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Recent advances in methods for service life prediction of building materials and components – an overview

SESSION: CIB T5S2 Service Life Prediction

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ABSTRACT

The need for "Sustainable Construction" necessarily imposes inherent requirements for specified levels of durability of building materials and components and it is understood that these can only be entrenched within the construction sector through standardization. However, a systematic and scientific approach to the development of these standards is fundamentally required. Hence, development work on methods for service life prediction is vital to achieving the necessary basis for the advancement of useful standards. Given the level of interest both nationally and internationally regarding achieving durability in products, standardization activities related to "service life and durability" are thus an on-going concern. Work generated within the CIB W80 / RILEM committee provides a basis for developing the necessary information from which standards can thereafter be drafted. This brief report provides an overview of recent activities of the CIB W80 / RILEM TC, its on-going work program and proposed programs of activities for 2003-2005. As well, insights into the collaborative efforts and related activities within ISO TC 59 SC14 and the PeBBu are offered.

Recent advances in methods for service life prediction of building materials and components – an overview

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ABSTRACT

The need for "Sustainable Construction" necessarily imposes inherent requirements for specified levels of durability of building materials and components and it is understood that these can only be entrenched within the construction sector through standardization. However, a systematic and scientific approach to the development of these standards is fundamentally required. Hence, development work on methods for service life prediction is vital to achieving the necessary basis for the advancement of useful standards. Given the level of interest both nationally and internationally regarding achieving durability in products, standardization activities related to "service life and durability" are thus an on-going concern. Work generated within the CIB W80 / RILEM committee provides a basis for developing the necessary information from which standards can thereafter be drafted. This brief report provides an overview of recent activities of the CIB W80 / RILEM TC, its on-going work program and proposed programs of activities for 2003-2005. As well, insights are provided into the collaborative efforts and related activities within ISO TC 59 SC14 – "Design life" and the Performance based building (PeBBu) thematic network initiative focused on "Construction materials" of the fifth EC framework on Competitive and Sustainable Growth.

INTRODUCTION

Considerable work has been carried out in the area of service life prediction as requisite tools for helping assess long-term environmental effects, for maintenance management of infrastructure systems, such as roads, bridges, waterways, water distribution and waste-water removal systems, or indeed for maintenance of building envelope systems, envelope components and related materials. Increasingly, building material and component manufacturers are seeking systematic methods to assess the likely risk to premature deterioration of existing products given specific climatic effects, or the most vulnerable exposure conditions of new products in specified systems.

The current joint CIB / RILEM technical committee (CIB W80 / RILEM TC 175-SLM) on methods of service life prediction of building materials and components was created in September 1996. Prior to this, the joint CIB W80 / RILEM Committees (71-PSL, 100-TSL and 140-TSL) have been responsible for a preparing a series of useful working documents [e.g. Sneck 1982; Masters and Brandt 1989; Sjöström and Brandt 1991] as well as co-ordinating the efforts required to bring about nine international symposia related to durability and service life issues and a tenth being planned for 2005 in Lyon, France. The number of significant contributions collectively presented in these conference proceedings provides a substantial depth of knowledge to the field [Vanier et al. 1999]. Full utilization of this body of knowledge for the benefit of manufacturers of building materials and components, designers, specifiers, constructors, as well as asset and property managers, requires the development of suitable guides and related information.

It is the aim of CIB W80 working jointly with the RILEM 175-SLM, to help develop the necessary guides, methods, and techniques that will enable practitioners to select the appropriate tools to predict service life. To achieve this aim, the focus of the technical committee is on integrating existing prediction and service life techniques, tools, and methods. This on-going exercise has in

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part been achieved through the committees' on-going support in developing the ISO standard 15686 prepared by the ISO TC59 SC14 on Design Life. The development of this standard has brought about broad recognition of the need to assess durability of components in all construction standards and this is being address in the EU and other national standards bodies. Additionally, on-going collaborative efforts with the PeBBu are likewise increasing the outreach of work being carried out within the CIB W80/RILEM technical committee (TC). This brief report provides an overview of recent activities of the CIB W80/RILEM TC, including collaborative efforts and outreach activities, and proposed programs of activities for 2003-2005.

ACTIVITIES OF THE CIB W80 / RILEM TC 175-SLM

Activities of CIB W80 extend back to 1978 and it has since seen different designations, the current one being CIB W80 / RILEM 175-SLM "Service life methodologies". It is at present in its third work term and the membership last met following the "International Workshop on Management of Durability in the Building Process" held in June 2003 in Milano, Italy [Daniotti 2003]. This provided further opportunities to finalise a work program for the 2003-2005 work term. An overview of collaobrative efforts with standards development is provided, recent activities of the second work program (1999-2002) are offered, and a brief outline is given of the proposed work program.

