The role of service life planning in construction industry; an exploratory review

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Abstract- The aim is to present a review of the scientific literature as regards service life planning and durability in buildings, infrastructure and their parts. The review focused on studies and works related to two main categories: the first related to the basic information on service life planning for buildings, the second, related to case studies and applications of service life planning in buildings. Results reveal that as regards theory and basic information on service life the studies mainly focus on studies on specific methods and models on service life planning in buildings and their components, as for applications and case studies, these largely focus on life cycle assessments to ascertain durability and environmental impacts for various materials and constructive components. It is concluded that the estimation of a building's service life not only comes in handy to plan its durability, but also because it is very useful when studies on Life-cycle assessment on buildings and their components are needed.

Keywords– Durability; Life-Cycle Assessment; Sustainable building design.

I. Introduction

A sustainable architectural project and the adequate use of technologies and practices in green construction provide the owner with saving of resources, at once they make the buildings work more efficiently, plus they improve the local and regional economy and the environmental conditions (Mohamed, 2019; Karim et Al., 2011; Silva et Al., 2019; Kiyanets, 2016; Feng & Hewage, 2014), which allows decreasing and mitigating impacts on the environment in several aspects:

-Decrease energy, thereby CO2 emissions to the atmosphere during the construction and use of buildings.
-Saving and use of water in the building.
-Increase the comfort inside and outside the building.
-Improvement of the environment and quality of life for the user at local, regional and global level.

Therefore, the design must be carried out following local and international environmental technical norms, also resorting to architectural and green construction design guides and even to models and methodologies of environmental design tried and accepted all over the world such as LEED®, BREEAM®, ESTIDAMA®, Green Star®, CASBEE®, etc. As regards LEED®, this is the most popular and most prestigious environmental design method in many countries around the world (Smith et Al., 2006; Wu et Al., 2016; Da Silva & Ruwanpura, 2009; Pulselli et Al., 2007; Mousa & Farag, 2017; Majumdar, 2019; Zou, 2019; Gelowitz & McArthur, 2018).

Furthermore, at the beginning of the buildings' design process, it is necessary to find out and plan the project's service life, as it will indicate the patterns of design, construction, use, maintenance, operability and end of service life. Service life understood as the period after the installation or construction over which a building or its parts meet or exceed the performance requirements for which they were built and constructed (ISO, 2000). Therefore, at the end of service life, significant corrective maintenance shall be carried out, reparation of construction components, and that has economic and functional impacts oftentimes different from that originally planned.

To plan a project's service life, there are several methods, both qualitative and quantitative:

1. Statistical methods such as the historical registration method, limited to buildings in similar conditions (Sjöström & Jernberg, 2010).

2. Engineering methods such as mathematical simulation and physical tests methods such as "accelerated ageing" which are useful in very specific cases of materials and construction components, which in addition to be costly, require experts in the field to be executed (Hovde & Moser, 2004).

3. Factor methods, such as ISO 15686 which are friendlier to architects but restricted by the designer's experience (Hernández Moreno et Al., 2017).

However, it has been pointed out that procedures on planning service life and durability are unknown by some architecture, construction, engineering professionals and of areas akin, which is considered a serious problem that has to be addressed professionally and using the updating and knowledge of the respective norms and methods. Moreover, durability understood as a building's or construction component's capacity to meet the optimal performance of its functions in a certain environment or place for a certain time, with no corrective maintenance or significant repairing (Canadian Standards Association, 2001).

II. THE ROLE OF SERVICE LIFE PLANNING IN CONSTRUCTION INDUSTRY

On the basis that a building's service life is virtually the longest stage of its life cycle, then the estimation in years or a determinate time for the buildings to last, is the variable we need to perform some calculations and simulations in terms of Life-cycle assessment as regards environmental impacts and costs of use, maintenance and operation of the buildings; therefore Life-cycle environmental assessment (LCEA) (Kneifel et Al., 2018: 7) determines a number of aspects in terms of:

- Global warming
- Use of resources
- Human health
- Water, soil and air pollution,

In terms of Life-cycle cost assessment (LCCA), it defines various costs in the building's service life (Kneifel et Al., 2018: 7), owing to:

- Maintenance
- Reparations
- Programmed replacements of constructive components

Owing to such reasons, for those calculations and estimations we need the variable corresponding to the building's service life.

III. NEED TO ESTIMATE SERVICE LIFE IN ARCHITECTURAL DESIGN IN CONSTRUCTION INDUSTRY

Estimating and planning service life in the design of process and construction of buildings is necessary to find out:

- The project's service life and durability.
- Maintenance planning and the building's operability.
- End of service life planning and decisions to make for possible reuse, deconstruction, demolition, dismantling or adaption.
- The estimation of service life is also useful to calculate a number of the project's environmental impacts as in terms of energy, materials, carbon emissions, carbon contents, etc. as it is an important variable for calculation over Life-cycle assessment (LCA) of the various materials, supplies and resources used in the construction.
- Planning and design of the durability of the project.

The most recommendable methods to estimate the buildings' service life, from the standpoint of this article's author, are those based on ISO 15686, since it is a qualitative method based on the designer's experience, for instance, it neither requires complex mathematical calculations nor "accelerated ageing" physical tests in the laboratory, thus it is considered a practical method for the early stages of planning and design of buildings and construction components.

IV. SCIENTIFIC LITERATURE REVIEW ON BASIC INFORMATION AND THEORY ON THE SERVICE LIFE OF BUILDINGS AND CONSTRUCTION COMPONENTS

Examples of theory and basic information on estimation and prediction of service life in the construction industry, can be revised and consulted in Table 1.

