Estimating the Service Lives of Building Products in Use

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Abstract: Reliable service life data of building products are of great importance when completing environmental LCA (life cycle assessment) reviews, for LCC (life cycle costing) and for maintenance planning tasks. A research project was set up to answer the following research questions: (1) what are reliable service life data of current used building products; and (2) how can generic data about the service lives of building products be tailored to specific project circumstances using the "factor method" described in the ISO (International Standard Organization) 15686 Series: "Buildings and Constructed Assets—Service-Life Planning". Experts of industry organisations for building materials and products made a final judgement of the new established reference service lives. Reference service lives of building products may show a large unknown bandwidth around the average. That will make the bandwidth of estimated service lives, taking the project situation of building components into account, very big. Experts have raised objections to the use the factor method for deriving mathematically a bandwidth of estimated service lives of a building product from the reference service life of the product. A practical analytical application of the factor method has been made by describing all factors and underlying criteria and a reference situation.

Key words: Factor method, life cycle assessment, life cycle costing, maintenance management, service life.

1. Introduction

Research into service lives of building products is scarce, while the use of these data is growing. Obtaining information on reliable (standardised) service lives of building components and products is of great importance for, amongst others, building owners, designers and consultants when completing environmental LCA (life cycle assessment) reviews, for LCC (life cycle costing) or WCC (whole life costing), and for maintenance management. Other reasons to obtain reliable service life data are the development of national and international standards and legislation (e.g., the Construction Products Directive of the EU (European Union) and Environmental Product Declarations), new national building codes, building defects insurance and the use of procurement routes like PPP (public private partnership) and PFI (private finance initiative).

For maintenance planning purposes, one has to know the service lives of the building components. If replacements cycles are known, the financial forecast can be made. This financial forecast for maintenance is of great importance for service life planning and life cycle costing of new buildings and (renovated) existing buildings.

According to the ISO (International Standard Organization) Standard 15686-5, life cycle costs are the costs of an asset or its parts throughout the life cycle, while fulfilling the performance requirements [1]. Generally, these are the cost for construction (including design and engineering), operation (including energy), maintenance and end-of-life (disposal and demolition). Life cycle costing and whole life costing methodologies are increasingly being used to compare new design and redesign alternatives. In refurbishment, irreversible decisions with major consequences for the costs in the use phase, for example cleaning, maintenance and energy, are made too. In new procurement routes, performance requirements instead of descriptive specifications are being used and operating and maintenance risks of built assets are

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transferred from clients to contractors. Working with performance requirements necessitates the provision of reliable information about alternative building products, including technical specifications with indications of service life and performance over time [2]. Reliable data about service lives of building component may reduce the calculated risk by the contractors.

LCA can be used to quantify the contribution of building activities in environmental effects [3]. LCA should concern the entire life cycle of the assessed product [4]. In an LCA study, the effects that the production, use and disposal of products have on the environment are calculated. In construction, the environmental effects are determined by first making an inventory of the flow of all substances to and from the environment over a building's complete life cycle [5]. Each substance's potential contribution to pre-defined environmental effects is calculated. In order to do this, for each environmental effect, the impact of a particular substance flow is compared with that of a reference substance, a process that is referred to as the "impact assessment". The quantified effects are usually abiotic depletion, global warming, ozone layer depletion, photochemical oxidation, human toxicity, fresh water aquatic eco toxicity, terrestrial eco toxicity, acidification and eutrophication. The complete set of environmental effects is known as the "environmental profile". Klunder and Van Nunen [6] provide some solutions for including the factor time, including technical service lives of building products in building LCAs, e.g., by sensitivity analysis.

The lack of reference service lives of building components and products led the SBR (Dutch Building Research Institute) in the 1990s of the last century to the publication of a service life catalogue of often applied building products [7]. This catalogue gives reference service livers of roughly 600 building products. Data were gathered from various sources and judged by experts. Only service lives were included on which consensus was reached by these experts. One

average technical service life of general building products is given. Specific attention is given to needed interim maintenance. An update of the data was considered since then.

