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Application of Service Life Planning to Existing Buildings – Perspectives on Condition Appraisal, Performance and Cost

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Abstract. *ISO 15686 on Service Life Planning of Constructed Assets provides guidance which is applicable to both new and existing constructed assets and their parts. However, there has been limited exposition of the applicability of the guidance to existing buildings. This paper provides perspectives on practical application of the principles to condition assessment (survey and appraisal) of the long-term performance of existing buildings, in particular in respect of the building envelope and how maintenance interventions and life cycle costs are predicted or estimated. The authors are currently actively involved through CIB W080 and ISO TC59/SC14 in preparing for the revision of the ISO 15686 standards to take account of experience over the last 20 years, including the development of the factor method and its applicability, and guidance on life cycle costing of existing buildings. The paper will develop key themes from the series of ISO 15686 standards, which are particularly relevant to assessment of existing buildings and other constructed assets.*

Keywords: *Residual Service Life, ISO 15686, Existing Buildings, Life Cycle Cost, CIB W080.*

1 Introduction

ISO 15686 on Service Life Planning is a series of standards which provide guidance on the overall process of service life planning, and different parts focus on different aspects of principles, techniques and methods. The scope of the whole Standard applies to both new and existing buildings and built assets, but the original focus was much more on planning at design stage, and it includes only limited specific guidance to adopt or adapt the principles to application to existing buildings or built assets. Currently, CIB W080 commission (Prediction of Service Life of Building Materials and Components) is actively involved in supporting the work of revision of most parts of ISO 15686 as part of its work to support pre-standardisation in this area.

ISO 15686-7 (ISO, 2017) deals with performance evaluation from practice, including the use of data from surveys. In this part of the standard, the Factor Method is seen as a general framework to deal with the project-specific in-use conditions, which often differ from those assumed in the reference in-use conditions which underly the Reference Service Life, covered in ISO 15686-8 (ISO, 2008). Part 7 recognises that in-use conditions and performance requirements can be subjected to change during the use phase of the life cycle. Additionally, it recognises that grades may be used to indicate both the condition of the assets (termed Performance Degrees – ranging from 0 or No Symptoms to 4 or Totally Unacceptable) and the reference service life Factor Categories (ranging from 0 – not available, rarely used to 5 where the in-use condition is very low or the Category is very severe). The (residual) service life is predicted from the level of the Performance Degree and the limit state or acceptable level of performance. Performance degrees can be correlated with exposure environmental conditions to develop damage functions.

This paper describes the application of this general guidance to two specific aspects of practice. Firstly, the application of the Factor Method to building envelopes on existing buildings was assessed and developed through on-site surveys in association with comprehensive literature reviews. In the second part of the paper, the application of ISO 15686 guidance to life cycle costing of existing buildings was undertaken in development of British Standard BS 8544, which also required consideration of performance, condition and residual service life. Finally, this paper intends to identify some common themes which are relevant to assessment of residual service life and how they impact cost and environmental assessment in particular.

2 Service Life of Building Envelope Components

2.1 Estimated Service Lives

A comprehensive literature review (Silva and de Brito, 2021) of published studies on the service life of different building envelope elements found a wide range of estimated or expected service lives. The ranges broadly were as follows: i) Rendered facades – 5 years to more than 60 years; ii) Painted surfaces – 3 years to 11 years – with a single outlier of more than 60 years; iii) Natural stone claddings – 25 years to 90 years; iv) Ceramic claddings – 18 year to 61 years; v) External Thermal Insulation Composite Systems (ETICS) – 10 years to 40 years; vi) Architectural Concrete Facades – 10 years to more than 60 years. A detailed analysis of these values reveal that there were different assumptions, designs, in-use and exposure conditions, and that in practice there were narrower expected life ranges once these variables were controlled. A proposed database includes source, region, climatic condition, and sample size as well as the service life (range) and commentaries. It was possible to derive an average and a standard deviation based on the sources reviewed for the façade claddings, and additionally pitched roof claddings and window frames were also reviewed.

A review on reference service life guidance for the Middle East Facility Management Association (*A MEFMA Publication Facility and Equipment Reference and Estimated Service Life Research Report*, 2014) and a long-standing dataset published by CIBSE in UK (Guide M on Maintenance, which includes an Appendix of expected service lives for building services equipment based on economic performance) also include fairly wide ranges similar to these for estimated service lives of other building components in use.