Table 1. Scientific literature review on the service life and basic information of buildings and construction parts

References	Basic information on service life and durability in buildings
Torres & Martínez, 2001	A work that looks for the best design for structural concrete utilizing revising degradation aspects and service limit states of constructive components.
Karbhari & Lee, 2011	The importance of finding out the rest of the service life of existing buildings at present is of much interest, all this through durable design and intention to extend the service life.
Peixoto de Freitas & Delgado, 2013	This book presents a compilation of works related to the improvement of durability of buildings utilizing the improvement and design of construction materials.
Vandenbroucke et Al., 2015	A study on how to resort to Life-cycle analysis is presented in view to rescue and extend the service life of construction components and also buildings.
Morini et Al., 2019	In this study, energy incorporated and carbon footprint will be used to assess the environmental load, not to replace a full life-cycle analysis, but to promptly offer reliable information to those involved in the design of a new product, utilizing using service life as an aspect to take into account.
Ranjith et Al., 2016	This work has intended to predict the service life of reinforced concrete structures taking mathematical models of corrosion into account.
Gao et Al., 2019	A new method to predict the structures in tunnels subject to corrosion induced by chlorides using real engineering data and genetic programming (GP).
Gardner et Al., 2019	Bases to assess the entire life-cycle of the materials used in the construction of buildings, having design service life among the variables to take into account.
Franzoni, 2011	This work discusses and summarizes the tools available at present to select construction materials, especially addressing the selection of materials in the stage of a working plan. Considering an important aspect of the projects' service life.
Mequignon et Al., 2013	The article’s goal is to study the impact of a building’s service life on greenhouse gas effect emissions. The influence of service life of a house with all its performance levels is studied according to the chosen technical solutions.
Lair et Al., 2001	Operational methods are studied and proposed to improve durability in the buildings’ service life planning.
Markeset & Kioumarsi, 2017	This work focuses on predicting the service life and durability in reinforced-concrete buildings attacked by chlorides over 100 years.
Taffesea & Sistonen, 2013	It presents the state of the art of service life prediction of repaired structures, using the concrete recovery-reuse method
Masters & Brandt, 1989	A systematic methodology is proposed to predict the service life of materials and construction components which is still successfully used as a reference at present.
Fulvio Re Cecconi, 2006	It presents a research report on testing methods to find out service life in components of buildings.
Kelly, 2007	A study on the basic theory of what design service life is and how to implement it in construction projects based on *British Standard BS 7543 (2003).*

ISO, 2011	These are the international norms that define the estimation of service life in buildings.
Department for Environment, Food and Rural Affairs, 2009	The bases and main methodologies are reported with a view to assessing and measuring the deterioration of buildings and their costs per life cycle.
LIFECON, 2003	It reports the main models and methodologies used to assess, plan and predict service life in buildings.
López-Celis et Al., 2006	It is a technical document that reports the behavior of the durability of concrete structures under various urban environments in Mexico, resorting a corrosion test, and their effects and improvements of the design of concrete mixtures.
Marteinsson, 2005	This work presents a discussion on the planning of service life and the role of the Factor Method in such task, especially in the discussion on the modification and development of the methodology.
Hernández- Moreno, 2011	The present work presents a review regarding planning service life over the process of design of buildings aimed at architects, builders and real-estate promoters, based on the ISO 15686 international standardization.
Silva & de Brito, 2019	This study analyzes two computational tools to help adopt maintenance policies based on service-life conditions developed for enveloping elements of buildings.
Nwodo & Anumba, 2019	This document aims to provide an updated systematic review of the life cycle assessment of buildings and discuss the main challenges in construction of life-cycle assessment.
Nägeli et Al., 2019	This document presents a method to optimally program the costs of maintenance and modernization at the level of the portfolio using research works on modelling of stocks of buildings and planning of maintenance modernization through life-cycle analysis in buildings.
Hernández-Moreno, 2015b	This work has as a main aim to generate and present various strategies and technical recommendations on design by the durability of the built urban environment which helps in the process of planning and design of the cities, mainly of the urban infrastructure, which is an important part of the cities.
Hernández-Moreno, 2011b	The document aims to provide an overview and approximation to the use of service life planning in the processes of sustainable design of buildings.
Hernández-Moreno et Al., 2017	A comparative analysis of design by the durability of two similar architectural projects from the architect's standpoint is presented to understand the actors that affect their service life utilizing a methodological approximation that entails analyzing various variables that affect and define the response variable that refers to Estimated service life for each building.
Hernández-Moreno & De Hoyos, 2012	It is a document based on the “tropicalization” of durability design strategies in buildings based on Canada’s LEED®.
Hernández-Moreno, 2019	It is a work on how to improve durability in construction materials and how to slow their degradation.
Hernández-Moreno et Al., 2017b	This is a work that comprises the proposal of a sustainability model in architectural design which includes, among others, the categories of service life planning and durability in buildings.
Dixit, 2019	In this article, a systematic review of the literature is carried out to identify key parameters that affect the recurrent calculations of energy incorporated into the buildings (therefore, it requires service life information). As well, a framework is proposed to identify the uncertainties that come from these parameters.

