Basics and recommendations on influence of service life of building components on replacement rates and LCA-based assessment results

A Contribution to IEA EBC Annex 72

February 2023

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Preface

This publication is an informal background report. It was developed as part of the international research activities within the context of IEA EBC Annex 72. Its contents complement the report “Context-specific assessment methods for life cycle-related environmental impacts caused by buildings” by Lützkendorf, Balouktsi and Frischknecht et al. (2023). The sole responsibility for the content lies with the author(s).

Together with this report, the following background reports have been published on the subject of “Assessing Life Cycle Related Environmental Impacts Caused by Buildings” (by Subtask 1 of IEA EBC Annex 72) and can be found in the official Annex 27 website (https://annex72.iea-ebc.org/):

– Survey on the use of national LCA-based assessment methods for buildings in selected countries (Balouktsi et al. 2023);
– Level of knowledge & application of LCA in design practice: results and recommendations based on surveys (Lützkendorf, Balouktsi, Röck, et al. 2023);
– Basics and recommendations on modelling of processes for transport, construction and deconstruction in building LCA (Soust-Verdaguer et al., 2023)
– Basics and recommendations electricity mix models and their application in buildings LCA (Peuportier et al., 2023)
– Basics and recommendations on influence of future electricity supplies on LCA-based building assessments (Zhang 2023)
– Basics and recommendations on assessment of biomass-based products in building LCAs: the case of biogenic carbon (Saade et al., 2023)
– Basics and recommendations on influence of future climate change on prediction of operational energy consumption (Guarino et al., 2023)
– Basics and recommendations in aggregation and communication of LCA-based building assessment results (Gomes et al., 2023).
– Basics and Recommendations on Discounting in LCA and Consideration of External Cost of GHG Emissions (Szalay et al. 2023)
– Documentation and analysis of existing LCA-based benchmarks for buildings in selected countries (Rasmussen et al., 2023)
– Rules for assessment and declaration of buildings with net-zero GHG-emissions: an international survey (Satola et al. 2023)

It is important to mention that parts of the analysis of service lives of building components in this report is based on a survey among experts which was realized during the first half of 2019. The authors would like to acknowledge the following survey contributors: Greg Foliente (Australia), Alexander Passer (Austria), Damien Trigaux (Belgium), Vanessa Gomes (Brazil), Antonin Lupisek (Czech Republic), Harpa Birgisdottir (Denmark), Bruno Peuportier (France), Thomas Lutzkendorf & Maria Baloutski (Germany), Chi Kwan Chau (Hong Kong), Eri Alsema (Netherlands), Dave Dowell (New Zealand), José Silvestre (Portugal), Tajda Potrc Obrecht (Slovenia), Antonio Garcia & Bernadette Soust-Verdaguer (Spain), Alice Moncaster (United Kingdom) and Manish Dixit (United States of America).

Summary

The operational and embodied GHG emissions are recorded and evaluated in a life cycle analysis of buildings. The embodied emissions are composed of the modules A1-A5 (upfront), B2-B5 and C1-C4. For reasons of simplification, concrete calculations usually focus on A1-A3, B4, C3-C4.

Module B4 makes a significant contribution to the results of a building LCA. Components and systems that are either replaced very frequently or cause high environmental impacts (initially and when replaced) are important. For the modelling of B4, there are different methodological questions for which methods need to provide answers. This is the aim of this report. It particularly discusses the service lives definitions, the service life values of building components/elements and their related uncertainties and variabilities based on values found in literature as well as default values used in A72 countries. The latter values were collected based on a survey among A72 experts. This report also illustrates the consequences/ influence on the result of the variability of service life values of building components, the replacement rate calculation method and the reference study period on the basis of a case study. Finally, recommendations are provided.

Table of content

Abbreviations

Abbreviations	Meaning
BITS	building integrated technical systems
CEN	European Committee for Standardization
CRB	Kompetenzzentrum für Standards in der Bau- und Immobilienwirtschaft
DHW	domestic hot water
eBKP	der elementbasierte Baukostenplan
ESL	estimated service life
EPD	environmental product declaration
GHGe	greenhouse gas emissions
ISO	International Organization for Standardization
LCA	life cycle assessment
LCC	life cycle costing
PDF	probability density functions
RSL	reference service life
RSP	reference study period of the building
SIA	The Swiss Society of Engineers and Architects
SL	service life of the material

Definitions

Component: item manufactured as a distinct unit to serve a specific function or functions. A **building component** is a part of a building, fulfilling specific requirements/functions (e.g. a window or a heating system). The service life of a building component can be shorter than the full service life of the building. Building components are sometimes referred to as “building elements” (ISO 21931-1:2022).

Environmental Product Declaration (EPD): claim which indicates the environmental impacts and aspects of a product, providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information (prEN 15978-1:2021).

Life cycle Assessment (LCA): LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy, and the associated environmental impacts directly attributable to a building, infrastructure, product or material throughout its lifecycle (ISO, 2006).

1. Context

Buildings are a combination of a variety of different components/elements with different reference service lifetimes. While the load bearing structure can generally be designed for a lifetime of 50 to 100 years, there are building elements that are likely to be replaced sooner, for example at 30 years for the windows. The service life of a building element also determines the number of replacements during the reference study period (RSP) of the building. These replacements are accounted for in the so-called module B4 replacement and generally covers the replacement(s) of building element, including the deconstruction and end of life of existing elements (materials, technical systems) as well as the production and installation of a new (and identical) element. Due to the different application context and in-use conditions, the service life and the related replacement rate of building elements remain uncertain parameters of the building LCA model. The uncertainty of the available service lives' data in literature affects the reliability of the building LCA results and more specifically the assessment of the replacements (Module B4 according to EN 15978). **Error! Reference source not found.**.1 presents the building life cycle stages according to SN EN 15978 highlighting the replacement module B4 object of analysis of this report.

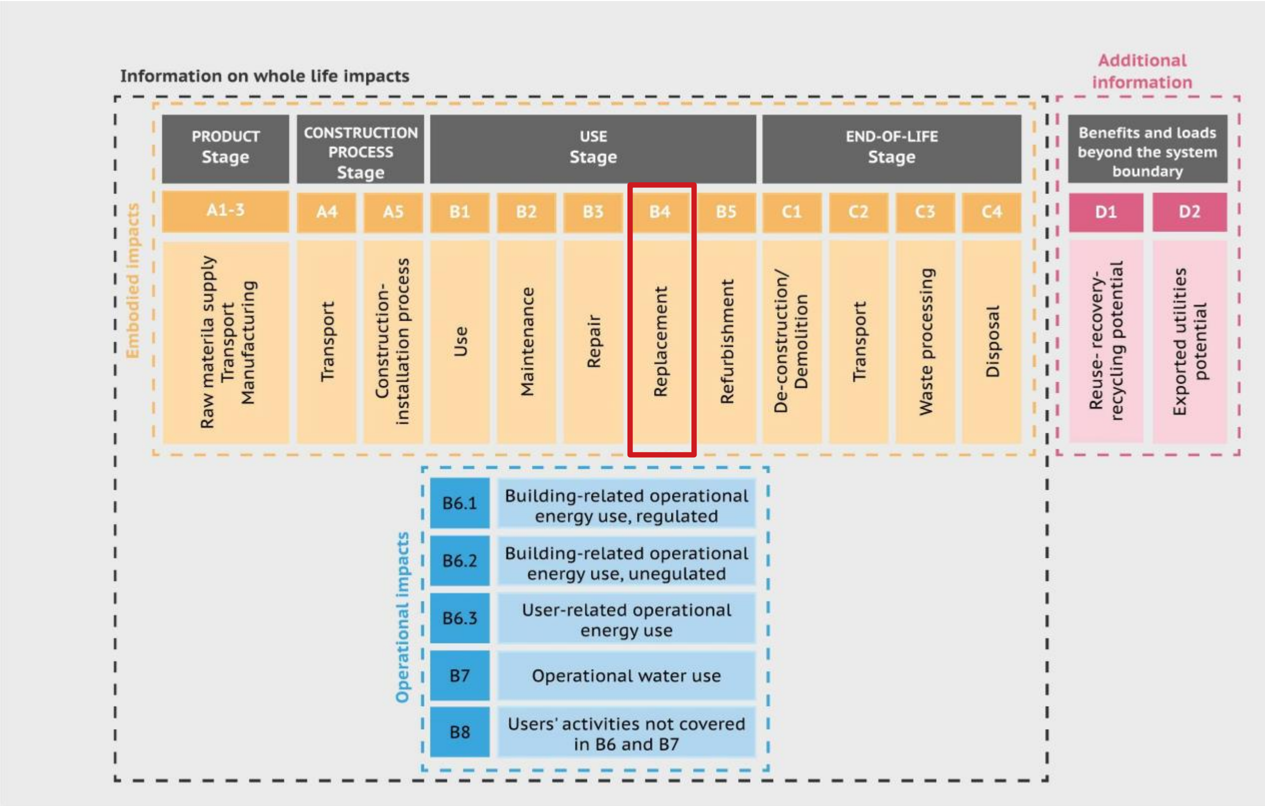

Figure 1.1: Building life cycle stages according to SN EN 15978 (CEN/TC 350, 2011) including the replacement stage

As far as the LCA of the replacement stage is concerned, it can be calculated, using Eq. 1,

$$LCA_{replacement} = \left(LCA_{\ Product\ and\ Construction\ Process} + LCA_{\ End\ of\ life}\right) * k \qquad (1)$$

where:

k is the replacement rate that occurs during the RSP of the building. It can be calculated for a given building element as shown in Eq. 2,

$$k = \frac{RSP}{SL} - 1 \qquad (2)$$

where:

RSP is the reference study period of the building according to SN EN 15978 (CEN/TC 350, 2011) (years);

SL service life[1] of the element (years).

