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*Editorial*

# Life Cycle Prediction and Maintenance of Buildings

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The sustainability of the built environment can only be achieved through the maintenance planning of built facilities during their life cycle, considering social, economic, functional, technical, and ecological aspects. Stakeholders should be conscious of the existing tools and knowledge for the optimization of maintenance and rehabilitation actions, considering the degradation mechanisms and the risk of failure over time. Knowledge concerning the service life prediction of building elements is crucial for the definition, in a rational and technically informed way, of a set of maintenance strategies over the building's life cycle. Service life prediction methodologies provide a better understanding of the degradation phenomena of the elements under analysis, allowing relating the characteristics of these elements and their exposure, use, and maintenance conditions with their performance over time.

This Special Issue intends to provide an overview of the existing knowledge related to various aspects of "Life Cycle Prediction and Maintenance of Buildings". In this sense, 12 original research studies were published, with the relevant contribution of international experts from Canada, Czech Republic, Finland, Germany, Italy, Poland, Portugal, Norway, and Sweden. These outstanding contributions address the maintainability and serviceability of buildings and components, the maintenance and repair of buildings and components, the definition and optimization of maintenance and insurance policies, the financial analysis of various maintenance plans, and the whole life cycle costing and life cycle assessment.

Vinokurov et al. [1] performed a detailed and extensive literature review in order to clarify how municipal building departments can adopt life cycle cost-effective measures to promote energy efficiency and a high-quality indoor climate in buildings. This study is focused on the design phase of the building's procurement process, describing the relationship between indoor climate quality, energy use (and GHG emissions), and the life cycle economy from the perspective of design-related factors. A list of energy efficiency factors that need to be considered in the municipal building procurement process is defined in order to aid practitioners in the selection of a design solution that optimise the value for public money, contributing to a more transparent procurement and decision-making process.

In Macedo et al. [2], an innovative approach for tailoring insurance products is proposed in terms of the risk of failure of the building's components, as well as the financial charges related with the maintenance of these elements, channelling the risks to the market. For this purpose, in this study an insurance policy model applied to natural stone claddings is designed. Deterministic and stochastic service life prediction models were used, considering only the age of the elements or encompassing its different characteristics. This approach intends to identify the insurable risk of the degradation of these claddings, examining how these risks are managed through the insurance method and thus analysing different insurance premiums according to the expected claims and to the risk load. This study provides an interesting approach for the definition of realistic risk-based insurance policies, incorporating mitigation activities through knowledge related to the stochastic performance of the claddings over time. This type of insurance product, considering the risk of failure of the cladding, benefits not only the insurer but also the policy holder.

A statistical survey of the pathology and rehabilitation of linoleum and vinyl floorings is presented in Carvalho et al. [3]. In this study, 101 floorings were analysed in six healthcare facilities in the Lisbon area, Portugal. Healthcare facilities were chosen as case study due to the specificity of the maintenance activities in these buildings. An expert inspection and diagnosis system was created, identifying the most common types of anomalies, their probable causes, the most adequate in situ diagnosis methods, and the most useful repair techniques. Moreover, this information was converted into matrices that relate anomalies and causes, anomalies and diagnosis methods, anomalies and repair techniques, and anomalies with each other. This study identifies the main sensitive concerns regarding the maintenance of these claddings over its life cycle in order to minimise the susceptibility of these floorings to different degradation mechanisms.

Nowogońska [4] proposed an original diagnosis method to describe and predict the aging process of buildings and their components. This methodology intends to characterise the technical condition of the element analysed, predicting changes in the performance characteristics of buildings over their service life. For that purpose, a Prediction of Reliability according to Exponentials Distribution (PRED) approach is adopted, applying Predicted Service Life of a Component (PSLDC) danger curves. The forecasting model, designed to predict the changes in the technical condition of buildings, can be extremely useful in aiding decision-making regarding maintenance works during a building's life cycle. Knowledge related to the aging process of buildings over their service life and the diagnosis of their loss of performance, in terms of their technical condition as well as the reasons behind damage, can be used to define repair needs and to establish adequate maintenance policies.