Rezaei et Al., 2019	In this document, life-cycle assessment (LCA) and building information modelling (BIM) is carried out over the early and detailed stages of the building.
Jin et Al., 2019	This study contributes to current research by identifying the key entry attributions and the workflow in Building Performance Analysis (BPA), revising cutting-edge research on the integration of BIM into BPA and researching the main research areas, namely: BIM-BPA interoperability problems, enabled in the context of the BPA life cycle.
Negishi et Al., 2018	This work proposes an original methodology to perform a dynamical life-cycle analysis of buildings using new tools still under development.
Wuyts et Al., 2019	This study presents a holistic vision of the pressing social and environmental concerns related to short-life buildings, which can be resorted to identify sustainable strategies to produce a circular-construction environment in Japan.
Illankoon et Al., 2019	This research study has as an aim to analyze the cost of the green buildings' life cycle, focusing on energy efficiency, water efficiency, indoor environmental quality (IEQ) and material criteria. Initially, this research study calculated the life cycle cost for several green buildings' requirements based on green grading tools for green buildings by Green Star Design® and As-Built version® 1.1.
Hu, 2019	This integrated assessment framework bases on Life-cycle assessment (LCA) and Multiple decision criteria method (MCDA).

(Source: those indicated as references in the left column)

By reading table 1, one identifies, eight topics in which the theory and basic information on the service life in building's design and construction is studies; these are:

- In the first place, studies related to specific methods and models to plan service life for buildings and construction elements.
- Secondly, information on studies on life-cycle assessment in construction and architecture mainly regarding energy and CO2 emissions.
- In the third place, the literature review deals with the extension of the buildings' and their components' service life.
- Four. The study of service life and durability of structural concrete components.
- Then, the study of service life and durability of construction materials in general.
- Another important aspect is the study of the remaining service life of the buildings.
- Apply BIM to the study of service life and durability in buildings.
- And finally, though no less important, the study of maintenance and its relation to service life and durability and design of buildings and their components.

V. REVIEW OF SCIENTIFIC LITERATURE IN WHICH SERVICE LIFE IS UTILIZED AS ASSESSMENT TERM IN CASE STUDIES OR APPLICATIONS

Examples of case studies in which service life is useful as information to carry out several studies referring to the life cycle analysis and assessment in the construction industry and service life or remaining service life in buildings and infrastructure, can be consulted in Table 2.

Table 2. Review of the scientific literature, in which service life is resorted to as assessment period in case studies or applications

References	**Case studies on service life and applications**
Biondini & Frangopol, 2012	The document mainly contains the study on how to measure the rest of service life in bridges and other urban infrastructure made of steel and concrete.
Raupach &	This document approaches principles and practices regarding diagnosis

Büttner, 2014	and design by service life to repair concrete components.
Li, 2016	It studies the durable design of concrete structures utilizing various models and methodologies in which the response variable is service life.
MacKenzie et Al., 2007	This study reports a guide to design by requirements of wood's service life in the construction industry.
Méquignon & Haddou, 2014	Utilizing life-cycle analysis, the document studies the environmental impacts of buildings over their service life as regards durable design and obsolescence.
Hardman et Al., 2006	This document presents a compilation of works on service life and durability of construction components mainly in outdoor conditions between components wall and window.
Peixoto de Freitas and Delgado, 2013	The authors present a compilation of various works related to the use of various analysis methods of durability and service life in the construction industry.
Pillai et Al., 2019	It presents a study to improve the conditions of service and durability in concretes reinforced with dust and fly ash.
Cheon et Al., 2015	It presents a study to predict the service life of ironworks utilizing accelerated ageing tests.
Taffese & Sistonen, 2016	This work presents a model a hygro-thermal prediction based on neuronal networks to calculate the temporary hygro-thermal condition and degradation in the façade concrete elements.
Bahtiar et Al., 2017	This work presents a study in which the rest of service life of a wooden structure ascertained utilizing mathematical models and of the percentage of deterioration degree.
Liu et Al., 2019	A methodology particular for the life-cycle assessment of the services of ecosystems and sustainability is presented.
Ismail et Al., 2016	The document presents results of research on the deterioration of the conditions of residential projects abandoned owing to degradation environmental conditions, and a predictive method for service life is proposed.
Pereira de Castro et Al., 2014	This article presents a comparative study of greenhouse gas emissions from the compositions of walls according to their service life.
Serralheiro et Al., 2017	This study proposes a methodology to predict the service life of architectural concrete façades, basically by measuring deterioration agents.
Antsupov et Al., 2016	The article deals with a new method to configure the solution of problems of the theory of reliability to seal in function of the wear resistance criterion of sealing elements.
Hodhod & Ahmed, 2014	This document focuses on the service life of slag concrete exposed to chlorides, utilizing a proposal that models its durability.
Vieira et Al., 2015	This article has as an aim to establish a model to predict the service life of rendered façades using a *Takagi-Sugeno* fuzzy logic model.
Setyawan et Al., 2015	The performance condition of a road and its damages are assessed, as well as the rest of the asphalt's service life in *East Line of South Sumatera*, also the relation between these two values is assessed.
Coffey et Al., 2018	This research focused on highways close to main metropolitan areas, areas in which roads are structurally solid but their expansion has become more costly, therefore their service life is analyzed for possible improvements.
Shohet & Paciuk, 2014	An empirical method was developed to predict the service life of a building's components, based on an assessment of their actual performance and on the identification of failure mechanisms that affect their durability.
Silva et Al., 2013	It presents an approach to assess the service life of "rendered" façades applying statistical tools, utilizing multiple linear regression analysis and artificial neural networks and mathematical models.