This current methodological background report discusses 4 methodological assumptions:

- the service lives (SL) of building elements (background definition, current values and their inherent variabilities/uncertainties),
- the different levels of details to define the service lives in an LCA, depending on the level of decomposition of the building model,
- the different building lifetime (or RSP in EN 15978) used to calculate the replacement rate,
- the calculation of the replacement rate k.

In order to quantify the effect of the service lives' uncertainty on the total LCA, building case studies are used in different countries to illustrate the current practice and the influence of these assumptions on the replacement stage calculation in building LCAs.

<u>Remark</u>: In this methodological report, the "*service life*" term is used for referring to all the different available terms such as lifetime / service life / duration of use for a building element (as presented in the next sub-section). For the temporal system boundaries in the life cycle of buildings, a distinction is made between the technical or economic service life on the one hand, and the reference study period (RSP) on the other. All statements in this background report relate to an assumed RSP.

[1] In the normative context e.g., following SN EN 15804 and SN EN 15978, this term is called "Reference Service Live" (RSL)

2. Status of Discussion

At present, different methodological assumptions are used to assess the replacement stage in a building LCA i.e.,

– The service lives definitions and values of building elements and their related uncertainties and variabilities
– The level of details for fixing the service life of a building element (cf. the different level of details for the building decomposition in the A72 report by Passer et al. 2023)
– The value for the RSP of the building
– The calculation method for the replacement rate

The following sections present a brief introduction of these different topics.

2.1 Service Lives Definitions, Service Life Values of Building Elements and their Related Uncertainties and Variabilities

This section reports the different definitions and values for the service life of building elements. It also presents some empirical evidence of the current variabilities in values used in LCA methodologies and in other contexts of use.

2.1.1 Different definitions of the 'service life'

Different service life values are defined in the literature for the building elements and technical systems. The term *'service life'* (or lifetime) can be defined in various ways, depending on the scope of the final user e.g. building designer, owner, LCA or LCC expert, (Lasvaux et al, 2020). According to Thiebat (2019), the service life of a building (and by extrapolation, the service life of building component and material, as well) can be classified into physical (service life that corresponds to the lifetime allowed by physical degradation procedures), functional (that takes additionally into account the *'performance/requirements ratio'*) or economic service life (service life that corresponds to the residual economic value). Furthermore, the international standard ISO 15686 (ISO, 2011, p.31), distinguishes among the service life, the reference service life, the estimated service life, the predicted service life and the service life assumption during the design (planned service life). In the Swiss context, the Swiss Society of Architects and Engineers (SIA) differentiates the technical service life (SIA, 2016), (SIA, 2015), from the useful life (SIA, 2016), (SIA, 2015) & (SIA, 2003) or the amortization period (SIA, 2010), used for LCA calculations. Furthermore, other terms related to service life exist[2] such as:

– Defined service life (based on conventions)
– Defined service life for calculations (*Rechenwert*)
– Guarantied service life
– (expected) Lifetime under defined conditions of use and maintenance
– Average length of stay (*mittlere Verweildauer*)

Table .1 presents some of the definitions, found in different CEN, ISO and SIA standards.

[2] Personal communication with T. Lutzkendorf, (26.03.2019)

Table 2.1: Example of definitions of the "lifetime" of building elements (not exhaustive)

Existing terminology	Source	Definition / Explanation
Lifetime	SIA 480 (SIA, 2016)	*"The technical lifetime is the period between the commissioning of a component and its subsequent replacement with a decrease in reliability or an increase in maintenance and replacement costs of its components"*
Technical lifetime *Technische lebens-dauer (de)*	SIA 480 (SIA, 2016)	*"period between the commissioning of a component and its subsequent replacement with a decrease in reliability or an increase in maintenance and replacement costs of its components"*
Duration of use *Wirtschaft Nutzungsdauer (de)*	SIA 480 (SIA, 2016)	*"Prescribed time interval elapsed between startup and replacement of a component or installation. The usage time is limited either by technical lifetime or by a possible replacement to meet new needs (comfort, aesthetics, new assignment, etc.) or to improve the technical performance (e.g. the balance sheet improvement energy)"*
Amortisation lifetime *Amortisationszeit (de)*	SIA 2032 (SIA, 2010)	*"The amortization period is the period during which the embodied energy (or other environmental impacts) for the manufacturing and disposal is amortized. With the exception of the foundation excavation and the supporting structure, the depreciation period corresponds to the duration of use (see definition above).* *For the foundation excavation and the support structure, the fixed amortization period is less than what would be the duration of use, so as not to load future generations with depreciation corresponding to the current investments in embodied energy"*
Predicted service life	ISO 15686-1 (ISO, 2011, p.31)	*"service life predicted from performance recorded over time in accordance with the procedure described in ISO 15686-2"*
Reference Service Life (RSL)	ISO 15686-1 (ISO, 2011, p.31)	*"service life of a product, component, assembly or system which is known to be expected under a particular set, i.e. a reference set, of in-use conditions and which can form the basis for estimating the service life under other in-use conditions"*
Service live	(Dulling, 2006)	*"period of time after installation during which a facility or its component parts meet or exceed the performance requirement"*
Estimated service life (ESL)	ISO 15686-1 (ISO, 2011, p.31)	*"service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, determined from reference service life data after taking into account any differences from the reference in-use conditions"*
Expected life when designing	ISO 15686-1 (ISO, 2011, p.31)	*"Life as the designer has indicated to the Client specification to support decisions"*

Multiple studies, as stated by Silvestre, Silva & de Brito (2015), have identified the deterministic (Factor Method as defined in ISO 15686 standard), the probabilistic and the engineering method (combination of the previous two), as possible ways to determine and predict the service life. In practice, the service life constitutes a quite complex material parameter, which is affected by a variety of different factors, not necessarily technical. Dulling (2006) mentioned that the service life is affected by the design level, the material and the workmanship quality, the maintenance level and cleaning (affecting the durability), the external and internal climate and the operational environment (affecting the degradation). Furthermore, as summarized by Cooper (2004), multiple scientific research suggested that among the parameters that influence the service life are 'the design, the technological change, the cost of repair and the availability of parts, the household affluence, the residual and resale values, the aesthetic and the functional quality, fashion, advertising and social pressure'. In the PI BAT project (Office fédéral des questions conjoncturelles, 1993), other parameters are mentioned, like the new legal requirements or the cost-effectiveness, among other external factors influencing the obsolescence of the materials. In addition, Jakob (2007) and Wilson, Crane & Chryssochoidis (2015) identified a variety of different parameters (socio-economic, etc.) behind material replacement for energy-efficient renovation in buildings.

Example of the Factor Method:
To obtain a prediction of the estimated service life (ESL), the factor method is used. It is defined in the ISO Standard 15686 (ISO, 2011), (ISO, 2012). It estimates ESL by weighting RSL values using on-site (expected) conditions of the element for seven factors known to influence service life (Bahr & Lennerts, 2010; Moser & Edvardsen, 2002).[3] For each of these seven factors, ISO standards suggest weights ranging from 0.8 for conditions that heavily accelerate element deterioration to 1.2 for conditions that greatly prolong the service life of an element. Under perfect conditions, ESL values can therefore exceed RSL values by a factor of almost 3.6, while under the worst possible conditions ESL is about 80% shorter than corresponding RSL.

The Factor Method, according to which the reference service life is corrected by seven factors, to account for the different non-technical parameters that affect the service life, has been criticized for its reliability, as stated in Straub (2015). Straub presented the main objections, concerning this method, of an expert committee gathered to examine the problematic of the service life of building products. Some of these objections of the committee concerned whether the factors should be multiplied, quantified or expressed in numbers. In addition, Straub summarizes further studies (Bahr & Lennerts, 2010; Nireki et al., 2002; Re Cecconi & Iacono, 2005) that proposed ways to optimize the Factor Method.

