Construction and Building Materials 24 (2010) 1718–1729

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

A systematic approach for maintenance budgeting of buildings façades based on predictive and preventive strategies

Inês Flores-Colen, Jorge de Brito *

DECivil-IST, Technical University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal

ARTICLE INFO

Article history:
Received 16 October 2006
Received in revised form 2 February 2010
Accepted 7 February 2010
Available online 1 March 2010

Keywords:
Maintenance
Predictive
Preventive
LCC
Expert system
Façades
Buildings
Claddings
Performance
Service life

ABSTRACT

Maintenance strategies are essential to control the first stages of degradation and prevent the failure of building elements. The selection of the most cost-effective and appropriate strategies can enable better budget allocation and can also minimize the decline in the performance of buildings during their whole life cycle. This paper characterizes a systematic methodology for selecting optimal maintenance strategies for façades based on different maintenance policies and interaction with the user. Life-cycle cost analysis is used to compare different maintenance scenarios using equivalent uniform annual cost (EUAC) for five façades' claddings. These scenarios are compared through the simulation of performance–degradation models and characterization of several parameters: service life, performance, minimum level of quality, maintenance operations, frequency and costs. The results allow the comparison of preventive and predictive maintenance strategies. This methodology, the result of a two-year academic research program, is intended to help clients, users, practitioners and decision-makers in the choice of facades' interventions (type, frequency and cost estimation) at buildings' design and post-occupancy stages. Finally, the future drawbacks and benefits of this study are discussed.

1. Introduction

During their service lives buildings deteriorate and become obsolete. As soon as they are built the process of decay begins, as well as the deterioration of the fabric and services [1]. The inevitable process of decay can be controlled and the physical life of the buildings extended if they are properly maintained [2]. Maintaining buildings costs money and therefore, although building maintenance can be planned and specified correctly, if the funding available is not adequate building failure will ultimately ensue [1]. Buildings may fail for a number of reasons: faulty design, faulty construction, faulty maintenance, faulty materials and faulty use. This paper is related to the faulty building elements that can affect the fulfilment of owner needs (needs of in-service budgeting control with accepted levels of comfort without potentially unsafe risks), emphasizing the importance of maintenance to achieve this. Faulty maintenance can be broken down into two parts: maintenance that has been carried out incorrectly and, more commonly, no maintenance having been carried out at all during the life of the building [1].

Faced with a shrinking maintenance budget, rising construction and maintenance costs, building maintenance management has been gaining momentum and one of the more important tasks is to minimize operating costs [2]. Therefore, the selection of the most cost-effective and appropriate maintenance strategies can result in better budget allocation. It can also minimize the deterioration in the performance buildings over their whole life cycle (design, construction, use and demolition).

Management, design and monitoring are complex processes that require knowledge of different fields and the consideration of different variables that make use of knowledge-based systems [3] or decision support models that can be transformed into computerized semi-automatic tools [4]. A number of techniques that have been developed and used for many years in the defence, aviation and oil industries to select the most effective maintenance strategies [5] have also been adapted for building pathology and maintenance with a growing number of applications:

- Diagnosis systems or expert systems that provide logical steps to diagnose building defects in a structured way, using diagnosis charts, data banks, fault trees and artificial intelligence or knowledge-based systems [6]; new applications for risk assessment of failures in building products (e.g. FMEA – Failure Mode Effects Analysis) [7].
- Models more suitable for helping designers to select the most feasible and economical maintenance and refurbishment actions in the conceptual phase of new or renovation projects; they can

* Corresponding author. Tel.: +351 218419709; fax: +351 218497650.
E-mail address: jb@civil.ist.utl.pt (J. de Brito).

0950-0618/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2010.02.017

be based on multi-criteria models [8], neural network techniques [9], probabilistic approaches (such as Monte Carlo simulation), life-cycle cost models (e.g. Eurolifeform European Research Project) [10] and others.
- Models to identify the most cost-effective and appropriate maintenance strategy for existing buildings and other facilities (e.g. bridge protection systems, infrastructures); more than one technique has been used in this field, e.g. FMEA with RCM (reliability-centred maintenance) [5], genetic algorithms in conjunction with stochastic methods (e.g. Markov-chain) [11,12] and others.
- Integrated decision-making tools to assist building owners, architects, contracting authorities and decision-makers in assessing building degradation, choice of optimal maintenance and refurbishment strategies (from a long-term financial investment point of view), improvement of energy and environmental performance (environmental challenge) for different types of buildings (INVESTIMMO and EPIQR for apartment buildings, SUREURO for post-war European residential buildings, TOBUS for office buildings, XENIOS for hotels) [13–18].