Lehner et Al., 2018	The article approaches the analysis of fatigue damage in aged steel structures utilizing a reliability assessment that includes the prediction of residual service life.
Yrieix et Al., 2014	The article evaluates the service life of insulating panels for construction utilizing mathematical models in stationary conditions.
Lighting Research Center, 2003	The work reports durability tests in residential lighting employing tests methods based on American standards.
Venta, 1998	The work presents a life-cycle analysis for construction products made of mortar and ceramics, in which service life variable is used as an essential part in the calculation of environmental impacts emitted by such materials.
Flager, 2003	It presents a study on the design of building structures as a solution for many of the service-life and durability problems in buildings.
Saba, 2013	It presents a work that researches on the durability of structures intending to improve the performance of the buildings' structural components via the identification of deterioration factors.
Rauf & Crawford, 2015	This study aimed to research the relation between service life and energy incorporated into the life cycle of buildings.
Hasik et Al., 2019	This study presents an approach to carry out a life-cycle assessment for the entire building in renovation projects, it puts forward an approach to carry out comparative evaluations between renovation and new construction and it demonstrates the approach in a case of adaptive reuse.
Robati et Al., 2019	This study examined the lifetime impacts of construction materials for the building based on a detailed assessment by life-cycle assessment which had been previously performed.
Souza et Al., 2018	This study intends to develop a model based on the factor method, to predict the service life of the ceramic coating systems in Brasilia, Brazil.
Rodrigues et Al., 2018	This work of this document aims to analyze the application of Life-cycle management of buildings to a case study in a renovation process, study the specific solutions and assess the corresponding service life using the factor method according to the ISO 15686 family.
Garrido et Al., 2012	This article presents and tests a methodology to predict service life, based on the statistical analysis of anomalies obtained in the inspection of buildings in use and the corresponding degradation curves obtained from deterministic models.
Liang et Al., 2017	To improve the thermal performance and prolong the service life of construction materials, fibre felt / silica aerogel composites were prepared.
Luay & Kherun, 2018	This document presents a study that shows the making of a life cycle cost assessment for a green building and how the life cycle cost variables were identified and how they were used for developing a life cycle budget for the life cycle of a green building that spans for 60 years.
Hernández-Moreno, 2015a	This work presents a life-cycle comparative analysis between three sorts of luminaries commonly used at present in architectural projects and indoor artificial lighting in buildings; comparing their environmental impacts to find out how they quantitatively contribute to global warming mainly from the CO2 emissions into the atmosphere.
Hernández-Moreno, et Al., 2014	This work focuses on the application of a methodology to estimate the useful or service life of any built asset; in this case, as an example, an architectural project of a modern-adobe dome in the city of Toluca, based on the ISO 15686 factor method.
Hernández-Moreno, 2017	This document approaches the planning of service life and durability in architectural projects over the design phases of the project based on theory and case studies, to estimate the service life each project may have.
Hernández-Moreno and Crúz-	The authors present a work related to the estimation of environmental impacts on the concept of water according to LEED® recommendations

Medina, 2011	also based on use of the service life for the evaluated period in a case study.

(Sources: the references in the first column)

From table 2, various applications on service life and durability in buildings can be determined:

- Firstly, life-cycle assessments to define durability and environmental impacts in various materials and construction components.
- Second, the application of durable design of reinforced concrete structures.
- Third, studies to estimate the remaining service life in buildings.
- Four, the applications of the methods to estimate service life and durability in buildings and construction components.
- Then, durable design of residential buildings.
- Analysis of façades by service life.
- Accelerated "ageing" tests in fittings and mortars.
- Durability in pavements and roads.
- Design by durability of insulating panels.
- Comparative of service life in lighting accessories.
- Durability and service life of ceramic coatings.
- Design and construction by durability of a modern-adobe dome.
- Analysis of environmental impacts on water and energy.
- Design by durability in wood components.

VI. CONCLUSIONS

Planning the service life of any project is important over the buildings' pre-design and design phase, since based on this planning the phases of construction, use, maintenance and even the end of the building's service life will be defined.

The main role of service life planning is to estimate the service life expectancy the building will have to be able to design the project according to minimal standards of durability.

The most recommendable methods to estimate service life in buildings, from the standpoint of this document's author, are those based on ISO 15686 method by factors, as it is a method of qualitative kind based on the experience of the designer and relatively easy to apply.

As a result of the revision of the scientific literature on the theory and basic information regarding service life in building design, it was found, in the first place, studies related to methods and models on the planning of service life in buildings and their construction components; followed by information referring studies on LCA in construction industry and architecture, mainly as regards quantification of CO2 emissions and environmental impacts of the energy used over the buildings' service life. The studies also focused on how to extend the service life of the buildings and their construction components, as well as the calculation of the remaining service life in existing buildings.

And as a result of the review of the scientific literature of the applications and case studies of service life on and durability in buildings, it may be concluded that the most relevant studies dealt with life-cycle assessments to find out the durability and environmental impacts of various materials and construction components, followed by studies related to the application to improve the durability of construction components made of reinforced concrete and in like manner, studies related to cases in which the remaining service life was calculated for existing buildings and construction components.

REFERENCES

Antsupov A.V., Rusanov V.A., Antsupova I.A. (2016). Modeling of Wear-Out Failures and Service Life Improvement of Sealing Units, *Procedia Engineering*, 150 (2016), 416-425. https://doi.org/10.1016/j.proeng.2016.06.757

Bahtiar E. T., Naresworo Nugroho, Mohamad M., Rahman A., Sari R. K., Wirawan W., Hermawan D. (2017). Estimation the remaining service-lifetime of wooden structure of geothermal cooling tower, *Case Studies in Construction Materials*, 6 (2017), 91-102. https://doi.org/10.1016/j.cscm.2017.01.001

Biondini F., Frangopol D. M. (2012). *Bridge Maintenance, Safety, Management, Resilience and Sustainability*, Boca Raton, FL: CRC Press/ Taylor & Francis Group.

Canadian Standards Association (2001). *S478-95 (r2001): Guideline on Durability in Buildings.* Canada: CSA.