2.2 Process of Deterioration of Cladding Components

The deterioration associated with building cladding components were examined by Shohet and Paciuk (Shohet and Paciuk, 2006). They demonstrate that there is a period of time during which deterioration continues in a linear trend, followed by a period during which deterioration becomes non-linear and accelerates. Their review of 154 samples across three types of envelope façade coatings (cementitious mortar, synthetic rendering and ceramic mosaic tiles) indicates that there were failure mechanisms which determined the point at which each system reached its limit state of acceptable performance. These directly affected the predicted service life. Their review also confirmed that faulty design or workmanship might be the cause of early failures, and might in some circumstances multiply the influence of the environmental agents generating exponential failures (e.g. in the case of adhered ceramic mosaic tiles where inadequate movement joints were provided).

2.3 Service Life of Renders

The condition of 100 rendered facades was analysed by Silva et al. (2016). Degradation agents and conditions were assessed based on an in situ review. Here again dynamic impacts were identified, and uncertainties impact on both the service life estimation due to both the randomness of environmental activity and limited ability to predict future events. Staining, cracking and loss of adherence to the substrate were identified as the main failure modes for renders, in order of seriousness of impact. Cracking can lead to water ingress, which may trigger detachment due to freeze/thaw action, leading to spalling and the end of life. This transition progress through different states links the failure modes to the condition assessment in the surveys. The examination of failures also highlighted the relevance of different environmental conditions, including the presence of maritime environments with salt spray, dampness and exposure to wind driven rain or a polluted environment all being aggressive environments which accelerate degradation. Of all the factors studied, distance from the sea was considered the most critical for early degradation, and it was considered overall the most important environmental factor, but absence of pollution delayed the rate of progress through the final stages of degradation to the point where performance was considered unacceptable. The paper also describes that ‘high, average or low’ qualitative ratings of risk on condition grading correlated with cost of repair and urgency of maintenance interventions to arrest degradation.

2.3 Service Life of Natural Stone Claddings

The issue of decision-making in respect of maintenance was specifically addressed by Silva et al. (2012) in respect of natural stone claddings. This included mapping the degradation agents affecting claddings against the Factor Categories within ISO 15686-8 for use of the Factor Method. They considered type of stone, colour of stone, type of finishing, distance from the sea, orientation, exposure to wind driven rain and exposure to damp and derived expected service lives for different levels of ‘acceptable condition’. The paper confirmed that distance from the sea and level of exposure to wind driven rain are both critical variables. Height of the building also had an influence within the dataset set reviewed, but it was not clearly correlated with deterioration, it might have originated in the occupants (in)ability to pay for maintenance. The size of the stone plates and associated joints and stresses were a relevant variable, and this triggered an examination of the level of degradation that was considered to be acceptable or otherwise for different tenures of building (domestic or commercial). Vandalism was also found to be a highly relevant factor (although it should be noted that suddenly operating forms of deterioration (such as fire or flood) are generally considered to fall outside the area of service life planning. Nevertheless, the presence or absence of abuse by occupants or the public may be a relevant consideration in respect of the point at which the service limit is reached. Overall, degradation severity is considered to relate to four failure paths in order of magnitude, namely:

i) Age; ii) Distance from the sea; iii) Type of finishing; iv) Size of the stone plates. Each of these are associated with different sub-factors which can be used to calibrate the values used in the Factor Method calculation to reflect the combination of relevant degrading agents. For example, in Portugal, North and West facing facades are likely to deteriorate sooner, as they tend to be damper, cooler and face the prevailing wind.

2.4 Service Life of Paint Finishes

The application of the Factor Method to paint finishes on the external building envelope was considered by Magos et al. (2016). A field survey of 323 coatings in situ highlighted that both external environmental conditions and the substrate were critical factors affecting the service life of paint finishes. Older buildings (i.e., those built prior to widespread adoption of Portland cement in renders, which typically used lime-based materials) had higher water and soluble salts in the substrate, thereby requiring a suitably permeable coating to allow water vapour to escape, while still providing sufficient resistance to the ingress of liquid water. Similarly to the other papers, the key features considered in addressed values for the use of the Factor Method estimates were distance from the sea, exposure to damp, exposure to wind-driven rain, orientation of facades and exposure to pollution sources. A five-point scale of degradation was adopted, with Level 3 (20% degradation) used as the limit state to establish the end of service life. Various failure modes were considered, ranging from staining and discolouration to cracking, peeling and blistering.