2.1.2 Different values of the service life

There are many sources and documentations providing service lives values for building elements. Some were recently reported in the Swiss DUREE research project (Lasvaux et al, 2020), funded by the Swiss Federal Office of Energy. This project started in 2017 an international, European and Swiss literature review to collect service lives data of building elements and technical systems. The data were then reported in a database with a decomposition of the building which started from the eBKP classification on construction cost. The database includes the five main categories of the functional nomenclature of the SN 506511 standard. These main categories where further decomposed into two-subcategories, according to SN 506511 and five more sub-categories were added in the DUREE database, in order to cover more detailed building components.

Service life data were collected from the following types of sources:

a. in the LCA literature (service lives values as conventional or recommended data to national LCA methodologies),
b. in the LCC literature (service lives support to LCC analyses)
c. in other sources grouped as "management" to depict different contexts of use:
   - building portfolio and real estate management,
   - professional owners,
   - experts from the bank & insurance sectors,
   - experts from the building energy management,
   - association of tenants & owners,
   - other expert groups,
   - specialised websites,
   - other.

[3] These factors include: (A) element's quality that accounts for the quality of materials but also potential damages occurring during transport and storage (B) design level that accounts for the integration of the element in the building structure hence its protection from erosive forces, (C) on-site implementation quality that assesses if the element has been correctly installed, (D) the internal physical environment that takes into account the erosive forces affecting the element from the inside (e.g. a window installed in a kitchen or bathroom), (E) external physical environment capturing the exposure to external corrosive forces, (F) use conditions that measures the element's usage intensity, and (G) maintenance conditions.

Other sources for service lives exist, such as the service lives data, provided in the IEA EBC Annex 72 (Subtask 1) during the Activity 1.1, based on surveys in order to define national methodologies, conducted in early 2019 (data from SB tool CZ (Czech Republic), Dutch program (The Netherlands), TOTEM LCA tool (Belgium), Denmark LCA method (Denmark), Pleaides ACV (France), University of Sevilla (Spain) based on Mithrarathe et al (2004), BRANZ estimate (New Zealand), BBSR Tables (Germany), etc.). The Annex 72 partners filled an Excel template with an extraction of the DUREE database building decomposition with national data of building elements' service lives. By doing so, the calculations of descriptive statistics for the Annex 72 can be based on the DUREE database.

2.1.3 Empirical variability of data provided by Annex 72 partners

Within this project, all partners were asked to reply to a survey as part of the subtask 1 related to the LCA methodology. Within this survey, a subsection was dedicated to the survey on building reference service lives as implemented in every country within their LCA methodologies (or tools) for buildings. Table 1.2 presents the countries that gave their data, but not all of them were subsequently used. When this happens, the reason is reported in the table below in the "comments" section.

Table 1.2: List of Annex 72 partners who provide the service lives used in their national LCA methodologies

A72 participating countries from which data were collected	Taken into account for the descriptive statistics	Comments
Australia	No	Service lives provided using a former building decomposition
Belgium	Yes	
Brazil	No	Only a few data were reported as Brazil has no measured service life database.
Czech Republic	Yes	-
Denmark	Yes	-
France	Yes	-
Germany	Yes	-
Hong Kong	No	Service lives provided using a different building decomposition
Netherlands	Yes	-
New Zealand	Yes	-
Portugal	Yes	-
Slovenia	Yes	-
Spain	No	Service lives were provided which come from literature sources from other countries
Switzerland	Yes	-
United Kingdom	No	Service lives provided using a different building decomposition
USA	Yes	Literature data were taken as individual data in the descriptive statistics calculation

Figure 2.1 shows the descriptive statistics of eight building elements, using the data provided by the Annex 72 partners. These building elements correspond to some building elements usually assessed during the LCA of a new building or for an energy-related building renovation. The values are represented using boxplots; the box representing 50% of the observed values (interquartile range), the whiskers the first and ninth percentile and the median is represented by the horizontal plain black line inside the box.

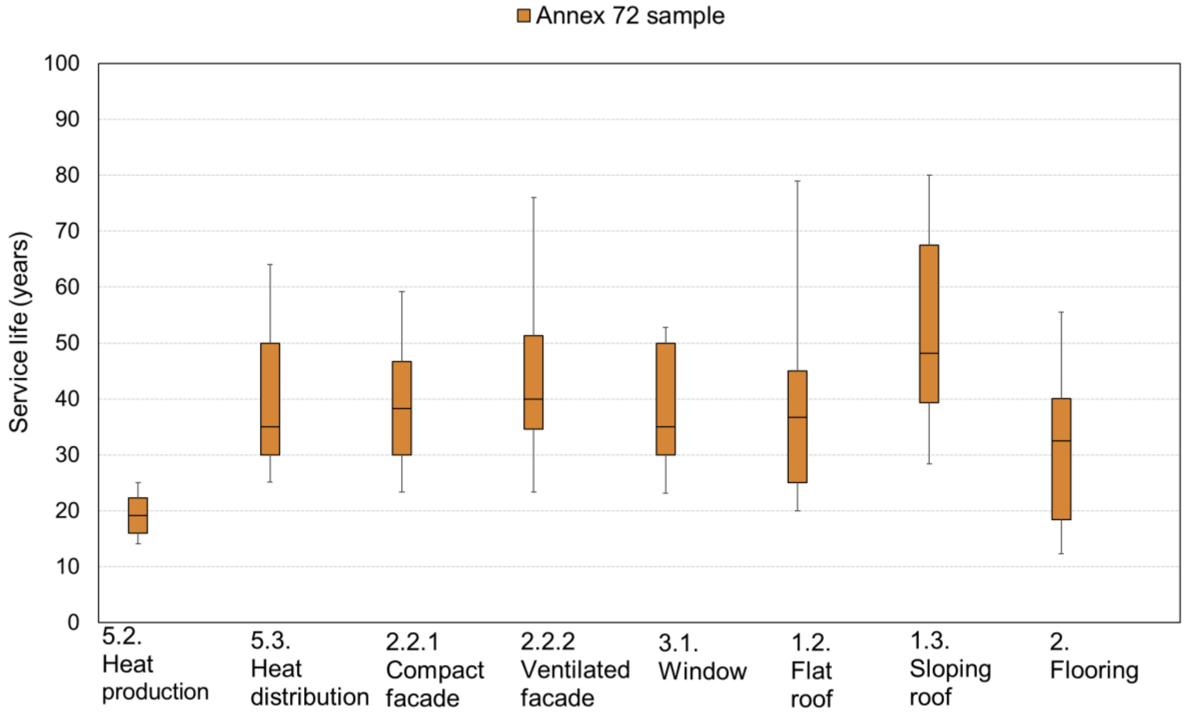

Figure 2.1: Descriptive statistics for eight building elements, from data reported by the Annex 72 partners as part of Activity 1.1. Survey on national LCA methodologies[4].

2.1.4 Empirical variability depending on the context of use of the data

As different definitions and contexts of use are identified in the literature (cf. Table 2.1), it is interesting to separate the service life data according to their context of use. As an illustration,