Cheon S., Jeong H., Hwang S. Y., Hong S., Domblesky J., Naksoo K. (2015). Accelerated Life Testing to Predict Service Life and Reliability for an Appliance Door Hinge, *Procedia Manufacturing,* 1 (2015), 169-180. https://doi.org/10.1016/j.promfg.2015.09.082

Coffey S., Park S., Myers-McCarthy L. (2018). Sensitivity analysis of the mainline travel lane pavement service life when utilizing part-time shoulder use with full depth paved shoulders, *International Journal of Pavement Research and Technology*, 11 (1), 58-67. https://doi.org/10.1016/j.ijprt.2017.09.003

Da Silva L., Ruwanpura J.Y. (2009). A review of the LEED points obtained in Canadian building projects to lower costs and optimize benefits, *Journal of Architectural Engineering,* 15 (2), 38-54. https://doi.org/10.1061/(ASCE)1076-0431(2009)15:2(38)

Department for Environment, Food and Rural Affairs (2009). *Assessment and measurement of asset deterioration including whole life costing, Science Report: SC060078/SR2*, Bristol, UK: Environment Agency, UK.

Dixit M. K. (2019). Life cycle recurrent embodied energy calculation of buildings: A review, *Journal of Cleaner Production*, 209 (2019), 731-754. https://doi.org/10.1016/j.jclepro.2018.10.230

Dwaikat L. N., Ali K. N. (2018). Green buildings life cycle cost analysis and life cycle budget development: Practical applications, *Journal of Building Engineering*, 18 (2018), 303-311. https://doi.org/10.1016/j.jobe.2018.03.015

Feng H., Hewage K. (2014). Energy saving performance of green vegetation on LEED certified buildings, *Energy and Buildings*, 75 (2014), 281-289. https://doi.org/10.1016/j.enbuild.2013.10.039

Flager F. Lee (2003), The design of building structures for improve Life Cycle Performance, *Thesis of Master of Engineering in Civil and Environmental Engineering*, Massachusetts Institute of Technology, USA.

Franzoni E. (2011). Materials Selection for Green Buildings: which Tools for Engineers and Architects?, *Procedia Engineering*, 21 (2011), 883-890. https://doi.org/10.1016/j.proeng.2011.11.2090

Gao W., Chen X., Dongliang Ch. (2019). Genetic programming approach for predicting service life of tunnel structures subject to chloride-induced corrosion, *Journal of Advanced Research*, 20 (2019), 141-152. https://doi.org/10.1016/j.jare.2019.07.001

Gardner H., Garcia J., Hasik V., Olinzock M., Banawi A., Bilec M. M. (2019). Materials life cycle assessment of a living building, *Procedia CIRP*, 80 (2019), 458-463. https://doi.org/10.1016/j.procir.2019.01.021

Garrido M.A., Paulo P.V., Branco F.A. (2012). Service life prediction of façade paint coatings in old buildings, *Construction and Building Materials*, 29 (2012), 394-402. https://doi.org/10.1016/j.conbuildmat.2011.10.057

Gelowitz M.D.C., McArthur J.J. (2018), Insights on environmental product declaration use from Canada's first LEED® v4 platinum commercial project, *Resources, Conservation and Recycling,* 136 (2018), 436-444. https://doi.org/10.1016/j.resconrec.2018.05.008

Hardman B. G., Wagus C. R., Weston T. A. (2006). *Performance and Durability of the Window-Wall Interface*, USA: ASTM International.

Hasik V., Escott E., Bates R., Carlisle S., Faircloth B., Bilec M. M. (2019), Comparative whole-building life cycle assessment of renovation and new construction, *Building and Environment,* 161 (2019), article 106218. https://doi.org/10.1016/j.buildenv.2019.106218

Hasik V., Ororbia M., Warn G. P., Bilec M. M. (2019). Whole building life cycle environmental impacts and costs: A sensitivity study of design and service decisions, *Building and Environment,* 163 (2019), article: 106316. https://doi.org/10.1016/j.buildenv.2019.106316

Hernández Moreno, S., Servín Cárdenas, P. Ocampo Lugo, D. G. (2017). Comparative analysis method for service life estimation in architectural and durable design, *Entreciencias: diálogos en la Sociedad del Conocimiento*, 5 (12), 1-9. DOI: /10.21933/J.EDSC.2017.12.213

Hernández-Moreno S. (2015a). Análisis comparativo por ciclo de vida de tres tipos de luminarias empleadas en los interiores de edificios, *Nova Scientia*, 7 (14). http://www.redalyc.org/articulo.oa?id=2033/203338783028

Hernández-Moreno S. (2017). *Casos prácticos sobre estimación de la vida útil en proyectos arquitectónicos*, México: EÓN/ Universidad Autónoma del Estado de México.

Hernández-Moreno S. (2019). *Degradación y durabilidad de materiales y componentes constructivos,* México: Fac Arq. UNAM/UAEMEX.

Hernández-Moreno S., Crúz-Medina M. (2011). Sustainable Management of Domestic Water Residues and Diminution of Discharges into Municipal Collectors in Mexico, *Theoretical and Empirical Researches in Urban Management,* 6 (2), 21-34. http://um.ase.ro/no62/2.pdf

Hernández-Moreno S., de Hoyos-Martínez J. (2012). Planning for Durability in Building Projects: Strategies and Technical Recommendations According to LEED® Canada, *Business Excellence and Management*, 2 (3), 5-10. http://beman.ase.ro/no23/1.pdf

Hernández-Moreno S. (2011). Importance of service life planning in sustainable architecture, *Management Research and Practice*, 3 (3), 21-31. http://mrp.ase.ro/no33/f3.pdf

Hernández-Moreno S. (2015b). Diseño por durabilidad en las ciudades, *arquiteturarevista,* 11 (1), 22-30. doi: 10.4013/arq.2015.111.03