Collaborative efforts and outreach

The CIB W80/RILEM committee has always maintained links with related CIB committees such as the W60 on performance-based standards, W94 on Design for durability and W86 on Building pathology. However, since 1993 its outreach has been extended in large part due to its close collaboration with both the ISO technical activities, in particular the ISO TC 59 SC 14 (Service life planning), and the Performance based building (PeBBu) initiative undertaken within the context of the fifth EC framework for collaborative thematic research on Competitive and Sustainable Growth. Brief overviews describing the nature of each collaborative effort are provided below.

Collaboration with ISO
The committee has been actively linked to the developed of an ISO standard on service life planning at least since 1993 when an ad hoc committee within the CIB W80 was formed to review the feasibility of supporting the development of a standard on service life planning. The basis for this initiative was the work that had been carried out within the CIB W80 over previous work periods as well as the various other initiatives that had or were taking place at the time. Particular mention is made of the Architectural Institute of Japan's *Principal guide for service life planning,* first published in 1991 but later translated to English in 1993 [AIJ 1993], the British Standard Institution [BSI 1992] *Guide to durability of buildings and building elements, products and components* and the Canadian Standards Association [CSA 1995] *Guideline on durability in buildings.*

In 1998, ISO TC 59 SC14 (service life planning) was created following which, the first three parts of the standard, ISO 15686 Buildings and Constructed Assets – Service Life Planning, were published in successive years starting in 2000. A brief overview of the different parts in provided below.

<u>Summary of standard and current progress</u> -
Part 1 - General principles [ISO 2000] - describes the principles and procedures that apply to design, when planning the service life of buildings and constructed assets. It is important that the design stage includes systematic consideration of local conditions to ensure, with a high degree of probability, that the service life will be no less than the design life. The standard is applicable to both new constructions and the refurbishment of existing structures.

Part 2 - Service life prediction procedures [ISO 2001a] - of the standard is mainly based on the Service Life Methodology developed by Masters and Brandt [1989]. It describes a procedure that facilitates service life predictions of building components. The general framework, principles, and requirements for conducting and reporting such studies are given.

Part 3 - Performance audits and reviews [ISO 2002] - is concerned with ensuring the effective implementation of service life planning. It describes the approach and procedures to be applied to pre-briefing, briefing, design, and construction and, where required, the life care management and disposal of buildings and constructed assets to provide a reasonable assurance that measures necessary to achieve a satisfactory performance over time will be implemented
Other parts on which work has commenced include:

- "Data requirements" (Part 4) intended for describing requirements of data in order to estimate the service life of a structure, building system, or building
- "Life cycle costing" (Part 5) to enable comparative assessment of the cost performance of buildings and constructed assets over an agreed period of time and
- "Guidelines for considering environmental impacts" (Part 6) - provides guidance on assessing the relative environmental impacts of alternate service life designs
- “Maintenance and condition assessment protocols for buildings" (Part 7) - guidance for improving the quality of durability and service life data derived from condition assessment of the existing building stock.
- "Reference service life" (Part 8) – provides guidance on the provision of reference service life for use in the application of ISO 15686-1 [ISO 2001b].

A more detailed overview of the ISO 15686 series of standards is provided by Sjöström et al. [2002]. Work undertaken within the CIB W80 / RILEM 175-SLM directly supports development of the standard.

Activities related to the PeBBu
(i) Background - The EU thematic network PeBBu (Performance Based Building) was initiated in 2001 as part of the broader fifth EC framework for collaborative thematic research on Competitive and Sustainable Growth [Sjöström and Lair 2003]. The specific domain within the PeBBu on Construction Materials and Components is to address issues related to the implementation and adoption of the performance-based standard on service life planning developed as the standard, ISO 15686. The impetus for this specific initiative emerged from the European Construction Products Directive (CPD) [Council of the European Communities 1988] that specifies the Essential (Performance) Requirements that should be met of constructed works during their intended working life. This necessarily resulted in the need for establishing performance requirements on all building products from which the life performance of the materials and products likewise has now to be assessed and declared
.
(ii) State-of-the-art The key idea in life design of a constructed work is the assumption that for each building component or product there is a reference service life that can be adjusted by factors (e.g. environmental load, material quality, workmanship, and other related factors) describing deviations from the reference situation to the actual building construction conditions. This permits reaching an adjusted service life estimate for the component or product that is then used in estimating the service life of the building or component. This factorial approach (‘factor method’) needs further development and refinement as regards the factors, the theoretical calculation methods, and the reference life data to be used. Of importance to the successful development of the PeBBu, is the involvement of the construction industry sector, as the main supplier of reference life data on materials and products must be the relevant industries.