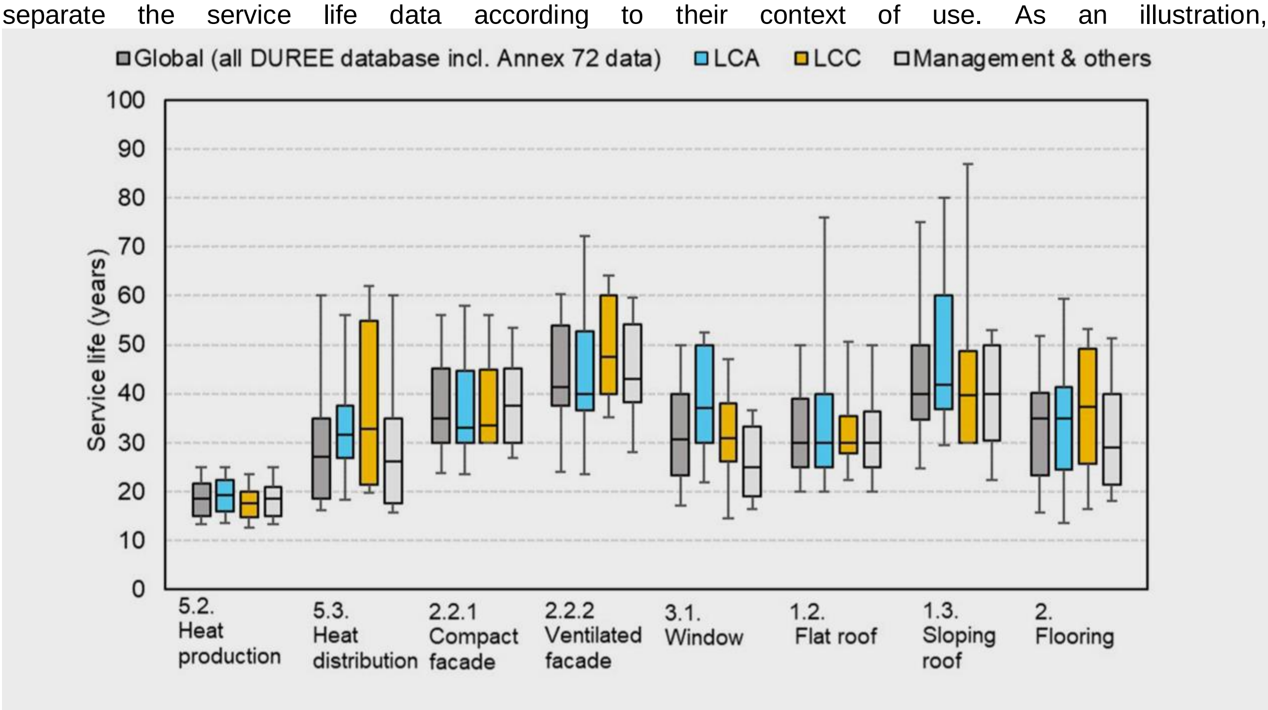

Figure 2.2 shows the descriptive statistics for the same building elements, using all the data gathered in the DUREE database during the Swiss DUREE project. The sample was separated in three source types, i.e.

[4] A compact facade is a plain facade (excl. structural element) that comprise an external covering, the thermal insulation (e.g., an EPS) and a mortar to glue the complex onto the structural wall.
A ventilated façade is a façade comprising an air tightness and the insulation inside a frame in wood or metal and a covering on the exterior.

service lives used for LCA[5] calculations, the ones used for LCC and the other ones used by building owners among others (called "management"). In the next result, the Annex 72 data are filling the different samples (mostly the LCA one and sometimes the LCC one if the service lives are also used for LCC calculations).

A quick look at the results confirms the inherent variability in the collected values. A substantial spread of service lives' can be observed for the eight building elements while it is possible to rank the elements by median service lives values from the heat producer with about 15-20 years to the ventilated façade with about (45-50 years). Median SL values for the other elements fall in-between. It can be concluded that there is no source type that presents systematically lower or higher service life data. More information can be retrieved from the DUREE report[6] and in the Data in Brief paper and Excel table gathering the descriptive statistics[7].

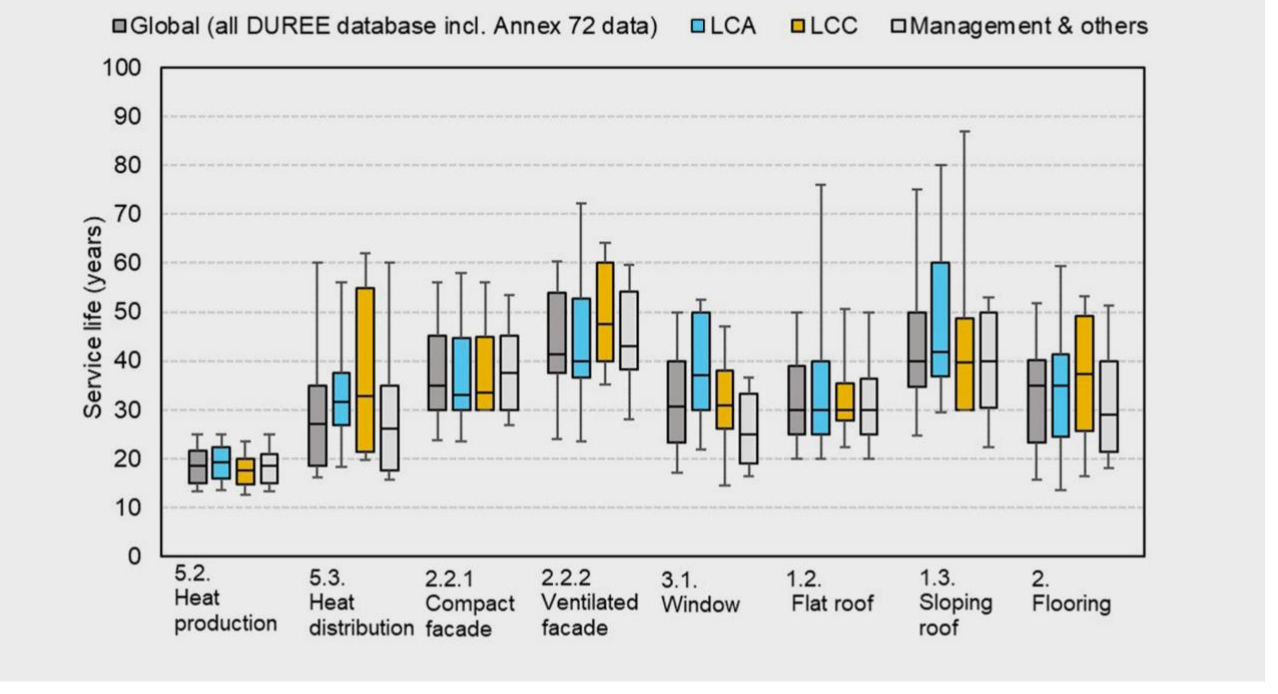

Figure 2.2: Example of reported values in the literature used for different purposes (LCA calculations, LCC calculations and other sources like professional building owners) based on the studies by Lasvaux et al (2020).

2.2 Level of Details for Fixing the Service Live of a Building Element

Figure 2.3 presents a general description of a building and its decomposition in different levels. Each building element (e.g., Roof) consists of several building components (e.g., C4.4 roof, F1 roof covering, G4 interior roof covering), which have different functions and belong to different construction categories. The classification system marks individual building components, based on the Swiss code of construction costs (e-BKP). Other decomposition systems exist and are further described in the A72 report by Passer et al. (2023) as well as by Soust-Verdaguer et al. (2020).

[5] And energy calculations

[6] Lasvaux S. et al 2019. "DUREE Project: Analysis of lifetimes of building elements in the literature and in the renovation practices and sensitivity analyses on building LCA & LCC case studies", Swiss Federal Office for Energy (SFOE), Final report, June 2019, available online: https://www.aramis.admin.ch/Texte/?ProjectID=38626 .

[7] K. Goulouti, P. Padey, A. Galimshina, G. Habert, S. Lasvaux 2019. "Dataset of service life data for 100 building elements and technical systems including their descriptive statistics and fitting to lognormal distribution", Data in Brief, Volume 36, June 2021, available online (Open Access): https://www.sciencedirect.com/science/article/pii/S2352340921003462

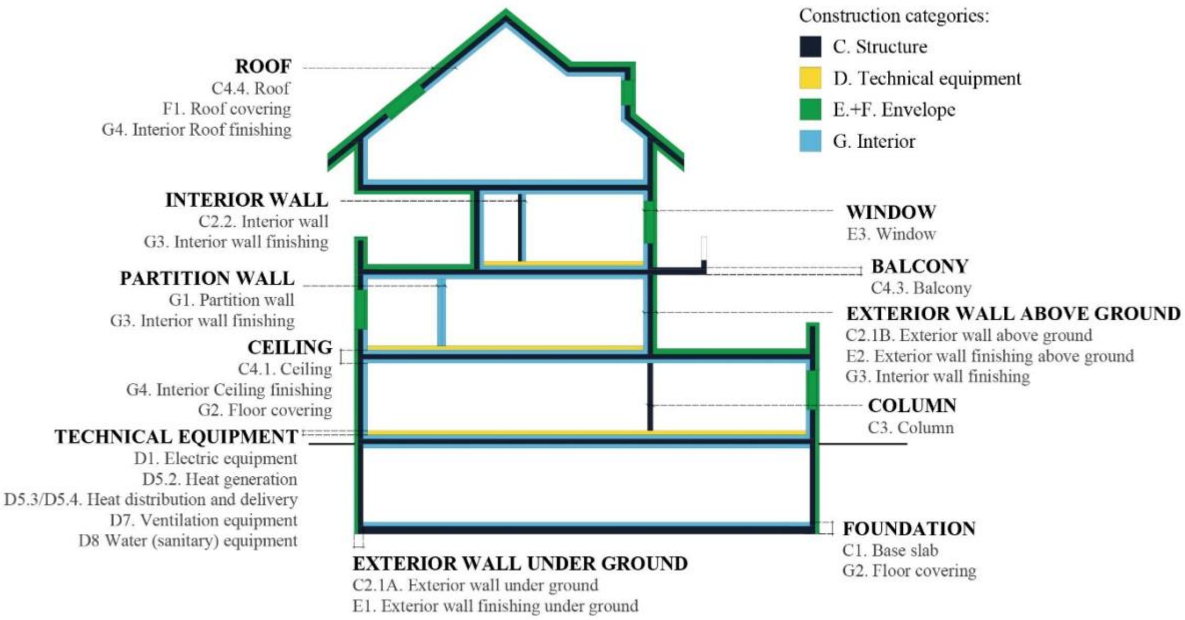

Figure 2.3: General description of the building, building element, building component and construction categories according to Cavalliere et al. (2019).