Hernández-Moreno S., Mejía-López M., Mendiola-Germán I., Sánchez-Vertiz-Ruiz R. L., Hernández-Moreno J. A. (2017). Green building rating systems and their application in the mexican context, *Theoretical and Empirical Researches in Urban Management*, 12 (4), 20-32. https://www.jstor.org/stable/pdf/26234012.pdf?refreqid=excelsior%3Afc7331735c3c9ba0a475366bfafee671

Hernández-Moreno, S., Ocaña-Ponce, J. A., Mejía-López, M. (2014). Application of ISO 15686 to estimate service life of a dome built with adobe technology in the city of Toluca, Mexico. *Acta Universitaria*, 24 (6), 16-20. http://www.redalyc.org/articulo.oa?id=41632950003

Hodhod O.A., Ahmed H.I. (2014). Modelling the service life of slag concrete exposed to chlorides, *Ain Shams Engineering Journal*, 5, (1), 49-54. https://doi.org/10.1016/j.asej.2013.08.001

Hovde, P.J., Moser, K. (2004). *Performance-based methods for service life prediction*, Trabajo presentado en: W080 Prediction of Service Life of Building Materials and Components (Joint CIBRILEM 2/3 Commission), International Council for Research and Innovation in Building and Construction and Swiss Federal Laboratories for Materials Testing and Research Laboratory for Concrete and Construction Chemistry (RILEM), Rotterdam, The Netherlands.

Hu M. (2019). Building impact assessment—A combined life cycle assessment and multi-criteria decision analysis framework, *Resources, Conservation and Recycling*, 150 (2019), article: 104410. https://doi.org/10.1016/j.resconrec.2019.104410

Illankoon I.M.C.S., Tam Vivian W.Y., Le Khoa N. (2019). Life Cycle Cost Analysis for Green Buildings, *Reference Module in Materials Science and Materials Engineering*, (en prensa). https://doi.org/10.1016/B978-0-12-803581-8.10784-2

Ismail M., Yew Ch. K., Muhammad B. (2016). Life-span prediction of abandoned reinforced concrete residential buildings, *Construction and Building Materials*, 112 (2016), 1059-1065. https://doi.org/10.1016/j.conbuildmat.2016.03.012

ISO (2000). *ISO 15686-1:2000; Buildings and constructed assets-Service Life Planning, part 1: General Principles*. Switzerland: International Organization for Standardization.

ISO (2011). *ISO 15686-1:2011: Buildings and constructed assets -- service life planning -- part 1: general principles and framework*, Switzerland: ISO.

Jin R., Zhong B., Ma L., Hashemi A., Ding L. (2019). Integrating BIM with building performance analysis in project life-cycle, *Automation in Construction*, 106 (2019), article: 102861, https://doi.org/10.1016/j.autcon.2019.102861

Karbhari-Vistasp M., Lee L. S. (2011). *Service Life Estimation and Extension of Civil Engineering Structures*, Woodhead Publishing, 2011. https://doi.org/10.1016/B978-1-84569-398-5.50014-6

Karim Md. R., Zain Muhammad F.M., Jamil M., Lai Fook C., Islam Md. N. (2011). Use of Wastes in Construction Industries as an Energy Saving Approach, *Energy Procedia*, 12 (2011), 915-919. https://doi.org/10.1016/j.egypro.2011.10.120Kelly D. J. (2007). *Design life of buildings: A scoping study*, Scotland: BRE.

Kiyanets A.V. (2016). Resource-saving Construction Technologies, *Procedia Engineering*, 150 (2016), 2124-2127. https://doi.org/10.1016/j.proeng.2016.07.251

Kneifel J., O'Rear E., Webb D., Landfield G. A., Suh S. (2018). *Building Industry Reporting and Design for Sustainability (BIRDS) Building Code-Based Residential Database Technical Manual*, NIST Technical Note 1999, USA: U.S. Department of Commerce. https://doi.org/10.6028/NIST.TN.1999

Lair J., Chevalier J. L., Rilling J. (2001). *Operational methods for implementing durability in service life planning frameworks*, CIB World Building Congress, April 2001, Wellington, New Zealand.

Lehner P., Křivý V., Krejsa M., Pařenica P., Kozák J. (2018). Stochastic Service Life Prediction of Existing Steel Structure Loaded by Overhead Cranes, *Procedia Structural Integrity*, 13 (2018), 1539-1544. https://doi.org/10.1016/j.prostr.2018.12.314

Li K. (2016). *Durability Design of Concrete Structures Phenomena, Modeling, and Practice*, Singapore: John Wiley & Sons.

Liang Y., Wu H., Huang G., Jianming Y., Huan W. (2017). Thermal performance and service life of vacuum insulation panels with aerogel composite cores, *Energy and Buildings*, 154 (2017), 606-617. https://doi.org/10.1016/j.enbuild.2017.08.085

LIFECON (2003). *Life Cycle Management of Concrete Infrastructures for Improved Sustainability: LIFECON DELIVERABLE D 3.2, Service Life Models*, Project information: CONTRACT N°: G1RD-CT-2000-00378. European Community under the Competitive and Sustainable Growth Programme, Finland.

Lighting Research Center (2003). *Durability testing for ENERGY STAR residential light fixtures*, final project report, United States Environmental Protection Agency (EPA), USA.