To make the life cycle cost calculations and the outcomes of LCA-studies more robust and to estimate the risk of shorter and longer life spans of the building components, a research project was set up to answer the following research questions: (1) what are reliable service life data of current used building products; and (2) how can generic data about the service lives of building products be tailored to specific project circumstances using the "factor method" described in the ISO 15686 Series: Buildings and Constructed Assets—Service-Life Planning [8].

2. Research Approach

The research methodology comprised a literature review and expert meetings. The literature review comprised the international literature about service life prediction, service life data and the factor method. The experts were appointed by a research steering group, constituted by the Dutch Building Research Institute, the Ministry of the Interior and Kingdom Relations, the Government Buildings Agency, the Ministry of Defence Support Command Real Estate, and scientists. The eight experts are working at universities, consultancy firms and large property owners. They cover all disciplines of real estate and building products and materials (timber, roofing, masonry, building services) and are well respected in their discipline.

In the first place, service life data of building products collected by standardized verifiable procedures in different countries and the use and criticism of the factor method were analysed, based upon a literature review and contacting scientists in Canada, Finland, France, Germany, Italy, Portugal and the UK. In the second place, ways to use the ISO 15686 methodology were explored during expert meetings. The experts were also asked to judge the (reference) service lives of the building components expressed in

the existing catalogue of 1998.

Finally, the service life data of building products are recorded in the Dutch National Environmental Database. This database was established to standardise all data for environmental life cycle assessments being used in environmental assessment tools (e.g., BREEAM (the building research establishment environmental assessment methodology)).

3. Literature Review

3.1 Reference and Estimated Service Life

Generally, three forms of service lives of built assets are distinguished: functional, technological and economic. The technical service life is the only service life that is tied to a building product or component. A functional or economic service life is defined by other influences, for example, the society (the demand for a product), or the price of fuel [9]. Therefore, if the reference service live of a building product or building component is mentioned, it is the technical service life. The ISO Standard 15686 defines the RSL (reference service life) as the service life that a building or parts of a building would expect (or is predicted to have) in a certain set (reference set) of in-use conditions [8]. The ESL (estimated service life) is defined as the service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, calculated by adjusting the reference in-use conditions in terms of materials, design, environment, use and maintenance.

Reference service lives are often provided by the manufacturers of building components. In the near future, they are obliged to provide these data to be used in EPD (Environmental Product Declarations) [10]. Here, a relationship is made with the ISO 15686 Series: "RSL information to be declared in an EPD covering the use stage shall be provided by the manufacturer. The RSL shall refer to the declared technical and functional performance of the product within a building. It shall be established in accordance with specific rules of European product standards and shall

take into account ISO 15686-1, -2, -7 and -8. When European product standards provide guidance on deriving RSL, such guidance shall have priority" [10].

3.2 Service Life Prediction

Service life predictions can be based on evidence from previous use, on comparisons with the known service life of similar components, on tests of degradation in specific conditions or on a combination of these [11]. Ideally, a prediction will be given in terms of the service life as a function of the in-use condition. Analytical and probabilistic (stochastic) methods for service life prediction assume that all factors in quantitative terms are known and that the relationships between the influencing factors or processes can be described in mathematical models. Fundamental and empirical research that makes use of standard test models is needed to develop these models [12, 13]. Several EU-funded international research projects were conducted on durability, service life models and service life prediction of building materials and components [14, 15]. ISO 15686-2 [11] gives a systematic methodology for service life prediction. Daniotti and Re Cecconi [12] give an overview of the current test methods (best practises) for service life prediction for several building components.

4. Service Life Data of Building Products

4.1 Criteria for Data Selection

The Dutch Building Research Institute wanted to re-evaluate the existing reference service lives and collect reliable reference service life data of current used building products, preferably using data sources that meet the ISO 15686 standard. The ISO standard gives the following criteria to the data records [1]:
- general information;
- scope (including purpose);
- material/component;
- methodology;
- reference in-use conditions;
- degradation agents;

- critical properties and performance requirements;
- reference service life;
- data quality;
- reliability of data;
- additional information considered;
- references.