As shown in Figure 2.3, the service life of a building element can be defined at different levels of details. However, as a building element gather different components with different functions, it is not appropriate to define a single service life for a multi-layered element. The service life is thus defined for each component (or layer). For instance, depending on the scope of the assessment, the service life can be attributed for 2 levels of details according to Figure 2.3:

1. construction categories (structure, technical equipment, envelope (wall and roof external coatings as well as windows and doors), interior (i.e., non-load-bearing walls and interior finishing))
2. detailed components & layers (e.g., roof covering, interior roof finishing etc.)

If more product-specific data are available, the service life can also be defined even further for specific product using the information of reference service live (RSL) in the Environmental Product Declaration (EPD).

Indeed, the definition of the service live in practice will be a function of two “limiting” criteria:

– First, representative renovation practices[8] should be considered in order to avoid misleading service lives definition. For example, in practice, if the rendering and the external insulation are replaced at the same time, the two components should not be distinguished in the view of their service lives even if literature sources provide a service live for the rendering and the insulation. At least, the lowest service life should be used for both materials (layers). The same problem exists with the windows (glazing and framing). They are generally replaced as a single component and thus define different service lives does not correspond to reality.
– Second, possible lack of service lives data for very specific elements or for innovative products may not allow attributing service lives in a lower level of details.

2.3 RSP Values for Buildings

The RSP period can vary depending on the national LCA methodology and the context of use of the assessment results. The national LCA methods generally uses conventional values for this parameter. In Switzerland, the LCA national method (Cahier Technique SIA 2032, 2010), (Cahier Technique SIA 2040, 2011) proposes 60 years. The SIA 480 standard does not define an RSP but the service life of the building

[8] And representative of the reference context of use as mentioned in EN 15804 and EN 15978.

structure instead. The SIA 480:2004 standard considers from 80 to 100 years (SIA, 2004) while the revised 2016 version considers from 40 to 120 years with an intermediate value at 75 years (SIA, 2016). In addition, the SNARC method, used in early design stages, considers 30 years (SIA, 2004). Other LCA methods in Europe consider 50 years (BBSR, 2011), 80 years (Izuba-Energies, 2019) or even 120 years (IEA - Annex 72, 2019).
Using 30 years can be appropriate in order to amortize the LCA of the construction over a short period (e.g. to comply with environmental / public policies goals such as the carbon neutrality by 2050) or for building typologies with shorter lifetime, while using 100 years allows to account for a longer life cycle, which may represent better the reality. In general, many national LCA methodologies consider 50 to 60 years to calculate the LCA[9].

In general, the service lives of structural building elements correspond/coincide to the RSP in a building LCA. The underlined assumption for the RSP will affect the number of times a building element needs to be replaced. As the service lives found in the literature (see

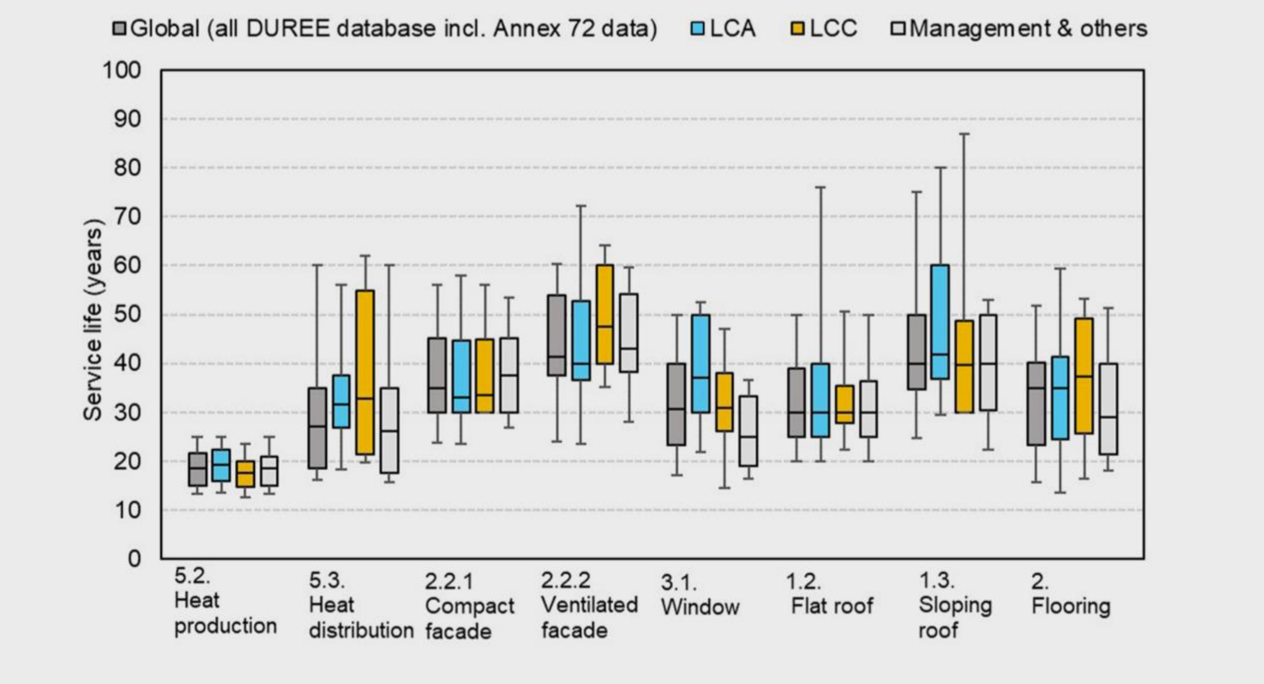

Figure 2) present substantial variations, the replacement rate will be a function of the elements' service lives and the RSP values.

2.4 Replacement Rate Calculation

Currently there are mainly two different approaches on how to deal with replacements in the life cycle inventory of a building:

- Approach A: Annualised impacts per building element;
- Approach R: Rounded up number of replacements of building elements;
- Approach S: Simulation of the building life cycle.

The three approaches are described in the following.

Approach A, Annualised impacts per building element

The annualised environmental impacts of a building element are calculated taking into account the service life (or the reference service life (RSL) or the adjusted expected service life) of the element. First, the

[9] Cf. SBE Graz paper from Rolf Frischknecht and the current Activity 1.1 on survey of national LCA methodologies

environmental impacts of manufacturing a particular building element (e.g. a window) are determined. Secondly, the environmental impacts are divided by the reference service life (RSL) of this building element (e.g. 30 years). These two steps are repeated for all the building elements, which compose the building under assessment. Finally, all resulting values, per year, are added up, a sum which corresponds to the annual environmental impacts of the building under consideration. This approach is applied in Switzerland in the technical bulletins SIA 2032 (SIA 2020) and SIA 2040 (SIA 2017), in which the distinction between initial efforts and efforts due to replacements are of little interest and the residual values are simply neglected.

Approach R1, Rounded up number of replacements
First, the number of replacements of a particular build-ing element (e.g. a window) is determined by dividing the reference service life (reference study period) of the building (e.g. 60 years) by its reference service life time (e.g. 30 years) minus 1. In this example, the windows will be replaced only once during the service life of the building. In case that the RSP of the building is 50 years, the exact number of replacements would be 0.67. Since fractional replacements are not possible, these values are rounded up to the next integral number (in the example: 1). Secondly, the environmental impacts of manufacturing a particular building element (e.g. a window) are determined. Thirdly, the environ-mental impacts of manufacturing all building elements of a building are added up to get the environmental impacts of the product stage (Modules A1-A3). Fourthly, the environmental impacts of manufacturing all building elements of a building are multiplied by the number of replacements and then added up to get the environmental impacts of replacements during the use stage (Module B4). Fifthly, the total environmental impacts of the product and the use stage are divided by the RSP of the building under assessment. This approach is required by the CEN standard on the assessment of the environmental performance of buildings.

Approach R2, rounded up number of replacements with a certain condition
This approach distinguishes the obtained values for the calculated number of replacements depending on a threshold. If the replacement rate is higher than a percentage (e.g., 20%) of its integer value it is rounded up, otherwise it is rounded down[10]. Like that, overestimation of the replacement rate can be avoided, in case is the number of replacements is very small, e.g. 1.05 times. Practically, this means that if the end of life of a building element is close to the end of the building RSP, this is no replacement.
However, even if Approach R1 and R2 reflect better the reality of the replacement rate, the use of the fractional one presents a negligible influence on the building LCA results, especially compared to the choice of the RSP value (cf. Case studies results' section of this report).