Objective, approach and focus - The intent is to foster, through the planned PeBBu workshops and support documentation, the further development, and anchoring the performance concept in the domain of materials and products with industry stakeholders. This will be achieved by providing guidelines (pre-standardisation) support documents on the life performance of materials and products. The project will focus on two basic items:

(i) Further development of the Factor method

(ii) Exploring and describing conditions and prerequisites for reference service life (performance) data for classes of building materials and components.

It is intended that activities within the CIB W80 / RILEM 175-SLM will help support development of both of the main focal points of this PeBBu domain. Additional and more detailed information regarding the PeBBu initiative are presented in Sjöström et al. [2002] and Sjöström and Lair. [2003].

Recent work carried out in CIB W80 / RILEM-175 SLM

The most recent work programme of CIB W80 / RILEM-175 SLM concluded in early spring 2002 and publication of reports is on-going. Activities in this work program were focussed on further developments of service life and durability methods in two key areas:

(i) Environmental characterization

(ii) Reliability and probabilistic methods

Within each of these areas, the contributions generated offer direct support to the ISO standard on Service Life Planning and related parts being developed by members of the ISO TC59 SC14 on Design life. This in turn eventually will allow practitioners to use this standard with a complementary set of guideline documents addressing specific technological areas.

Environmental characterisation

This task group focussed on the characterisation of the degradation environment, and followed on work previously carried in CIB W80 on this theme (Subgroup 2 report “Environmental Characterization Including Equipment for Monitoring”). On this basis, a task group report was prepared [Haagenruud 2003] in which the intent over the course of the work program was the:

- Development of systematic knowledge on the type and form of degradation agents to be used in models of degradation (basis for development of damage function approach);
- Coupling of field and laboratory tests based on damage function approach;
- Development of automatic and continuous monitoring of key degradation factors to validate degradation models;
- Validation of dose-response functions in the building micro-environment domain, and;
- Development of damage (life) functions (performance-over-time functions) based on knowledge of dose-response functions.

As the TC does not undertake research as such, the task has been merely to “review” and summarise the development of environmental characterization and summarizes the relevant parts of a previous commission report (Subgroup 2 report “Environmental Characterization Including Equipment for Monitoring”), provides an overview of chapter 4 of “GIS and the Built Environment” [CIB 2000] and in addition, summarises recent findings concerning damage functions, environmental characterization and classification, and “stock-at-risk” mapping.

Reliability and probabilistic methods

This work item was divided into three sub-tasks that focus on different approaches to SLP and includes:

Sub-task 1 "Probabilistic" (also referred to as ‘theoretical’ and ‘stochastic’)
Sub-task 2 "Engineering approach"
Sub-task 3 "Factor method"

Draft final reports for all sub-work items are available and final reports are intended to be ready in 2004.

Sub-task item 1 "Probabilistic" — The sub-task item intended as a consensus document in which the development of a fundamental and scientific approach and framework for different SLP levels is provided [Siemes 2003]. It focussed on developing a detailed plan to incorporate reliability based design methods for material, components and elements of the building. An overview report has been prepared which is divided into three parts:

Part 1 – Advances basic principles of probabilistic service life design
Part 2 – Provides more details on degradation and statistical models.
Part 3 – Offers a brief overview on probabilistic service life design methods with references to literature.

The sub-task report is not intended as a complete state-of-the-art literature review as it is only intended to show the progress in the development of probabilistic service life design much of which was developed within the Duracrete EU sponsored project [Siemes 2003].

Sub-task item 2 "Engineering approach" — The scope of the sub-task item included the following steps, all of which were reviewed in the draft report [Moser 1999, 2003]:

- Gain an overview on the main methods applied to research and large engineering projects using a scientific approach. These methods often apply mathematical models and stochastic processing to the design data.
- Investigate possible modifications to the Factor method that enhances the scientific basis for the method.
- Define as to what an "engineering method" should be in terms of complexity of models applied and type and amount of data employed.
- Propose an, or several engineering design methods preferably developed on and applied to typical case studies.

The sub-task report provides a literature review and an appraisal of the state of the art. Three examples are shown to illustrate the proposed procedure for different basic equations and different quality of input data.

