and global costs of buildings comprise both the construction costs and the maintenance and repair costs; (c) the knowledge that durability is a key part of the quality and performance of the construction elements; (d) the awareness that the

A. Silva et al., *Methodologies for Service Life Prediction of Buildings*,
Green Energy and Technology, DOI 10.1007/978-3-319-33290-1_1

visual appearance and the ageing of the structures contribute to their loss of performance (DuraCrete 2000); (e) the awareness of the owners and insurers that the failure of construction elements has implications not only on the building's performance but also may cause serious damage to users (in this context, it becomes very important to evaluate the risk of failure of construction elements, their main mechanisms of failure and the impact/severity of rupture).

Besides the reasons mentioned above, service life prediction also assumes an important role in the economic and environmental sustainability of the construction sector. In fact, the knowledge of the service life of building elements is necessary in order to apply economic analysis tools, such as LCC (life-cycle cost), a methodology that accounts for the total cost of building elements during their life cycle (Lounis and Daigle 2008). Likewise, in environmental terms, there are tools such as LCA—life cycle assessment that quantify the environmental impacts of materials and construction processes throughout the building's life cycle (Optis and Wild 2010). However, currently, various studies in the literature that apply LCC and LCA tools do not adequately contemplate the service life of the construction elements, using instead standard values (Adalberth 1997; Keoleian et al. 2001; Thormark 2002); generally, these studies apply an average service life value for a given building element, without considering the specific conditions that it will be subjected to, thus introducing additional uncertainty—or errors—in the analysis (Aktas and Bilec 2012). Time and again, it has been suggested that LCA and LCC analyses need to apply realistic service life data, adjusted to the construction element under analysis (Grant et al. 2014). However, the service life of any given element may vary significantly from building to building, since each building is a prototype that responds to unrepeatable conditions. Therefore, service life prediction models intend to express degradation patterns not so much directed to a specific building, but identifying the common points between different buildings, according to a number of key characteristics, degradation mechanisms and established performance requirements.

A survey conducted by Brisch and Englund (2005) to a group of researchers, standardization committees, universities, manufacturers, associations and consultants related to the construction area revealed that 63 % of the experts surveyed believe that service life prediction methods are extremely important and only 6 % consider that these models are not relevant. However, when considering the use of these methods, only 40 % use this type of methodologies and 13 % assume that they are totally ignorant on this subject. To make matters worse, data related with the durability and service life of buildings and materials are not even included in the majority of the architecture and construction projects. Therefore, even though the usefulness of the service life prediction methodologies is widely accepted in the scientific community, their application is still incipient. Furthermore, despite the number of studies regarding the service life and maintenance of buildings and components that have been published in recent decades, the application of such methodologies still presents some limitations, mainly due to the complexity of degradation phenomena and the lack of reliable tools for their modelling. Overcoming this situation, involves the adoption of a number of assumptions within service life prediction methodologies that must be properly grounded. As mentioned by Field (2009), to model a real world phenomenon, whatever it may be, it is necessary to build models that cover information gathered in this actual situation. Martin (1985) refers that a scientific model can be seen as an abstraction of a real system and must include two conflicting attributes: realism and simplicity. The model should function as a reasonably accurate approximation of the real system, containing a number of important parameters for their correct description; however, it should not be so complex that makes it impossible to understand and manipulate. The definition of efficient and accurate tools to evaluate the degradation of construction elements over time is becoming increasingly important, allowing estimating the time after which it is necessary to intervene. A study performed by Moser (2004) discussed the work done by different authors in this area and concluded that more studies were needed in order to identify the parameters that influence the service life of the construction elements, being necessary to create viable mathematical relationships that allow applying these methods.

1.2 Motivation

The deterioration of buildings does not occur uniformly: since buildings are composed of various subsystems, which degrade at different rates, it can be assumed that they are composed of several layers of durability, with different service lives, which are distinct from the structure's service life. Façade claddings have a fundamental role in the performance of buildings, functioning as the first and foremost protective layer from environmental degradation agents of the wall and the structure. As a result, the buildings' envelope—sometimes also referred to as the skin of the building—is very prone to defects, with direct consequences on the quality of the urban space, on the comfort of users and in repair and maintenance costs (Kirkham and Boussabaine 2005). The degradation of the envelope can lead, in some situations, to structural problems to such an extent that the rehabilitation of the built heritage usually always implies the evaluation and monitoring of the external surface of the buildings (ASCE/SEI 30-00: 2000). Finally, in recent years, due to the use of innovative materials and complex constructive technologies, external surfaces have gained an increased importance, being currently considered and designed as part of the building (Schittich 2002).