Liu X., Charles M., Bakshi B. R. (2019). Including Ecosystem Services in Life Cycle Assessment: Methodology and Application to Urban Farms, *Procedia CIRP*, 80 (2019), 287-291. https://doi.org/10.1016/j.procir.2018.12.004

López Celis R., Pérez Quiroz J. T., Torres Acosta A. A., Martínez Madrid M., Martínez Molina W., Ariza Aguilar L. E., Zamudio Cíntora E., Genescá Llongueras J., Valdez Salas B. (2006). *Durabilidad de la infraestructura de concreto reforzado expuesta a diferentes ambientes urbanos de México*, Publicación técnica N° 292, Querétaro, Mexico: Secretaría de Comunicaciones y Transportes.

MacKenzie C. E., Wang C. H., Leicester R. H., Foliente G. C., Nguyen M. N. (2007). *Timber service life design guide*, Project number: PN07.1052, Australia: Forest and Wood Products Australia Limited.

Majumdar M. (2019). *LEED: Leadership in Energy and Environmental Design: A LEED Rating System: A Global Tool to Assess Sustainability in Buildings, Communities and Cities*, Reference Module in Materials Science and Materials Engineering, Elsevier, 2019, ISBN 9780128035818. https://doi.org/10.1016/B978-0-12-803581-8.10717-9

Markeset G., Kioumarsi M. (2017). Need for Further Development in Service Life Modelling of Concrete Structures in Chloride Environment, *Procedia Engineering*, 171 (2017), 549-556. https://doi.org/10.1016/j.proeng.2017.01.371

Marteinsson B. (2005). Service life estimation in the design of buildings a development of the factor method, *Doctoral Thesis*, KTH Research School Department of Technology and Built, Centre for Built Environment Environment, University of Gävle, Gävle, Sweden.

Masters L. W., Brandt E. (1989). Systematic methodology for service life prediction of building materials and components, *Materials and Structures/Matériaux et Constructions*, 1989 (22), 385-392.

Mequignon M., Haddou H. A., Thellier F., Bonhomme M. (2013). Greenhouse gases and building lifetimes, *Building and Environment*, 68 (2013), 77-86. https://doi.org/10.1016/j.buildenv.2013.05.017

Mequignon M., Haddouc H. A. (2014). *Lifetime Environmental Impact of Buildings*, Australia: Springer.

Mohamed M. A.A. (2019). Saving Energy through Using Green Rating System for Building Commissioning, *Energy Procedia*, 162 (2019), 369-378. https://doi.org/10.1016/j.egypro.2019.04.038

Morini A. A., Ribeiro M. J., Hotza D. (2019). Early-stage materials selection based on embodied energy and carbon footprint, *Materials & Design*, 178 (2019), article: 107861. https://doi.org/10.1016/j.matdes.2019.107861

Mousa R. A., Farag A. A. (2017). The applicability of LEED of New construction (LEEDNC) in the middle east, *Procedia Environmental Sciences*, 37 (2017), 572–583. https://doi.org/10.1016/j.proenv.2017.03.044

Nägeli C., Farahani A., Österbring M., Dalenbäck J. O., Wallbaum H. (2019). A service-life cycle approach to maintenance and energy retrofit planning for building portfolios, *Building and Environment*, 160 (2019), article: 106212. https://doi.org/10.1016/j.buildenv.2019.106212

Negishi K., Tiruta-Barna L., Schiopu N., Lebert A., Chevalier J. (2018). An operational methodology for applying dynamic Life Cycle Assessment to buildings, *Building and Environment*, 144 (2018), 611-621. https://doi.org/10.1016/j.buildenv.2018.09.005

Nwodo M. N., Anumba Ch. J. (2019). A review of life cycle assessment of buildings using a systematic approach, *Building and Environment*, 162 (2019), article: 106290, https://doi.org/10.1016/j.buildenv.2019.106290

Peixoto de Freitas V., Delgado J. M. P. Q. (2013). *Durability of Building Materials and Components*, Berlin: Springer-Verlag Berlin Heidelberg. DOI 10.1007/978-3-642-37475-3

Pereira de Castro E. B., Mequignon M., Adolphec L., Koptschitz P. (2014). Impact of the lifespan of different external walls of buildings on greenhouse gas emissions under tropical climate conditions, *Energy and Buildings*, 76 (2014), 228–237. http://dx.doi.org/10.1016/j.enbuild.2014.02.071

Pillai R. G., Gettu R., Santhanam M., Rengaraju S., Dhandapani Y., Rathnarajan S., Basavaraj A. S. (2019). Service life and life cycle assessment of reinforced concrete systems with limestone calcined clay cement (LC3), *Cement and Concrete Research*, 118 (2019), 111-119. https://doi.org/10.1016/j.cemconres.2018.11.019

Pulselli R.M., Simoncini E., Pulselli F.M., Bastianoni S. (2007). Emergy analysis of building manufacturing, maintenance and use: Em-building indices to evaluate housing sustainability, *Energy and Buildings*, 39 (5), 620-628. https://doi.org/10.1016/j.enbuild.2006.10.004

Ranjith A., Rao K. Balaji, Manjunath K. (2016). Evaluating the effect of corrosion on service life prediction of RC structures – A parametric study, *International Journal of Sustainable Built Environment*, 5 (2), 587-603. https://doi.org/10.1016/j.ijsbe.2016.07.001

Rauf A., Crawford R. H. (2015). Building service life and its effect on the life cycle embodied energy of buildings, *Energy*, 79 (2015), 140-148. https://doi.org/10.1016/j.energy.2014.10.093

Raupach M., Büttner T. (2014). *Concrete Repair to EN 1504: Diagnosis, Design, Principles and Practice*, Boca Raton, FL: CRC Press/ Taylor & Francis Group.