For reliable data, at least the methodology, the reference in-use conditions and the critical properties should be clear. The ISO standard also gives the rules for validation of data sources that are not fully in accordance with the standard. In brief, depending on the quality of the data source, a laborious process with more extensive research and validation by experts has to take place.

4.2 Available Databases

Although the wide field of applications systematic international data records of reference service lives of building components do not exist or are not public accessible. The availability of RSL data of building products that already meet the ISO standard criteria is very limited. The research centre CSTB (Centre Scientifique et Technique du Bâtiment) of France and the Research Group on Durability of Building Components of the Polytechnic of Milano are establishing a French-Italian database for reference service lives of building components, based upon the ISO standard [16].

The data records that exist vary, e.g., some take the used materials as a reference and others the compounded building products, some describe the reference in-use conditions, others do not. A complicating factor is that the in-use conditions and critical properties in one country or region valuated as being "normal" or "average", might not be normal or average at all for another country. In Germany, some databases exist, but without any information about the reference in-use conditions and the properties [17]. In the UK, some service life databases are especially meant for contractual liabilities and insurance purposes, e.g., the HAPM (housing association property mutual)

component service life [18] and the building services component manual [19].

Research by the Royal Institute of Chartered Surveyors meets some of the ISO criteria but not all [20]. To establish this database, a list of generic building components (over 300), used in normal conditions, was presented in a questionnaire to surveyors who are experienced in inspections of existing property. The results are based upon 92 respondents. They were asked for the average or typical life span, and the minimum and maximum life spans of building products. They were not asked for statements about the causes for a shorter or longer life, but only the life expectancy. Assumptions that the examiners had to take into account were:

- The components are installed according to instructions of the supplier or best practices (this is partially verifiable in practice, if visible);
- The components meet the requirements of installation and use;
- The components are subject to average exposure;
- The components are maintained according to instructions of the supplier or as directed by trained personnel.

Although the methodology of this UK database looks very sound, a number of problematic issues related to expert judgements remain, like the unknown experience of the surveyors with the building products and their geographical location. Unfortunately, the database lacks clear statements for interim maintenance.

4.3 New Service Life Catalogue

The lack of robust international data sources forced the SBR to take the existing Dutch service life catalogue as the starting point for the new one and to ask the experts to judge the service lives and to add new building components and their service lives.

The catalogue provides service live data of about 400 generic building products. The reference service lives are an average based on given assumptions. In

practice, the service life of the building products will be around this average with a certain distribution. Recorded service life data concern substructure and frame, external walls, upper floors and floor finishes, roofs and roof finishes and window and external doors. Paints are not included as separate products. Paintwork is seen as an maintenance activity necessary to maintain the service life of substrates. Compared to the existing catalogue internal components, fittings, sanitary appliances and building services were left out (see Table 1 for a sample of the service life catalogue).

5. Practical Application of the Factor Method

5.1 Factor Method

The factor method modifies reference service lives by factors to take account of the specific in-use conditions. The ISO 15686 says that the factor method does not provide an assurance of a service life: it merely gives an empirical estimate based on what information is available. It is different from a fully developed prediction of service life. Certain parties involved in building projects may be concerned about

Table 1 Example of service lives of building components: flat roof coverings.

Material	Specification	RSL (years)
Metals	Steel, trapezium, galvanized, coated	50
	Steel, trapezium, galvanized	15
	Aluminium, folded, enamelled	60
	Aluminium, folded, coated	40
	Copper, folded	75
	Zinc plates, 10% overlapping	75
	Zinc, folded	75
Bitumen felt	Modified	30
Synthetics	PVC (polyvinyl chloride)	30
	EPDM (ethyleen propyleen dieen monomeer)	30
	POCB (polyolefine copolymerisaat bitumen)	30
Others	Green roofs (moss/sedum/herbs) on modified bitumen felt	40
	Green roofs (moss/sedum/herbs) on EPDM	40

Source: SBR, 2011.

liability for forecasting future performance. For the avoidance of doubt, the recommendations of this part of ISO 15686 are not intended to implement contractual liabilities and the expectation is that "best efforts" will be applied, but that forecasts cannot be expected to always be either accurate or precise [8].