South facing façades tend to present lower degradation rates (due to reduced period of wetness as a result of higher solar radiation). But the level of solar radiation did increase the rate of the less critical failures such as discolouration. Textured paints showed better resistance to degradation than smooth ones. Paint coatings applied to render performed worse than those applied to previous paint layers. This result was considered to probably be attributable to variations of render over the first few years after application (presumably due to the occurrence of efflorescence). But the critical issue was maintenance, those which were easier to inspect (and presumably therefore also easier to maintain) had higher estimated service lives. The most critical features for impact on the service life were considered to be the distance from pollution sources and the orientation of the façade.

3 Life Cycle Costing – UK Guidance on Application to Existing Building Components

3.1 UK Implementation of ISO 15686-5 Principles

Life cycle costing is dealt with in ISO 15686-5 (ISO, 2017), and, alongside other parts of the series, currently primarily addresses service life planning at design stage, but does include principles which are equally applicable to existing buildings and components. Amongst other aspects it recognizes that client requirements may change post completion of a building project, that life cycle costing (LCC) may be a relevant technique in assessing different investment scenarios, such as adapting or redeveloping an existing facility, and that generally it is used going forward from whatever stage of the procurement or use phase of the life cycle that is current at the time of assessment. Earlier costs are considered spent, and not considered in cost analysis. It is presumed that LCC is progressively revised as better data becomes available. It acknowledges that for existing facilities the LCC plan is developed from current information and survey information used to fill in information gaps. It requires both timing and costs during operation and maintenance to be defined. Maintenance is widely defined, including reactive, proactive and preventative maintenance, as well as replacements and associated management activities.

ISO 15686-5 requires emphasis to be given to the most significant cost variables. It recognizes that the service life, life cycle and design life may vary from each other, and from the period of analysis. The period of foreseeable need or occupation of the asset (the entire life cycle) is the preferred period of analysis. A shorter period (e.g., reflecting contractual liabilities or standard investment periods), or costs beyond the period of analysis may nevertheless impact on the client, in which case they may need to be considered. It explicitly states that obsolescence should be considered in setting the period of analysis 'as it can cause the unplanned end-of-service life or a change of use'. It also endorses sensitivity analysis to demonstrate the impact of changing assumptions on variable value, recommending that plausible ranges of uncertainties should be considered, indicating that the major effects can be associated with changes in the period of analysis or the discount rate, or on unreliable assumptions about maintenance, repair or replacement cycles or costs. The informative worked examples include tables showing the effect of changing the discount rates, the costs or the estimated service lives.

Within the UK the original publication of ISO 15686-5 in 2008 was simultaneous with an industry-sponsored guidance document - the Standardised Method of LCC (BCIS, 2008). This provided links to existing capital cost breakdown structures and data sources allowing cost consultants to apply the principles in the ISO with clear and consistent mapping and worked examples. This was followed in 2013 by BS 8544 (BSI, 2013) which did the same explicitly for applying LCC principles to existing buildings. The objective of this was stated as to 'fully integrate the process of creating and implementing two plans: maintain and renewal'. The prime purpose for LCC of maintenance is to calculate the cost to maintain an acceptable level of performance of the asset(s), including replacing with like for like or modern equivalents. The process of undertaking LCC of maintenance takes place in four stages: i) Brief – covering scoping, strategy, methodology and assembly of existing data; ii) Capture – covering reworking of existing data, identifying gaps in data, identifying additional data and undertaking initial LCC planning; iii) Evaluate – covering review of plans against budgets, prioritization against funding scenarios, budget allocation and works scheduling and approval of plans; iv) Implement – covering preparation of works programmes, expenditure with associated monitoring and auditing, period review, data updating, and evaluation of lessons learned.

The typical applications for LCC of maintenance were considered to be (Figure 1): i) For evaluation of whether to maintain or invest in the whole building or in functional units; ii) For evaluation of detailed options (e.g. when to repair or replace) at various levels of detail (elemental, system, sub-elemental or component level); iii) To audit provision of maintenance plans on behalf of the funder or other stakeholder groups responsible for maintenance; iv) To use LCC of maintenance plans as part of a wider estate or portfolio level review for relocation or consolidation strategies. BS 8544 explicitly covers the need to achieve an optimal balance between maintenance and renewal works, while avoiding over or under-maintaining. The brief for the LCC work needs to cover the maintenance life cycle strategy (e.g. compliance levels required to meet safety, customer experience, resilience or sustainability targets) which may vary from project to project. It also explicitly requires that the methods, rules and assumptions should be transparent with obvious data gaps to be resolved by e.g. surveys of physical condition assessment and remaining life assessment. It requires recognition of short term budgets (annual) and medium- or longer-term budgets, to support the maintenance and renewal plans. Maintenance and renewal tasks must be ranked in order of priority to ensure that essential works can be met within the budget limitations. It is recognized that some works may be deferred, but that there will be both cost and potentially performance implications of deferrals. All maintenance works fall into one of the following categories: i) Absolute minimum – required to meet statutory / legal and mandatory obligations; ii) Optimal – fit-for-function critical maintenance – required to meet business needs and functional usage; iii) Discretionary – potential to defer or to adopt a ‘run to failure’ policy for non-critical assets; iv) Vacate space strategy – works necessary to maintain a safe and secure facility while it is in the process of decommissioning or while it is ‘mothballed’, i.e. not in use pending a decision being made about its future use.