Rezaei F., Bulle C., Lesage P. (2019). Integrating building information modeling and life cycle assessment in the early and detailed building design stages, *Building and Environment*, 153 (2019), 158-167. https://doi.org/10.1016/j.buildenv.2019.01.034

Robati M., Daly D., Kokogiannakis G. (2019). A method of uncertainty analysis for whole-life embodied carbon emissions (CO2-e) of building materials of a net-zero energy building in Australia, *Journal of Cleaner Production*, 225 (2019), 541-553. https://doi.org/10.1016/j.jclepro.2019.03.339

Rodrigues F., Matos R., Alves A., Ribeirinho P., Rodrigues H. (2018). Building life cycle applied to the refurbishment of a traditional building from Oporto, Portugal, *Journal of Building Engineering*, 17 (2018), 84-95. https://doi.org/10.1016/j.jobe.2018.01.010

Saba D. (2013). Investigating the Durability of Structures, *Thesis of Master of Engineering in Civil and Environmental Engineering*, Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology, USA.

Serralheiro M. I., de Brito J., Silva A. (2017). Methodology for service life prediction of architectural concrete facades, *Construction and Building Materials*, 133 (2017), 261-274. https://doi.org/10.1016/j.conbuildmat.2016.12.079

Setyawan A., Nainggolan J., Budiarto A. (2015). Predicting the Remaining Service Life of Road Using Pavement Condition Index, *Procedia Engineering*, 125 (2015), 417-423. https://doi.org/10.1016/j.proeng.2015.11.108

Shohet I. M., Paciuk M. (2004). Service life prediction of exterior cladding components under standard conditions, *Construction Management and Economics*, 22 (2004), 1081–1090. DOI: 10.1080/0144619042000213274

Silva A., de Brito J. (2019). Do we need a buildings' inspection, diagnosis and service life prediction software?, *Journal of Building Engineering*, 22 (2019), 335-348. https://doi.org/10.1016/j.jobe.2018.12.019

Silva A., Dias J.L., Gaspar P.L., de Brito J. (2013). Statistical models applied to service life prediction of rendered façades, *Automation in Construction*, 30 (2013), 151-160. https://doi.org/10.1016/j.autcon.2012.11.028

Silva R.V., de Brito J., Dhir R.K. (2019). Use of recycled aggregates arising from construction and demolition waste in new construction applications, *Journal of Cleaner Production*, 236 (2019), article: 117629. https://doi.org/10.1016/j.jclepro.2019.117629

Sjöström, C., Jernberg, P. (2010). International standards for design life of constructed assets. En: *CIB World Building Congress*, paper 192, (pp. 1-6), (CIB). Wellington, New Zealand. Bruno Daniotti y Fulvio Cecconi (Ed.). CIB W080: Test Methods for Service life Prediction. Rotterdam (pp. 1-6), CIB Publication, The Netherlands. http://site.cibworld.nl/dl/publications/w080_wg3_report.pdf

Smith T.M., Fischlein M., Suh S., Huelman P. (2006). *Green Building Rating Systems: a Comparison of the LEED and Green Globes Systems in the US*, USA: USGBC. https://www.researchgate.net/publication/230838441_Green_Building_Rating_Systems_a_Comparison_of_the_LEED_and_Green_Globes_Systems_in_the_US

Souza J., Silva A., de Brito J., Bauer E. (2018). Service life prediction of ceramic tiling systems in Brasília-Brazil using the factor method, *Construction and Building Materials*, 192 (2018), 38-49. https://doi.org/10.1016/j.conbuildmat.2018.10.084

Taffese W. Z., Sistonen E. (2016). Neural network-based hygrothermal prediction for deterioration risk analysis of surface-protected concrete façade element, *Construction and Building Materials,* 113 (2016), 34-48. https://doi.org/10.1016/j.conbuildmat.2016.03.029

Taffese W. Z., Sistonen E. (2013). Service Life Prediction of Repaired Structures Using Concrete Recasting Method: State-of-the-Art, *Procedia Engineering*, 57 (2013), 1138-1144. https://doi.org/10.1016/j.proeng.2013.04.143

Torres-Acosta A. A., Martínez-Madrid M. (2001). *Diseño de estructuras de concreto con criterios de durabilidad:* Publicación Técnica No. 181, México: Secretaría de Comunicaciones y Transportes, Instituto Mexicano del Transporte.

Venta G. J. (1998). *Life Cycle Analysis for of bricks and mortar products*, Canada: ATHENA™ Sustainable Materials Institute.

Vieira S.M., Silva A., Sousa J.M.C., de Brito J., Gaspar P.L. (2015). Modelling the service life of rendered facades using fuzzy systems, *Automation in Construction*, 51 (2015), 1-7. https://doi.org/10.1016/j.autcon.2014.12.011

Wu P., Mao Ch., Wang J., Song Y., Wang X. (2016*). A decade review of the credits obtained by LEED v2.2 certified green building projects, Building and Environment*, 102 (2016), 167-178. https://doi.org/10.1016/j.buildenv.2016.03.026

Wuyts W., Miatto A., Sedlitzky R., Tanikawa H. (2019). Extending or ending the life of residential buildings in Japan: A social circular economy approach to the problem of short-lived constructions, *Journal of Cleaner Production*, 231 (2019), 660-670. https://doi.org/10.1016/j.jclepro.2019.05.258

Yrieix B., Morel B., Pons E. (2014). VIP service life assessment: Interactions between barrier laminates and core material, and significance of silica core ageing, *Energy and Buildings*, 85 (2014), 617–630. http://dx.doi.org/10.1016/j.enbuild.2014.07.035

Zou Y. (2019). Certifying green buildings in China: LEED vs. 3-star, *Journal of Cleaner Production*, 208 (2019), 880-888. https://doi.org/10.1016/j.jclepro.2018.10.204