The seven factors are listed from A-G:
- A: quality of components;
- B: design level;
- C: work execution level;
- D: indoor environment;
- E: outdoor environment;
- F: in-use conditions;
- G: maintenance level.

The factor method offers the possibility to make a correction of the reference service life using the factors and criteria. Each factor has the default value 1.0. An effect that leads to life extension results in a value greater than 1.0, and lifetime shortening gives a value lower than 1.0. Factor values less than 0.8 or greater than 1.2 imply that the chosen RSL is not suitable and should not be used [8]. The factor values are determined by the underlying criteria. For each factor, several possible criteria exist. The factors are multiplied giving the ESL in a formula: ESL = RSL·A·B·C·D·E·F·G.

The obtained ESL is focused on a specific situation. This allows for a building to indicate specific influences. Two identical products, applied at different locations or otherwise used, will also get a different lifespan. The key is to know the situational factors (which do not involve incidents) and value them. If the situation is similar to the described principles of the RSL, the value is 1.0 and the RSL and the ESL are equal.

5.2 Criticism of the Use of the Factor Method

The factor method would be a realistic and practical method to obtain estimated service lives of building components in use. However, since the standard exists, scientists and experts around the world express

objections to use it and make suggestions to enhance the method [21-23]. Bahr and Lennerts [21] argue that the ISO 15686 does not give any information on reference service lives or the values of the factors. The proposed adapted German model does give statements with regards to the application of reference service life parameters. They also suggest to differentiate between primary and secondary influencing factors. The values of the influencing factors are, opposed to the ISO, restricted in their model, enhancing transparency and significance. To minimize the subjectivity of the factor method, Re Cecconi and Iacono [23] evaluated Factor A of the factor method: quality of components. They introduce "evaluation grids" to establish the value of each sub-factor. The forthcoming French-Italian database will content grids, which will drive users in choosing the right values of each (sub-) factor according to the context conditions in which building components are placed [16, 24].

The Dutch experts also expressed great doubts about applying the factor method according to the ISO standard. The acknowledge of the availability of reliable RSL data precedes knowing the bandwidth of the ESL. To know the RSL of building products more, longitudinal research has to be executed. Their objections are:

• The RSL of each building product has a certain unknown bandwidth;

• The question is whether the factors can be expressed in numbers. The attention points can be mentioned, but they are difficult or impossible to quantify;

• The question is whether the factors themselves can and should be multiplied. The factors may be interdependent;

• The question is the use of the method and described factors for building services.

To meet the critics, the SBR decided to make a practical application of the factor method that meets the concerns expressed and that makes a connection to international research into service lives of building products possible in the future.

5.3 Guideline for Factors and Criteria

The existing factors are classified into properties and inherent performance level, in-use conditions and stages. The described reference situation refers to the average conditions and common construction practice in the Netherlands. Deviations from the reference situation will result in a longer or shorter estimated service life of the building product. Fig. 1 shows how the estimated service life of a building component
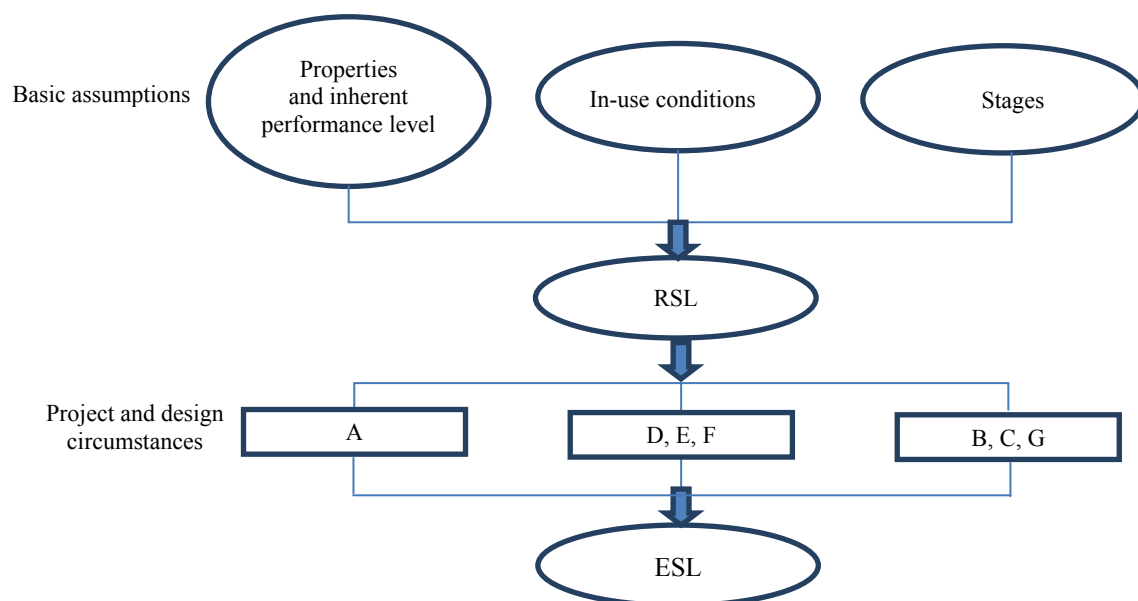