Currently, stakeholders in the construction sector select a given cladding system considering various parameters such as: the visual appearance; the thermal and acoustic performance of the claddings; the type of support; the cost of the materials applied; among others. Generally, designers base their decision on commercial documents, being relatively easy to fulfil the performance requirements at "instant zero", i.e. at the instant that the building is put into use. However, designers rarely considered other properties, whose analysis is more complex, such as: (i) the ageing of materials in situ, i.e. the interaction between time and the elements that constitute the cladding system; (ii) the interaction between the materials applied in the cladding and the environmental exposure conditions; (iii) the potential effects of changes in material's performance in the overall performance of the assembly (Fagerlund 1985). In fact, in most cases, the information available on a given material is not directly operable when its performance over time is unknown for a given set of environmental exposure conditions. Therefore, for an effective selection, use and maintenance of a façade's cladding system it is essential to know with some accuracy the following aspects: (i) the façade's expected service life; (ii) the forecasted degradation mechanisms—chemical, physical and mechanical; (iii) the properties of materials applied on the façade and their execution conditions; (iv) ensure the compatibility between the cladding system and the structure; and (v) the effects of environmental exposure conditions and of the use of the building.

The study of the durability of façade claddings during their service life is a fundamental dimension for most decisions related to the built environment. Data on the their durability allow assessing their overall cost, considering both the initial cost (in the construction phase) and the maintenance costs combined with the service life, enabling the selection of the most economically attractive proposal. This book intends to contribute to the study of durability and expected service life of buildings, based on the working assumption that the service life of façade claddings (and other non-structural elements) can be modelled by different mathematical approaches with different levels of accuracy and complexity, leading to results with various degrees of richness of information.

1.3 Scope, Objectives, Methodology and Background of the Proposed Research Work

1.3.1 Scope of the Study

Service life prediction of buildings depends on the characterization of the materials, associated with the development of mathematical and computational models able to describe the physical degradation phenomena (NMAB 1996). As mentioned by Yatim et al. (2005), a model to predict the service life of buildings can result from the evaluation of existing buildings as well as from the statistical analysis of the variables that influence their service life. In this sense, this book intends to apply and develop different methodologies for service life prediction of façade claddings, by performing through the book and especially in Chap. 7, a comparative analysis of the applicability and validity of the proposed models. For this, advanced statistical tools are applied, thus combining the study of the degradation of façade claddings under real in-use conditions (based on an extensive fieldwork) with the development of mathematical models. The proposed models are divided into different innovation levels:

- As a starting point, models previously applied to the service life prediction are used, such as: a simple regression analysis or degradation curves (Shohet et al. 1999; Gaspar and de Brito 2008b; Silva et al. 2011a); a classic approach to the factor method (Bourke and Davis 1999; Gaspar and de Brito 2008a; van Nunen 2010; Silva et al. 2012); Markov chains—less common in the service life prediction of non-structural elements, but which have been widely applied in the monitoring of bridges' degradation state—models based on non-linear regression analysis, as is the particular case of Gompertz and Weibull curves (Garrido et al. 2012);
- These models are then expanded into new approaches. The simple regression model evolves into a multiple linear regression model, thus introducing more than one explanatory variable in the model. These models are further expanded to multiple non-linear regression models which, in addition to incorporating several variables, adopt non-linear relationships between them;
- Other models, which have been previously applied in the construction industry and whose applicability to service life prediction seems appropriate are analysed, such as artificial neuronal networks;
- In a different investigation approach, models that usually are not applied to the service life prediction are used in this book. Logistic regression has been applied in the literature to predict the remaining life of patients and their survival within the medical sciences; it is assumed that a model able to accurately predict the life of a patient can also be capable of predicting the service life of façade claddings (with the appropriate adjustments naturally). Likewise, fuzzy logic models are applied to service life prediction, leading to results similar to those obtained with artificial neural networks, but using linguistic concepts, more subjective, to model the degradation phenomena;
- Finally, new prediction models are defined in the book, such as a stochastic approach to the factor method, whose modelling depends on an algorithm developed by the authors.

It should be noted that other models could be analysed. However, the aim of this study is not to describe and implement all the possible models for service life prediction but instead provide the decision-maker with a set of reliable models with different characteristics, which can be applied according to user-established criteria. In each chapter, two methods are analysed (which produce similar information), providing alternative ways to solve the problem under analysis.