Sub-task item 3 "Factor method" — The Factor method is one which has been promoted in the AIJ (Japanese) Guide for Service Life Planning of Buildings [AIJ 1993] as well as in the subsequent ISO standard 15686-1 on Service life Planning [ISO 2000]. Although this method has been suggested as an alternate means of estimating service life of components and materials, previous use of this method has not been documented, A state-of-the-art report has been prepared that contains the development, evaluation and use of factor methods for service life prediction as it is presented in ISO standard 15686-1 [Hovde 2003]. The introduction and background information provide a review of activities over the past decade that address the need for service life prediction tools given the increased focus on sustainable construction both internationally and on a national level. Mention is made of international standardization with ISO as well as the harmonization within the building and construction sector of the EC. More recently, developments of the various factors used in this method been demonstrated by Marteinsson [2003].

Outline of proposed Work program for 2003-2005

At the previous annual meeting held in Italy, a notional program developed in 2002 [Lacasse and Sjostrom 2003] for the new work term proposed focusing on three items: (i) The provision of data needed for service life planning, (ii) Data analysis, and (iii) Performance requirements. Following discussion as to the practicality of advancing on many topics as compared to focusing on a specific task that could be completed in the timeframe of the present work program, it was decided that emphasis would be placed on the first of these items, provision for data, and that two basic items were to be developed: (i) the use of FMEA (failure modes effects analysis), and; (ii) the further development of information related to obtaining Reference Service Life data for building components (products). Each of these items is briefly described in turn.

Failure mode effects analysis

The method of failure modes and effects analysis (FMEA) was developed and used in the aircraft industry as early as the 1960's [Lair 2003] as a means to help ensure adequate levels of systems reliability and maintainability during the production phase given the many different components that potentially could cause failure in modern aircraft. It was subsequently adapted to the automobile industry in the 70's and it is a method that has gained increased exposure in the construction industry in particular in the development of industrial complexes such as nuclear power plants and offshore oil platforms. These significant construction projects involve complex structural and operating systems for which failure of key elements could potentially bring about significant safety concerns and this tool provides a ready means to assess the risk of system failure.

For building construction, it was suggested as a useful tool for the curtain wall industry to help mitigate risk of premature failure arising from problems that might be encountered not only over the course of fabrication, but also during installation [Layzell 1997, Layzell and Ledbetter 1998].

The applicability of FMEA to help assess the durability of building materials and components was first suggested by Lair and Le Teno [1999] and thereafter further refined by Lair [2000]. The failure modes multi-model approach proposed by Lair and Le Teno includes three basic items: (i) FMEA; (ii) data set gathering and classification; (iii) data set assessment using evidence theory.

Evidence theory provides a tool to quantify the belief or measure of certainly in specific events when the probability of occurrence is unknown. The notion proposed by Lair and Le Teno is that a set of "belief functions" can be attributed to corresponding sets of service life data for a given product of system, each representative of the strength of evidence for that set of data. As different data sets on a given product are accumulated, the degree of evidence is enhanced so that when data from different sets are "combined", their sum relates to the overall plausibility of the data to provide a measure of the service life of that product. Thius the mapping provides a quantitative measure of the expected life of the products given different and diverging sets of service life data. This concept is illustrated in a plausiblity-belief mapping shown in Figure 1.

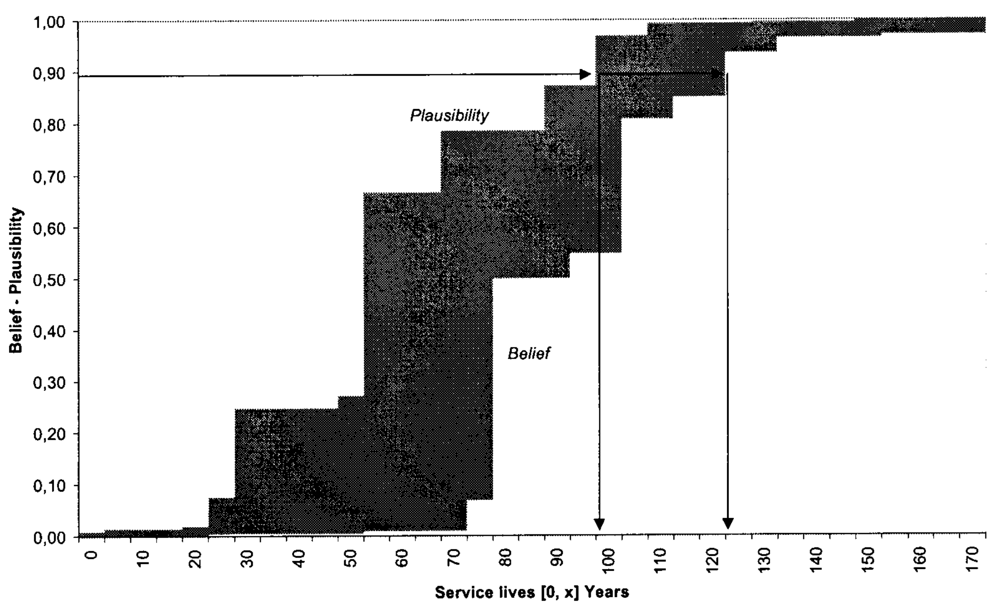

Figure 1 – Service life plausiblity-belief mapping [Lair and Le Teno 1999]

FMEA is used to understand the functionality and hierarchy of building elements including the interrelation among the different systems (building envelope, structure) sub-systems (cladding, windows, doors, roofing membrane) and other components of the building.