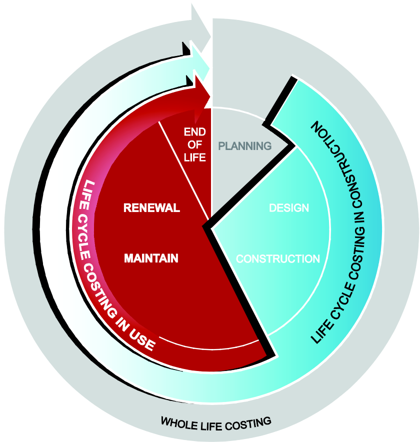

Figure 1. LCC in construction projects and LCC in use

3.2 Techniques Included for Reporting and Prioritization of Works

Once the required works are identified a process of determining criticality and associated prioritization typically follows. Business criticality techniques considered include not only the compliance requirements but also reputational risks and the availability of resources (both cost and human resources). The other aspect is understanding how the current and future projected asset performance helps to identify the predicted interventions (timing and level of investment). There are worked examples such as: i) Asset criticality ranking (often using red/amber/green RAG ratings); ii) Predicted Asset Remaining Life (PARL) ranking – where parameters on expenditure are used to trigger interventions, e.g. major repairs to critical assets when PARL is less than 20% but greater than 5%; iii) Condition categorization and ranking – examples of ranking methods which provide a qualitative attribution of condition with associated actions; iv) Facility Condition Indexing (FCI) – which provide triggers for interventions or disinvestment when remedial works cost reaches a set percentage of renewal cost, e.g. 25%.

3.3 Asset Data Structures

BS 8544 contains breakdowns of how asset data at different levels within an organization can be mapped to bring the information together. A worked example covers data from a custodial (prisons) estate covering the hierarchy of Region, Site, Building/ Block, Floor, Space and System or Component. The asset taxonomy below that goes into the specific type of component and the specification, and it is at this level that both reference service life and maintenance can be allocated generically. Guidance on maintenance schedules published by BESA (see https://www.sfg20.co.uk) or in-house data sets can be used to provide required maintenance at component level, together with associated time, frequency and skill allocations which permit costing to be assessed. A specific instance or example of a component will have its own condition and environmental assessment, and these will affect the remaining service life.