A cross-domain Decision Support System (DSS) for maintenance optimization was proposed by Moretti and Re Cecconi [5]. In this study, the maintenance optimization is achieved through a wiser allocation of economic resources. For that purpose, four indexes are used: (i) a Facility Condition Index (FCI), (ii) an index measuring the service life of the assets, (iii) an index measuring the preference of the owner, and (iv) another measuring the criticality of each component in the asset. These four indexes are transformed into a Maintenance Priority Index (MPI), which can be used for maintenance budget provision. An average MPI for the whole building can be obtained based on the computation of the MPI of each asset within the building; however, the methodology proposed in this study does not allow comparing different elements among buildings within a portfolio. In this sense, the scalability of the methodology proposed needs to be further investigated. Nevertheless, the DSS proposed could be integrated into a Building Information Modelling (BIM) approach, allowing an effective asset and facility management. Furthermore, with the necessary adaptations, other parameters or metrics could be included in the DSS model in order to aid the prioritization of the maintenance interventions in buildings.

A methodology for building Life Cycle Cost (LCC) estimation, which supports investors in identifying the optimum material solution for their buildings on the level of functional parts, was established by Biolek and Hanák [6]. This methodology encompasses the investor requirements and relates them to a construction cost estimation database and to a facility management database. The methodology proposed is applied and tested for a case study, with a "façade composition" as functional part, with the sublevel "external thermal insulation composite system (ETICS) with thin plaster". The results obtained revealed that there is not a generally applicable optimum ETICS material solution, mainly because differing investors have different requirements and due to the unique circumstances of each building and its users. This study points out different future research directions, essentially: (i) the adoption of sustainable criteria in the selection of the best solution, combining LCC and LCA calculations; (ii) the incorporation of information attained from in-use buildings and BIM models to enable a more comprehensive LCC evaluation.

Orlowsky et al. [7] analysed the durability of 11 different water repellents applied on Obernkirchener Sandstones. The performance of the hydrophobic agents applied is analysed after the samples have been subjected to long-term weathering (30 years of outdoor weathering) in seven different locations in Germany. After 24 and 30 years of outdoor weathering, the treated stone surfaces revealed discolouration and staining. The authors measured the colour changes, identifying the presence of black crusts, the deposition of particles, and biogenic growth, which have caused the gradual darkening and significant changes in the sandstones' colour over time. After 30 years, all the agents show a decrease in performance, but some protective agents still provide an effective hydrophobic layer. Succinctly, the authors [7] concluded that: (i) the protective agents based on isobutyltrimethoxysilane show a clear loss of performance after 2 years of outdoor weathering; (ii) agents containing siloxane, the low-molecular methylethoxysiloxanes, show a good performance, which is similar to, partly better than, that of the oligomer methylethoxysiloxane; (iii) the agents with oligomer siloxane based on an isooctylmethoxy-structure have a higher performance loss than the agents containing low-molecular methylethoxysiloxanes; (iv) after 30 years of outdoor weathering, the effectiveness of the protective agents based on silicone resin is comparable to that of low-molecular siloxanes. Concerning the exposure conditions, the degradation of the treated stones is higher in southern Germany than in North Rhine-Westphalia, mainly due to a longer weathering time of 6 years as well as the rougher environment. On the other hand, in North Rhine-Westphalia, the prolonged exposure to temperatures under 0 °C and relative humidity above 80% leads in general to a higher degradation compared to Duisburg and Dortmund.

Di Bari et al. [8] proposed a methodology to consider the seismic hazard in the enhancement and extend of the buildings service life. For that purpose, a life-cycle-based decision support tool for building renovation measures was created and applied to a selected case study, as a "Proof-of-Concept". A probabilistic approach is proposed in this study in order to overcome the limitations of the "static" analyses; in this sense, the probabilistic methodology proposed allows considering dynamic effects and different sources of uncertainty. This probabilistic approach of life cycle assessment (LCA) and life cycle costs (LCC) analysis can reduce the risk of miscalculation due to uncertainties, while preventing misleading LCA-based decisions. This approach enhances the analyses through the addition of supplementary parameters related to environmental, economic contingencies, and external factors, leading to a more complex model but aiding the practitioners in making more conscious choices. The methodology proposed, performing both probabilistic LCA–LCC analyses, allows evaluating in a more accurate manner the relevance of a seismic retrofit, considering the performance of the construction under seismic actions and the risk of long-term losses due to the lack of a suitable anti-seismic structural system.