The use of a multifaceted operational approach has been suggested as a means of implementing the ISO standard on service life planning, ISO 15686, in practice [Lair et al. 2001, Sjöström et al. 2002]. The method is proposed for estimating the reference service life of a building component (RSLC) on the basis of service life data using the basic three items in the approach: (i) FMEA; (ii) data gathering and (iii) data analysis. Further refinement of the approach was provided by Lair and Chevalier [2002] in which the durability assessment methodology is described. The method is extended from design and implementation to an in-use assessment tool for maintenance management. Additional work by Talon et al. [2003] is reported on developing a simplified tool for decision making in both the design and in-use stages of building.

The examples provided in the literature suggest that the method is readily adaptable to many building systems. Indeed, it has been demonstrated for certain roofing systems, insulated glass units, and for window and IG unit systems. The method has apparently been applied to many other building systems [Lair and Chevalier 2002] and a comprehensive guide to these would provide useful to other organizations seeking to undertaken service life studies in a systemic fashion. Hence devlopment of a guide to make the system more widely applicable would be useful.

Reference Service Life data

The reference service life is a term used in the Factor method described in the ISO standard on Service life planning, ISO 15686-1. The Factor method has been described in great detail in a number of publications [Hovde 2003] and in its' essential form it provides for estimating the Service life of building products, components or building systems. The factor method, as pointed out by M, is not a degradation model, but a method by which to transfer knowledge on service life from a known reference condition to a project specific condition and this is a method that is typically used in engineering design.

The reference life is used to estimate the service life of a building or its components (ESLC) on the basis of adjusting the reference service life (RSLC) through the use of various in-use conditions, or factors that relate to differences in the quality of the materials, workmanship, environment and other factors that are known to alter these conditions. The reference service life is the service life that a building or parts of a building (component) would expect (or is predicted to have) in a certain set (reference set) of in-use conditions. Or simply stated:

$$ESLC = RSLC * A * B * C * \ldots\text{(factors); for which } A, B, C\ldots \leq 1$$

The development of the factor method and its applicability to different cases has been reported by Hovde [2003] and more elaborate methods have also recently been promoted by Moser [2003]. One key item in using the method as reviewed by Marteinsson [2003] is that of determining what the Reference Service Life (RSLC) of a product or component is prior to using the Factor method. It has been assumed in the development of the method that for practical reasons industry would likely be best placed to provide such information in the long run.

With this in mind, considerable work has been prepared for identifying what the reference service life of a product or component might be as described in the working draft of ISO 15686-8 [ISO 2001b]. In this working draft standard, guidance is provided in regards to the provision, selection, and formatting of RSL data. Provision of data implies locating and assessing the usefulness of the data that might exist within an organisation. Once assessed, data may be selected and but thereafter needs to be formatted to be useful for the Factor method described in the standards. However, the focus has been made on providing a basic structure for reporting RSLC data so that some commonality among the different data sets could be achieved. It is aslo noted in ISO WD 15686-8 [ISO 2001b] that few systematic studies on service life prediction exisit and that there is an urgent need to gather relevant data to help demonstrate the concept.

Less work has focused on how an industry, or an organization having interest in establishing basic values for service life actually develops the data. Indeed, it is suggested in ISO WD 15686-8 that to generate of new data, the methodology described in ISO 15686-2 should be used [ISO 2001b]. However, the method described in this reference is generic in nature and examples need to be prepared and additional information provided to make this a practical alternative for use in industry. Hence some guide or primer on the development of reference service life would be useful to promote the use of the factor method in the ISO standard on service life planning.

SUMMARY

The current work program is intended to develop additional information to promote the use of the ISO standard on design life in particular the use of the Factor method. It will also contribute to the further refinement of methods of data gathering and analysis. In this respect, there still is considerable work to be completed in related areas in particular regarding characterizing different methods of service life estimation and models of prediction and degradation. As yet, a comprehensive reliability approach to service life prediction has not been developed although parallel efforts are being made in the area of concrete - perhaps these will in time be adapted for other building materials.

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