[10] Such calculation rule is currently implemented in existing building LCA tools

Approach R3, component-specific rounded up

The analysis of the aging process of real buildings shows that the replacement rate in the case of components is often overestimated[11]. Most of building components often turn out to be more robust than expected, or the building owners are more tolerant of an aged state. An approach can be that for such building components, the calculated number of replacements is always rounded down and no replacement is assumed in the last 5-10 years of the life cycle model. However, the situation is different with technical equipment that is critical for safety and efficient operation. In these cases, since a planned replacement must always be carried out, and often is mandatory, the number of replacements can be rounded up. This leads to a component-differentiated approach which so far is not seen applied in any of the national methods, tools, but is presented as a possibility in the draft of upcoming EN 15978.

Approach S: Simulation of the building life cycle

A simulation process accounts for environmental impacts using a one-year time step[12]. Each building element has an age counter, incremented each year. When the age reaches the life span, impacts corresponding to the replacement processes are added. Replacement is not considered anymore after 90% of the building life span.

[11] See: Ritter, F. (2011). Lebensdauer von Bauteilen und Bauelementen-Modellierung und praxisnahe Prognose (Vol. 22). TU Darmstadt.

[12] E.g. Pleiades ACV EQUER, see Polster, B., Peuportier, B., Blanc Sommereux, I., Diaz Pedregal, P., Gobin C. and Durand, E. Evaluation of the environmental quality of buildings - a step towards a more environmentally conscious design, Solar Energy vol. 57 n°3, pp 219-230, 1996

3. Illustration of the Approaches and their Consequences based on a Case Study

3.1 Service lives definitions and values of building elements and their related uncertainties and variabilities

This section presents a case study that draws on the findings of the Swiss DUREE research project (Lasvaux et al, 2020) and the related journal paper (Goulouti, Padey, Galimshina, et al., 2020).
Service lives data, collected in the DUREE database[13] and combined with Annex 72 service lives data (collected in the survey on national LCA methodologies) present a substantial variability and uncertainty as shown in the
Figure 2.1 and 2.2. It is thus important to assess whether their empirical variabilities affect the reliability of the building LCA results and more specifically the reliability of the replacement stage calculation. The data were used, for the determination of the probability density functions (PDF) for each building component of the case studies. In this building case study, they are first used to calculate a replacement rate k (see Eq. 1) for each element type by dividing each service life with a reference study period (RSP) chosen at 60 years. Then, the service life data were transformed in replacement rates and the PDFs of the element types were defined, by fitting a lognormal distribution. The present study takes into account the uncertainty of the element types service life (input of the model) in the building LCA (output – response of the model).

Remark & Scope of the probabilistic LCA: All the other uncertainties related to the parameters of the building LCA e.g. uncertainty of the operational energy use of the building and the LCA are not within the scope of this study. By doing so, the relative importance of the service lives' uncertainties is solely evaluated, taking into consideration that a small uncertainty on the total LCA result (output), derives from an insignificant influence of the service life (input).

One way to identify the error propagation, due to the uncertainty of the input on the output, is to use the Monte Carlo method within a probabilistic framework. 40'000 Monte Carlo simulations are computed in order to probabilistically take into account the replacement of the building elements. Like that, the Probability density functions (PDF) of the LCA outputs are defined. Finally, the Sobol' Sensitivity Indices are calculated following (Saltelli et al, 2008) to determine the impact of the service lives' variability on the LCA uncertainty, for the different building elements.

This methodology is applied to one Swiss residential building case study located in Zürich and for the greenhouse gas emissions (GHGe) indicator. Table 2.1 presents the characteristics of the residential building.

Table 2.1: Characteristics of the new constructed residential building

General information	B1
Construction type	Medium weight
Materials for the structure	Wood & concrete
Type of facade	Compact & ventilated
Type of roof	Sloping roof
Energy reference area	350
Energy standard	Minergie-ECO
Accommodation units	2

[13] Based on the Swiss DUREE research project, final report available here: https://www.aramis.admin.ch/Texte/?ProjectID=38626

Basement	Yes
Number of floors	3
Heating & ventilation systems	
Heating device	District heating
Energy source	Wood chips
Solar panels	No
Annual energy demand (MJ/m²y)	
Heating	106
Domestic Hot Water (DHW)	75
Ventilation	24

The life cycle domains and phases of materials and building integrated technical systems (BITS) are defined according to SIA 2032 (SIA, 2010) and SIA 2040 (SIA, 2011) as shown in Table 3.2. The basic life cycle domains are the Construction and that of the Operational energy use. Table 3 shows the different life cycle domains and the corresponding phases taken into account, in the present study. No other environmental impacts were considered in this approach (e.g. maintenance, or environmental impact due to mobility of the users, as stated in SIA 2040).

The baseline RSP value is first defined at 60 years and the replacement rate is fractional. In the next sections, alternative assumptions will be evaluated.

Table 3.2: Life cycle stages of a building adapted from SN EN 15978; in green the included stages for the "construction" domain and in orange the "operational energy use" according to SIA 2032 and SIA 2040.

	According to SN EN 15978 standard												
	Product stage			Construction process stage		Use stage				End-of-life stage			
	Raw material supply	Transport	Manufacturing	Transport	Installation	Use, Maintenance, Repair	Replacement	Operational energy use	Operational water use	Deconstruction / demolition	Transport	Waste processing	Disposal
	A1	A2	A3	A4	A5	B1-B3	B4	B6	B7	C1	C2	C3	C4
According to SIA 2032 & 2040	Manufacturing						Replacement	Operational energy		Disposal			
Construction	X						X			X			
Operational energy use								X					

(X = calculated in the LCA of the Swiss residential building according to the SIA technical books)

The Swiss building element classification scheme, for cost estimation, eCCC-Bât in French, (or eBKP-H, in German) is used to classify the building elements. The classification of eBKP-H nomenclature has already been used to report the service lives data. Each building element consists of several building components, which have different functions and belong to different construction categories.

In this case study, the service lives data are those of the second level of analysis according to the Swiss DUREE research project (Lasvaux et al, 2020). This means that 16 difference service lives data are used for the modelling of the replacement phase of the building LCA.

Figure 3.1 presents the result of the probabilistic LCA (the first part entitled the ***uncertainty analysis*** of one new construction case study (B1), for the GHG emissions) compared to two deterministic LCA suing deterministic service lives from Swiss documentations (SIA 2032 and CRB). The probabilistic LCA (right, noted “DUREE DB”) is about [μ=22 kg $CO_{2\text{-eq}}/(m^2y)$, $\sigma^2=3^2$], while the deterministic LCA, from SIA 2032 reports a value of [20.4 kg $CO_{2\text{-eq}}/(m^2y)$] and CRB [mean=19 kg $CO_{2\text{-eq}}/(m^2y)$]. The results show that the uncertainty of the replacement rate can significantly affect the LCA uncertainty. The replacement stage in the probabilistic LCA, accounts for 14% to 36% of the GHG emissions for the B1 residential building.

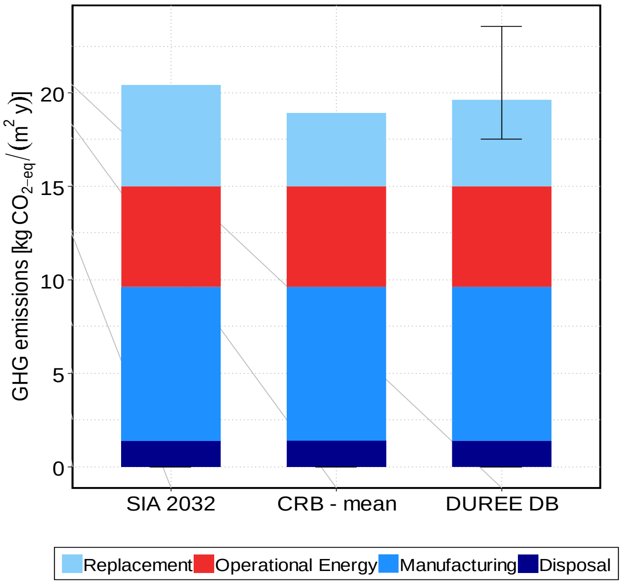

Figure 3.1: Contribution analyses for the probabilistic LCA and comparison with the deterministic LCA, using the SIA 2032 and CRB - mean service lives (taken from Lasvaux et al (2020) and Goulouti, Padey, Galimshina, Habert & Lasvaux (2020))

Figure presents the synthesis of the second part of the probabilistic LCA (i.e., the ***sensitivity analyses*** using the Global Sensitivity Analysis and Sobol Indices (Saltelli et al, 2008)) for the GHG emissions of the residential building B1.