Fig. 1   From RSL to ESL.

could be deduced from the reference service live, following the ISO factors: quality of components (A), indoor environment (D), outdoor environment (E), in-use conditions (F), design level (B), work execution level (C) and maintenance level (G).

The properties and inherent performance level of the building product determine whether the required or desired performance can be achieved. The reference service lives of specific building products are based on the properties and inherent performance level of these specific building products. If another product alternative is being applied belonging to the same group of building products without notice of the reference service life of this alternative, one has to judge the properties and the inherent performance level compared to the known one. One has to think about the resistance to deformation, durability, stability and sensitivity for aesthetical, mechanical, biological agents and degradation, and sensitivity for incorrect use.

5.3.1 Indoor Climate

The life of building products used indoors is subject to the conditions of the indoor climate (Table 2). The average Dutch indoor environment is the basic assumption: a relative humidity between 30%~70%, with no external sources of moisture present. The indoor humidity can not only be displayed in a percentage, it also has something to do with the time of wetness and variations therein. The reference is that temperature ranges between 15 °C and 25 °C, and that the temperature fluctuations are limited. In the reference situation, there are no contaminants in the air. The air velocity is within "acceptable limits". Assuming there is ample opportunity to ventilate, no favourable environment for biological agents is formed and fungi will not occur.

5.3.2 Outdoor Climate

The life of building products used outdoors is subject to the conditions of the outdoor climate (Table 3). The soil can affect the life of certain components (foundation, walls). Basic assumptions are that no

(extreme) variations in the soil occur and the absence of external stresses. If extremes in humidity and temperature occur, this may negatively affect the life of the product. For example, frequent variations in temperature can (by swelling and shrinkage) reduce the service life. Shelter of the project, for instance, by trees, can prevent from extreme temperature changes.

5.3.3 Building Function and Use

The building function and use may shorten or extend the service life of the building products (Table 4). The reference is that a building product is applied according to the requirement of the manufacturer or supplier. This means, for instance, that building products for applications in public buildings have such properties, expected that the building products will be used very frequently. Application of this product in housing

Table 2 Factors and criteria of indoor climate.

Criteria	Specification
Humidity	Extent, variations, condensation, rising damp, cold bridges
Temperature	Air temperature, variations
(Chemical) substances	CO_2, carbon, chlorine, etc.
Air flows	In relation to pollution
Biological agents	Presence and preventing agents
Light	In relation to discoloration and aging

Table 3 Factors and criteria of outdoor climate.

Criteria	Specification
Humidity	Duration, variations, associated with the building orientation
Temperature	Air temperature, variations, shelter
(Chemical) substances	CO_2, soot
Biological agents	Presence and preventing agents
Soil	Variations
External load	Vibrations from nearby (rail) roads, factories, etc.
Light	In relation to discoloration and aging

Table 4 Factors and criteria building of function and use.