1.3.2 Background of the Proposed Research Work

This book follows a series of studies concerning the service life prediction of non-structural components performed at Instituto Superior Técnico. Data regarding the evaluation of the degradation condition of façade claddings are collected during an extensive fieldwork that is used to benchmark the results obtained by each model proposed. The research has been published in various international journals, co-authored by the authors of this book. From those, the following studies are highlighted:

- Gaspar P., de Brito J. Service life estimation of cement-rendered facades. Building Research & Information 2008a; 36(1): 44–55;
- Gaspar P.L., de Brito J. Quantifying environmental effects on cement-rendered facades: A comparison between different degradation indicators. Building and Environment 2008b; 43(11): 1818–1828;
- Gaspar P. Service life of constructions: Development of a method to estimate the durability of construction elements. Application to renderings of current buildings (in Portuguese). Ph.D. Thesis in Engineering Sciences, 2009, Instituto Superior Técnico, Technical University of Lisbon, Portugal;
- Bordalo R., de Brito J., Gaspar P., Silva A. Service life prediction modelling of adhesive ceramic tiling systems. Building Research and Information 2011; 39 (1): 66–78;
- Silva A., de Brito J., Gaspar P. Service life prediction model applied to natural stone wall claddings (directly adhered to the substrate). Construction and Building Materials 2011a 25(9): 3674–3684;
- Silva A., Dias J.L.R., Gaspar P.L., de Brito J. Service life prediction models for exterior stone cladding. Building Research and Information 2011b; 39(6): 637–653;
- Silva A., de Brito J., Gaspar P.L. Application of the Factor Method to maintenance decision support for stone cladding. Automation in Construction 2012a; 22(3): 165–174;
- Silva A., de Brito J., Gaspar P.L. Probabilistic analysis of the degradation evolution of stone wall cladding (directly adhered to the substrate). Journal of Materials in Civil Engineering 2013a; 25(2): 227–235;
- Silva A., Dias J.L.R., Gaspar P.L., de Brito J. Statistical models applied to service life prediction of rendered façades. Automation in Construction 2013b; 30: 151–160;
- Silva A., Gaspar P.L., de Brito J. Durability of current renderings: a probabilistic analysis. Automation in Construction 2014; 44: 92–102;
- Chai C., de Brito J., Gaspar P., Silva A. Predicting the service life of exterior wall painting: techno-economic analysis of alternative maintenance strategies. Journal of Construction Engineering and Management 2014; 140(3): 04013057;
- Emídio F., de Brito J., Gaspar P., Silva A. Application of the factor method to the estimation of the service life of natural stone cladding. Construction and Building Materials 2014; 66: 484–493;

- Galbusera M.M., de Brito J., Silva A. Application of the factor method to the prediction of the service life of ceramic external wall claddings. Journal of Building Performance of Constructed Facilities 2014; 10.1016/j.conbuildmat.2014.05.045, 19–29;
- Silva A. Statistical modelling of service life prediction of façade's claddings (in Portuguese). Ph.D. Thesis in Engineering Sciences, 2015, Instituto Superior Técnico, University of Lisbon, Portugal;
- Silva A., Neves L.C., Gaspar P.L., de Brito J. Probabilistic transition of condition: render facades. Building Research and Information 2015a, DOI:10.1080/09613218.2015.1023645;
- Silva A., de Brito J., Gaspar P.L. Stochastic approach to the factor method: durability of rendered façades. Journal of Materials in Civil Engineering 2015b; 10.1061/(ASCE)MT.1943-5533.0001409, 04015130;
- Vieira S.M., Silva A., Sousa J.M.C., de Brito J., Gaspar P.L Modelling the service life of rendered façades using fuzzy systems. Automation in Construction 2015; 51: 1–7;
- Silva A., de Brito J., Vieira S.M., Gaspar P.L. Fuzzy systems in service life prediction of natural stone claddings. Journal of Performance of Constructed Facilities 2016a, 10.1061/(ASCE)CF.1943-5509.0000860, 04016005;
- Silva A., Gaspar P.L., de Brito J. Comparative analysis of service life prediction methods applied to rendered façades. Materials and Structures 2016b; DOI 10.1617/s11527-016-0832-6, pp. 1–18.

1.3.3 Objectives and Methodology

This book intends to accomplish the following objectives:

I. Develop a set of effective methodologies for service life prediction of façade claddings to be used by different stakeholders in the construction sector;
II. Understand the evolution of the degradation of various types of façade claddings according to their age;
III. Analyse the influence of the claddings' characteristics in their degradation process (identifying degradation patterns associated with specific degradation mechanisms) such as: the environmental exposure conditions; the quality of materials; the design and execution level; the use and maintenance conditions;
IV. Rank the most relevant characteristics to the explanation of the degradation process, analysing the causal relationships between deterioration agents;
V. Predict the service life of façade claddings with a well-known precision, achieving an average value associated with a set of dispersion measures;
VI. Perform a comparative analysis of the proposed methodologies, providing some recommendations for the implementation of each model to a specific application.