In Lacasse et al. [9], the impacts of climate change on the durability and maintainability of building envelope materials and elements are analysed. This study presents a literature review, related with the durability of building envelope components, considering the expected effects of climate change on the longevity and resilience of these components over time. For that purpose, the climate loads expected in the future under different climate change scenarios, were analysed. This study is especially focused on the climate change of Canada. The future climate loads were compared with the climatic effects arising from loads sustained under current historical climate conditions. This study [9] concludes that, in the next few decades, the general climate of Canada tends to become warmer, with some locations experiencing more intense and frequent rain events of longer duration, thus producing heightened wind-driven rain loads. The study provides theoretical specifications for the selection of products given climate change effects, aiding the maintainability and the selection of construction products to achieve climate resilient performance over the buildings' service life.

Jalilzadehazhari et al. [10] evaluated the profitability of a ground source heat pump, photovoltaic solar panels, and an integrated ground source heat pump with a photovoltaic system as three energy supply systems for a single-family house in Sweden. This study evaluates the profitability of the supply systems through the calculation of the payback period (PBP) and the internal rate of return (IRR) for these systems. The IRR and PBP are obtained by considering three different energy prices, three different interest rates, and two different lifespans. Moreover, the profitability of the supply systems was analysed for four Swedish climate zones. The authors [10] concluded that the ground source heat pump system was the most profitable energy supply system, providing a lower PBP and a higher IRR for all the climate zones analysed, when compared with the other energy supply systems. Furthermore, the results reveal that increasing the energy price improved the profitability of the supply systems in all climate zones. This study can be adapted and generalised to countries with similar climate conditions; nevertheless, the cost-effectiveness of the renewable energy resources varies according to the investment costs, the energy prices, and the evolution of energy policies.

The influence of reinforcing steel corrosion on life cycle reliability assessment of existing reinforced concrete structures is analysed in [11]. This study evaluates the influence of different degradation conditions and several reinforcing steel and concrete classes on the time-dependent reliability curves proposed. A special procedure to evaluate material properties and their statistical parameters based on cluster analysis was adopted for the implementation of the method proposed. Croce et al. [11] applied this method to thousands of historical test results dating back to the 1960s, concerning the concrete compressive strength and yield stress of steel rebars, to establish the resistance classes for both materials as well as for the estimation of the related statistical parameters. The application of the methodology is illustrated for significant case studies, consisting of reinforced concrete elements, part of residential, shopping and storage buildings, focusing on the effects of corrosion in steel rebars under different environmental conditions, resulting in no degradation to high degradation effects. The authors emphasize the relevance of the methodology proposed and the results obtained by comparing the time-dependent reliability curves with the target reliability levels currently adopted in the Eurocodes, performing a critical discussion about the results obtained.

Finally, Grynning et al. [12] adopted a multimethod research approach to evaluate the basic criteria, trends, applications, and developments related to climate adaptation in building maintenance and operation management (MOM) practices in Norway. The current status of the application and extent of climate adaptation practices in relation to MOM is analysed. For that purpose, three case studies involving different Norwegian building owner organizations were examined. The results of this study revealed a significant gap between theory and practice regarding the consideration of climate adaptation in MOM. This study reveals that the concept of climate adaptation is only addressed as a high-level strategic issue and that there is a need to incorporate the concept at lower organizational levels. The case studies analysed highlight the need for a generic and structured climate-adaptive MOM framework in order to support the incorporation of climate adaptation in current MOM practices at different scales and organizational levels. This study anticipates that the implementation of this flexible and transferable framework is expected to provide a basis for increasing further knowledge on climate adaptation. Further developments to the proposed model should include the introduction of more tangible and tailored tools and processes, including checklists or scoring systems accompanied by relevant climate adaptation factors and plans.

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