Despite the range of studies already carried out, new approaches to the efficient management of maintenance of different buildings' components, materials and systems are being developed all the time. In this context, the following aspects justify the previous statement:

(1) The choice of optimal maintenance strategy should be based on an analysis of different maintenance policies (e.g. reactive, corrective, preventive, time-based maintenance, condition-based maintenance, re-design) [1,5,19,20]; it is necessary to distinguish the maintenance concept from other terms normally used in building renovation, such as refurbishment, retrofit and modernization [1,4,21].
(2) To globally address the issue of maintainability, the approaches of building performance and building LCC are essential [2] – maintainability is the ability of a functional unit, under given conditions of use, to be kept in, or restored to a state in which it can perform a required function when maintenance is performed under given conditions and using stated procedures and resources [22].
(3) Building performance evaluation is a crucial procedure that offers feedback as a function of the performance of building materials and components for future improvement [23,24]; even if it is a complex issue, it is crucial to define in each study which component(s) of performance is(are) being studied: functional, physical or financial [25].
(4) There is still little information regarding general in-use performance of components and materials [26]; this adversely affects the practical application of theoretical models in maintenance management.
(5) The reliability of the prediction of a building's service life strongly influences the effectiveness of a maintenance policy [27]; methods based on coupling life-cycle cost assessment and service life prediction are needed [28,29]; economic tools are needed for assessing the life-cycle cost advantages and disadvantages of new materials relative to conventional materials [30].
(6) Users perceptions, needs, expectations and budget are relevant issues to the real implementation of maintenance models [13,31].

This paper first sets out a systematic approach for selecting optimal maintenance strategies for façades in different stages of the life cycle process (design and in-use stages). Secondly, relevant parameters to be included in databases are discussed. Then, different maintenance scenarios are simulated for façade claddings; these are based on theoretical concepts with a view to evaluating the future benefits of this methodology for practitioners, users and decision-makers. Finally, some needs for future research are suggested and the advantages and disadvantages of this methodology are presented. Ongoing research by the authors has focused on the integration of previous methodology with experimental and empirical methods for in-use performance assessment of plastered façades. This is an extension of the work described in this paper and is not included in it.

2. A systematic approach proposal for façade maintenance

2.1. General remarks

The façade is a key element of a building and it influences its comfort, safety and aesthetics. The overall performance of the façade depends on the performances of its components: separation, support and facilities [32]. The poor design of construction details, a bad choice of the façade materials (e.g. plaster with high porosity in a marine environment), its inadequate application, and non-existent maintenance are the core of current problems in buildings' façades.

The systematic step-by-step methodology proposed in this paper is meant to provide technical support for façade design, inspection and maintenance management, integrating informatics-based modules (databases) associated with different maintenance strategies (Fig. 1). In this methodology, the user defines the component of the façade to be studied and the objective of the analysis (design façade or existing façade) using several options. Three types of analysis can be performed, depending on previous statements and the knowledge of the behaviour of the component to be studied:

- Preventive maintenance (or planned maintenance): the items included in this category are those scheduled for predefined, regular intervals to ensure the component's continued good performance [1]; this type of maintenance reduces non-planned works and allows the estimation of overall costs.
- Predictive maintenance (or condition-based maintenance) by performing inspection planning: the predictions involved in this type of maintenance show an important capacity for improved accuracy [20]; it has for some time been a useful tool for reducing life-cycle costs and finding more efficient ways of using maintenance budgets [32]; it is an appropriate maintenance strategy for elements whose condition and performance can be suitably monitored [11,33].
- Reactive maintenance: this is associated with the correction of unexpected anomalies and is almost always an emergency procedure, leading to unavoidable extra costs; it is important to standardize technical procedures that allow the minimization of the drawbacks of this type of maintenance.

The preventive and predictive maintenance strategies are classed as proactive maintenance, which prevents problems before they occur [20] and so cuts the cost throughout a building's service life.

The fact that this systematic approach is modular allows the future addition of supplementary modules to define the service behaviour of each element, thereby contributing to the characterization of the overall performance of the façade itself [34]. This technical approach intends to systematize procedures, according to the strategy and type of maintenance, in order to be used in a knowledge-based system. The result is the continuous and