Criteria	Specification
Intensity	Building function, private/public, commercial/residential
Loads	Variations, overload
Type of use	Incorrect, vandalism

means a longer life. Also, frequent variations in load can negatively affect the longevity, if the building product as required by manufacturer or supplier is not explicitly taken this into account. The basic principle is that loads are more or less continuous and practically no overload occurs. The reference is based on proper use and no vandalism.

5.3.4 Design

Building products are selected during the design stage (Table 5). How products are exposed during their lifetime is determined. The positioning of the building component may be positive or negative. The reference is a "normal" position for the product. A frame, for instance, is always part of a wall exposed to the elements. If the frame is strongly affixed inward (e.g., an indoor balcony), the estimated service life will be longer. Specific details and the presence of many connections with other components can be negative for the life of the product. The reference assumes that the construction product is accessible for the necessary maintenance. Another assumption is that the materials used in the selected building product are compatible with the materials adjacent to the building product, e.g., the galvanic corrosion of metals.

5.3.5 Execution

The production of the building can affect the life of the building product (Table 6). The reference is production on site. Production methods such as prefabrication meaning production under controlled conditions, may increase the life of building products. To ensure that implementation occurs as previously expected, the execution takes place according to rules (processes, procedures and instruments). These rules do not guarantee, but encourage to ensure quality. In particular for the management and maintenance stage, it is important to record any changes to the design and used materials and products. The reference is that the registration is made. Another reference is a limited exposure to the elements before installation. The products are delivered "just-in-time" or being stored protectively.

Table 5   Factors and criteria design.

Criteria	Specification
Positioning	Exposure, shielding from weather, drainage, orientation, height
Detailing	Connections
Provisions for maintenance	Accessibility, space to work
Material compatibility	Suitability of the (combination) of materials
Dimensioning	Construction, subdivision, excess

Table6   Factors and criteria execution.

Criteria	Specification
Production	Prefab, in situ, working conditions, method of execution and exposing during execution
Discipline regarding execution rules and skills	Quality systems, supervision performance, competences, expertise and experience staff
Tracking changes	Registration for maintenance
Transport and storage on site	-

Table 7   Factors and criteria maintenance and management.

Criteria	Specification
Maintenance planning	Implementation of preventive maintenance on schedule
Discipline regarding maintenance rules and skills	Quality system maintenance contractor, supervision performance, quality of materials, competences, expertise and experience maintenance staff
Tracking changes	Registration for maintenance
Availability of spare parts	-

5.3.6 Maintenance and Management

Maintenance can be of great influence for the service life (Table 7). The reference is a well maintained building. This involves planned preventative maintenance, such as lubricating moving parts, cleaning and paintwork, and planned interim replacements of building parts with a shorter lifetime than the entire building product. Proper preventive and corrective maintenance is assumed and carried out according to maintenance instructions. The reference is that spare parts remain available.

6. Conclusions

There is a lack of reliable reference service life data of building products, needed for environmental and

economic reasons for reliable environmental life cycle assessments and life cycle cost calculations. All available international service life databases are not in accordance with criteria for reliable data, set down in the ISO 15686 series.

In the Netherlands, a review of the existing service life catalogue was made by expert judgements. In the near future, a data format according to ISO 15686-8 [25] should be used by suppliers of building products to declare the service lives of their products and the reference in-use conditions and critical properties. These data could be combined with data by property owners and managers, consultants and surveyors, etc. in accordance with ISO 15686-7 [26]. Especially the Dutch Governmental Buildings Agency will do further research to the service lives of building services.

By means of the standardised factor method, reference service lives of building products can be modified to take account of the project and design circumstances. Experts have raised objections to use the factor method for mathematically deriving a bandwidth of estimated service lives of a building product from the reference service live of the product. However, the factor method described in the ISO 15686 series offers good opportunities to take the project or design specific situation of building products into account, not mathematically but analytically. Generic data about the service lives of building products can be tailored to specific project circumstances by describing the factors and underlying criteria, and the reference in-use conditions.

European Research Communities should cooperate to develop an international service life database of building components and to address the factors and underlying criteria for service life estimation. The factors and criteria have to be placed in each national context.

Acknowledgments

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