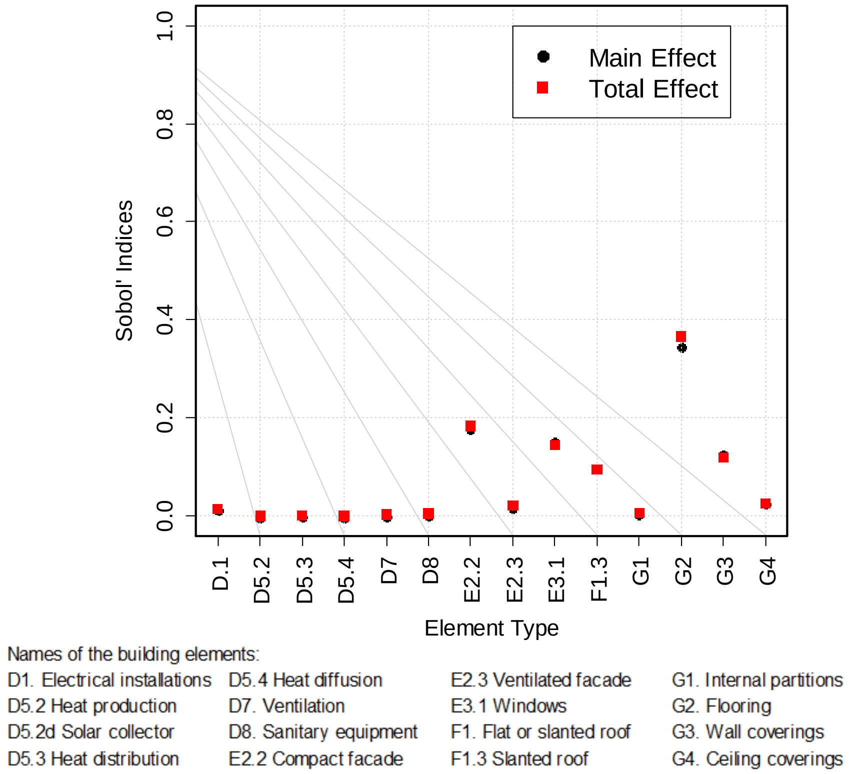

Figure 3.2: Sobol' sensitivity Indices (main and total effect) for the GHG emissions of building B1 taken from Lasvaux et al (2020).

The outcomes of this building LCA case study are the following:

– If a threshold is defined at 0.10 for the sensitivity indices, only six element types out of 16 are the most influential on the LCA uncertainty, i.e. E2.2 (compact façade), the E3.1 (windows), the F1.3 (sloping roof), the G2 (flooring), G3 (internal finishing). This means that special attention should be given when defining the service lives for these element types in further LCA calculations;
– The uncertainty of the technical systems service lives (D element type) present low impact on the LCA uncertainty for the GHGe. If this finding remains valid for other case studies and LCA indicators, the LCA model could be simplified and conventional deterministic values would be sufficient to model this aspect, instead.

3.2 Level of Details for Fixing the Service Live of a Building Element

The same building case study (B1) is used as already presented in Table 3.1. In connection to the Annex 72 (Passer et al. 2023), the building LCA can follow different building decomposition (from major element to sub-elements and layers of materials). In Switzerland, the eBKP-H nomenclature form the CRB (Code for the construction costs) is used with different levels of details. It is thus possible to break down the building LCA in a sum of different elements, each one having its LCA value and its service life. In connection to the Life Cycle Cost (LCC), such approach exists and allows to define a service life for one main category (e.g., the technical equipment) but also for a sub-category (e.g., the heating system) and another more precise element (e.g., the heat producer). Table presents the number of service lives that can be for two different levels of details (taken as an example, as other configurations are possible). By doing so, it is possible to conduct building LCA with a varying level of details.

Table 3.3: eBKP-H codes and the corresponding names of the element types included in the case studies taken from Lasvaux et al. (2020).

eCCC-Bât element types considered	Building LCA New construction case study	
	First analysis	Second analysis
C. Structure	fixed at 60 years	fixed at 60 years
D. Technical equipment	X	
D1. Electrical installations		X
D5. Heating system		
D5.2 Heat production		X
D5.2d Solar thermal collectors		X
D5.3 Heat distribution		X
D5.4 Heat emission		X
D7. Ventilation and AC systems		X
D8. Sanitary equipment		X
E. Facade rendering	X	
E2. Facade rendering against exterior		
E2.2 Compact facade		X
E2.3 Ventilated facade		X
E3. Windows, doors		
E3.1 Windows		X
F. Roof	X	
F1. Covering		
F1.2 Flat roof		X
F1.3 Slanted roof		X
G. Interior	X	
G1. Internal partitions		X
G2. Flooring		X
G3. Wall coverings		X
G4. Ceiling coverings		X
Total number of service lives' values	***4***	***16***

For example, a building LCA can be calculated in early design or in a simplified approach using the 4 main categories (structure, technical equipment, facade rendering, roof, interior) with one LCA value (based on statistics or aggregated data) and service lives for each category. It is also possible to have a more detailed analysis as show in Table . In practical application, the need for a low level of details may be justified by the need of doing a quick & simplified LCA[14] (also valid for a quick & estimated LCC) while more detailed analysis will be justified to compare more defined case building projects. Different types of screening, simplified and detailed LCA, can be done and more information is provided in the Annex 72 report by Passer et al. (2023).

As an illustration, probabilistic GHG emissions using PDF of service lives can be calculated for both levels of analysis (from Table), Figure . These results present the same values as in
Figure 3.1 by providing the complete PDF instead of the “error bar” for the probabilistic GHG emissions (noted “DUREE DB” in the graphics.

[14] Here, the proposed building decomposition comes from the “life cycle cost” perspective & community. It can be used for building LCA and building LCC that do not aim at linking building energy simulation (BES) and building LCA as the building elements of the thermal envelope (used in BES) and those not included in the BES (such as the foundations) added for the building LCA are not differentiated.

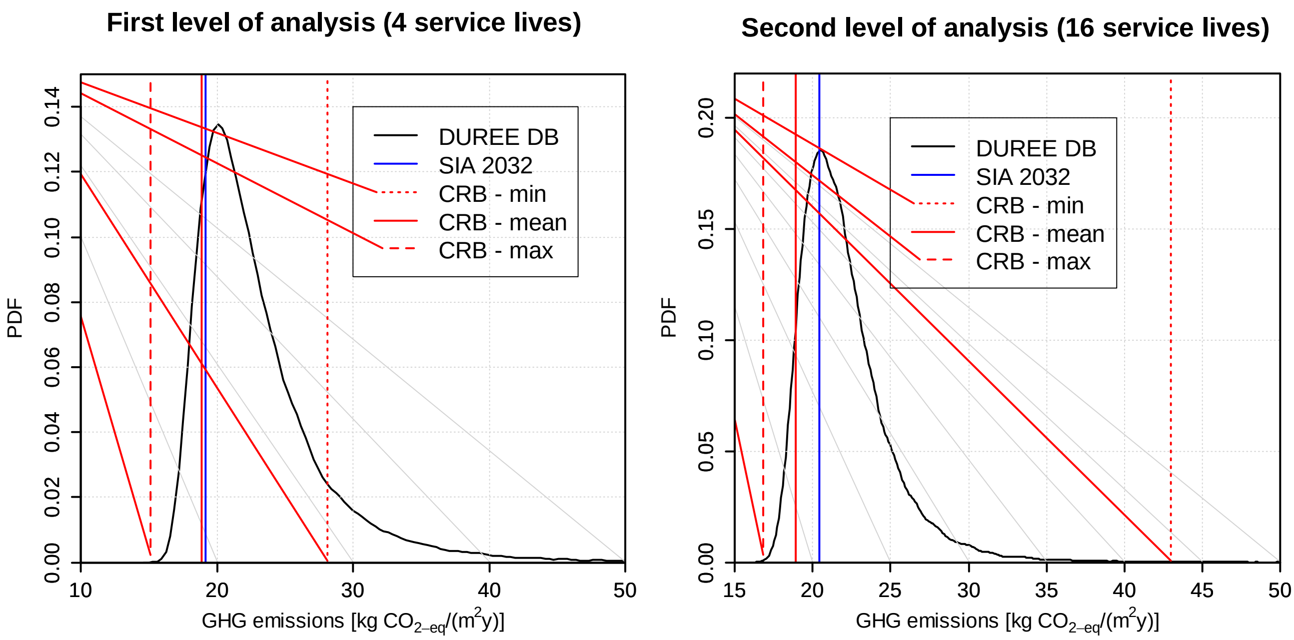

Figure 3.3: PDF of the probabilistic LCA for the B1 case study in the first level of analysis and comparison with the deterministic LCA, using the SIA 2032 and CRB service lives (left); PDF of the probabilistic LCA for the B1 case study for the second level of analysis as presented in the previous section (right), adapted from the DUREE research project (Lasvaux et al, 2020)

In Figure (left), the probabilistic LCA in the first level of analysis is calculated [$\mu = 23.22$ kg CO_2-eq/(m^2y), $\sigma^2 = 5.5^2$] and compared with the deterministic LCA of the SIA 2032 [19.2 kg CO_2-eq/(m^2y)] and CRB [min=28.1 kg CO_2-eq/(m^2y), mean=18.9 kg CO_2-eq/(m^2y) and max= 15.1 kg CO_2-eq/(m^2y)][15]. The three CRB values (min – mean – max) correspond to the minimum, mean and maximum service lives, which mean maximum, mean and minimum replacement rates, respectively. The most probable value of the LCA, i.e., the mode of the distribution (xm=20 kg CO2-eq/m2y) is slightly higher than the deterministic SIA 2032 and CRB–mean (4% and 6% respectively). Figure (right) shows the PDF of the probabilistic LCA for the second level of analysis, along with the deterministic LCA, from SIA 2032 [20.4 kg CO_2-eq/(m^2y)] and CRB [min=43kg CO_2-eq/(m^2y), mean=19 kg CO_2-eq/(m^2y), max=17 kg CO_2-eq/(m^2y)].