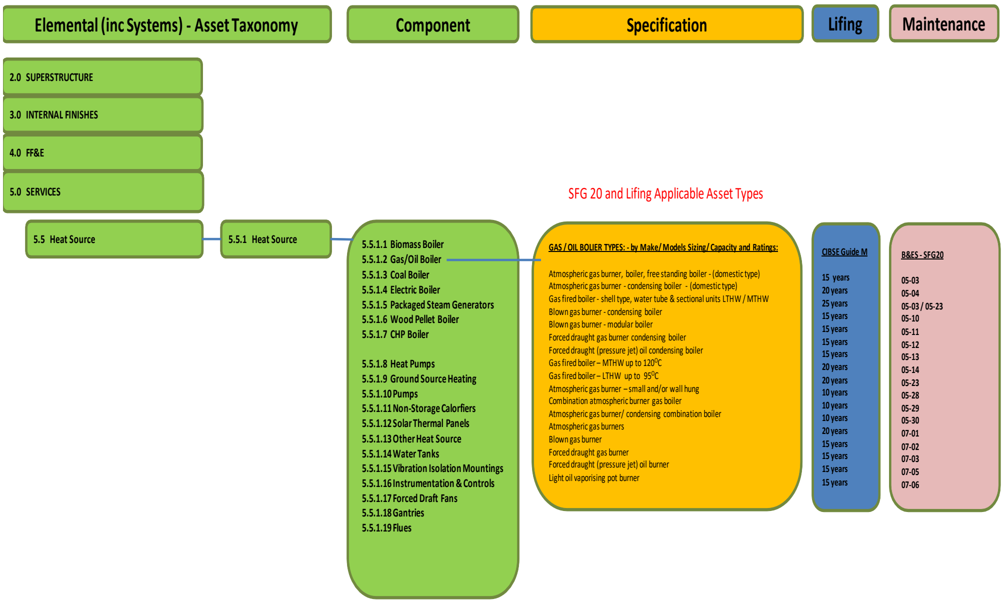

Figure 2. Asset Data Structure from BS 8544

4 Future Application of Service Life Planning to Existing Buildings and Components

In the same way as people, buildings age which results in degradation of some aspects of performance; ultimately buildings and their components reach a service limit which is difficult to define but critical to establish when estimating service lives. The difference between some ultimate technological limit to life and the limit imposed by acceptability in use is discussed in recent papers on the links between obsolescence and the end of the service life (Silva et al., 2021). Typically, a conventional limit state description is required to ascertain the point at which utility is deemed inadequate, as users' requirements constantly change over time. The concept of serviceability - based on work during the 1980's and 1990's, including by past members of CIB W080 such as Brandt, Masters, Davis and Szigetti - has been further developed (Thomsen, 2015) to bring in the concept of obsolescence being on a matrix covering endogenous to exogenous drivers, resulting in a range of physical and behavioural manifestations of obsolescence. The end of service life can be triggered by physical degradation, by changing functional and technological demands, by changing legal requirements, by social or by aesthetic demands. It can also be driven by unacceptable cost in use or by inability to maintain to reverse or limit degradation. Obsolescence may appear before physical degradation is present, and therefore the concept of the 'match' between performance and demand will need to be considered in future work. The guidance will need to evolve to provide clarity on how to use the understanding of what is serviceable, acceptable and remains useful in estimating the service life of components and buildings. There is a balance to be struck between accuracy and pragmatism, but how data is recorded and mapped will be critical to using it in future. We can now recognize that not only the service life, but also the maintenance interventions, their impact and cost and therefore the number of cycles required in the remaining service life affects not only the LCC but also estimates of environmental impact using life cycle analysis (LCA) and beyond that in adoption of circular economy (CE) principles. We also can see that the drivers of degradation are inherently linked to climate change and to the scenarios modelling different futures.

References

BCIS and British Standards Institution (2008). *PD 156865 Standardised Method of Life Cycle Costing in Construction*.

British Standards Institution (2013). *BS 8544 Guide for life cycle costing of maintenance during the in-use phases of buildings.*

CIBSE (2014 / 2020). *Guide M Maintenance Engineering and Management – A guide for Designers, Maintainers, Building Owners and Operators and Facilities Managers, with revised Appendix 12.*

ISO/TC59/SC 14 (2017). *ISO 15686-5: Buildings and constructed assets – Service-life planning – Part 5: Life-cycle costing.*

ISO/TC 59/SC 14 (2017). *ISO 15686-7: Buildings and constructed assets — Service-life planning — Part 7:* Performance evaluation for feedback of service life data from practice.

ISO/TC 59/SC 14 (2008). *ISO 15686-8: Buildings and constructed assets — Service-life planning — Part 8: Reference service life and service-life estimation*.

Magos, M., de Brito, J., Gaspar, P.L., Silva, A. (2016). *Application of the factor method to the prediction of the service life of external paint finishes on facades.* Materials and Structures, 49, 5209-5225.

Middle Eastern Facility Management Association MEFMA (2014). *Facility and Equipment Reference and Estimate Service Life Research Report.*

Shohet, I. M., Puterman, M., and Gilboa, E. (2002). *Deterioration patterns of building cladding components for maintenance management*. Construction Management and Economics, 20(4), 304-314.

Silva, A., de Brito, J., and Gaspar, P. L., (2012). *Application of the factor method to maintenance decision support for stone cladding*. Automation in Construction, 22, 165-174.

Silva, A., Neves, L. C., Gaspar, P. L., de Brito, J (2016). *Probabilistic transition of condition: render facades*. Building Research and Information, 44(3), 3010318.

Silva, A., and de Brito, J., (2021a). *Service life of building envelopes: A critical literature review*. Journal of Building Engineering, 44, 102646.

Silva, A., de Brito, J., and Gaspar P. L., (2021b). *Conceptualization of service life prediction in Report Prepared by CIB W080 - Prediction of Service Life of Building Components and Materials.*

Thomsen, A., van der Flier, K., and Nieboer, N., (2015). *Analysing obsolescence, an elaborated model for residential buildings*. Structural Survey, 33(3), 210-227.