This example shows the feasibility to calculate the probabilistic LCA using different levels of analysis (and building decomposition) for both the LCA and the definition of the service lives.

3.3 RSP Values for Buildings

The same building case study (B1) is used as already presented in Table 3.1. The building RSP is varied from 30 up to 120 years, with intermediate values of 50, 60, 80 and 100 years, in order to identify the influence on the LCA of this methodological convention. The intermediate values derive from the most common used RSP among the LCA methodologies, applied in different countries (Janjua et al., 2019). The calculation was conducted for the B1 building case study. The contribution analyses and the sensitivity indices were calculated for the GHG emissions indicator.

Error! Reference source not found. presents the contribution analyses of the Swiss building B1 for the different RSP, for the probabilistic LCA for the GHG emissions. The median of the replacement rate is plotted, along with the first and third quartiles. As expected, looking at the median value, the share of the manufacturing stage decreases, from 57% to 23%, while the replacement environmental impact increases,

[15] The 95% confidence interval of the mean is narrow [$\mu = 23.22\ \mathrm{kg\ CO_{2-eq}}\ /(\mathrm{m^2y}) \pm 0.05$], revealing the accuracy of the simulations.

from 15% to 42%, when shifting from 30 years to 120 years. This is due to the shift in the life cycle stages, when the RSP is extended: the share of the replacement phase increases, since replacement occurs more times, during 120 years, while the impact of the initial construction (manufacturing stage) decreases, since it is apportioned to much more years.

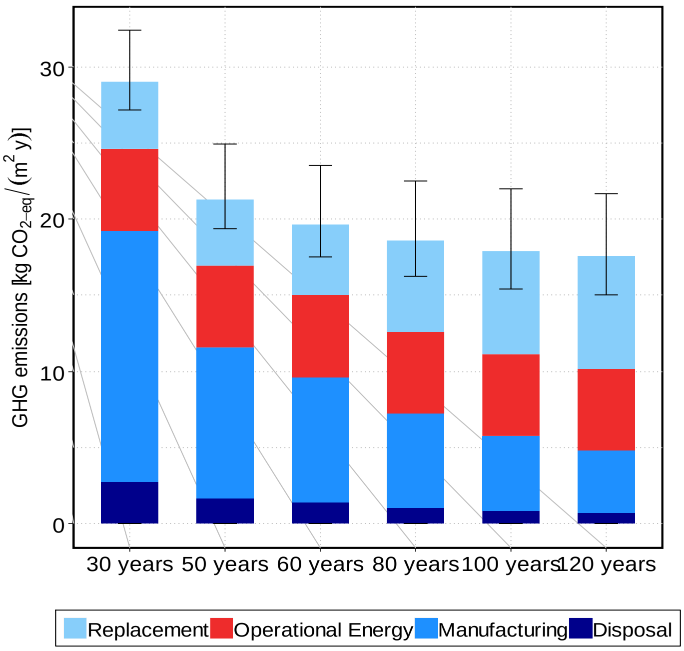

Figure 3.4: Contribution analyses for the probabilistic GHG emissions using the DUREE database for different building lifetimes of 30, 50, 60 80, 100 and 120 years, taken from Lasvaux et al (2020) and Goulouti, Padey, Galimshina, Habert & Lasvaux (2020)

Figure presents the results of the ***scenario analysis*** for the 6 different RSP values using the Sensitivity Analysis and Sobol' Indices of the probabilistic LCAs. The outcomes of the sensitvity analyses for different RSP for one building (B1) are the following:

– The same influential building elements can be identified as presented in the Swiss case study in Section 3.1
– Varying the reference study period (RSP) of the building from 30 to 120 years leads to a significant variation of the sensitivity indices of the most influential element types. Thus, the RSP is an influential parameter on the LCA and LCC uncertainty.

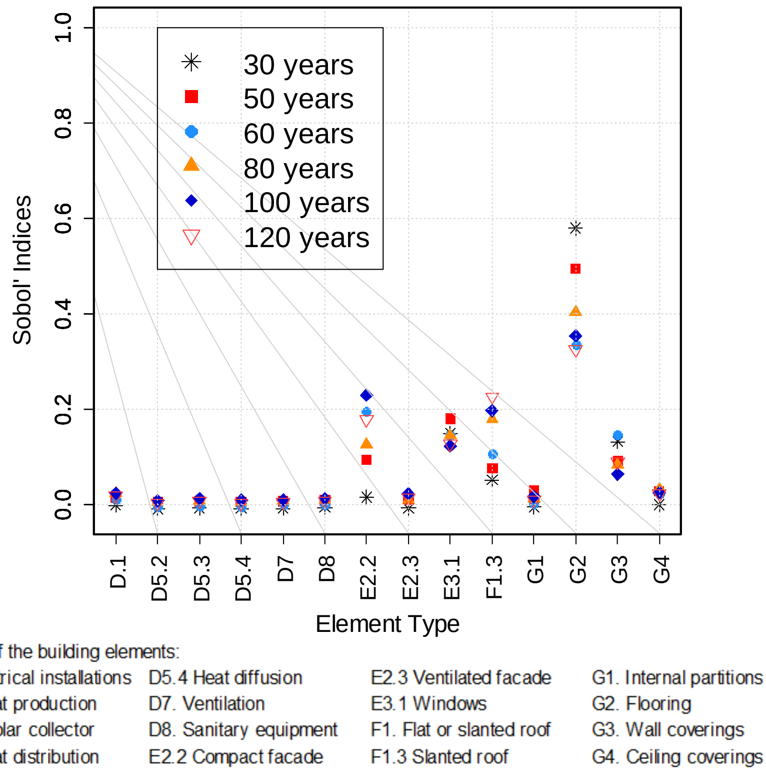

Figure 3.5: Sobol' Indices for the GHG emissions and the B1 case study for different building lifetimes of 30, 50, 60, 80, 100 and 120 years, taken from Lasvaux et al (2020) and Goulouti, Padey, Galimshina, Habert & Lasvaux (2020)

3.4 Replacement Rate Calculation

The same building case study (B1) is used as already presented in Table 3.1. The baseline scenario for reporting the LCA results in above sections considers the fractional mode, as defined in SIA 2032 and SIA 2040. In the current section, the fractional mode is compared with the rounded mode, according to SN EN 15978 (CEN/TC 350, 2011). In addition, the "rounded - 20%" mode is included. According to this mode the replacement rate is rounded up, in case that it is higher than 20% of its integer value, otherwise it is rounded down. Such a calculation mode may be implemented in some of the building LCA calculation software, as for example in Logiciel Pleaides ACV (Izuba-Energies, 2019). Like that, overestimation is avoided in case that the replacement rate is very small, e.g. k = 1.05.

Figure presents the PDF of the B1 case study for the GHG emissions. The three different ways of calculating the replacement rate result to slightly different PDFs (differences approximately 14%, for the mean), with the following properties, i.e. $[\mu = 24.5 \text{ kg CO}_{2-\text{eq}} /(\text{m}^2\text{y}),\ (\sigma^2 = 2.7^2)]$, $[\mu = 25.5 \text{ kg CO}_{2-\text{eq}} /(\text{m}^2\text{y}),\ (\sigma^2 = 3^2)]$, $[\mu = 22.0 \text{ kg CO}_{2-\text{eq}} /(\text{m}^2\text{y}),\ (\sigma^2 = 3^2)]$, for the rounded 20%, rounded up and fractional mode, respectively.

Figure presents the Sobol' Indices for the three different calculation modes for the replacement rate. The results show that the tendency of the sensitivity indices remains the same, independently of the calculation type. As a result, even if rounded up, or rounded - 20% may better reflect the reality of the replacement rates, the use of the fractional replacement rate does not change the order of the sensitivity indices and their impact on the LCA uncertainty.

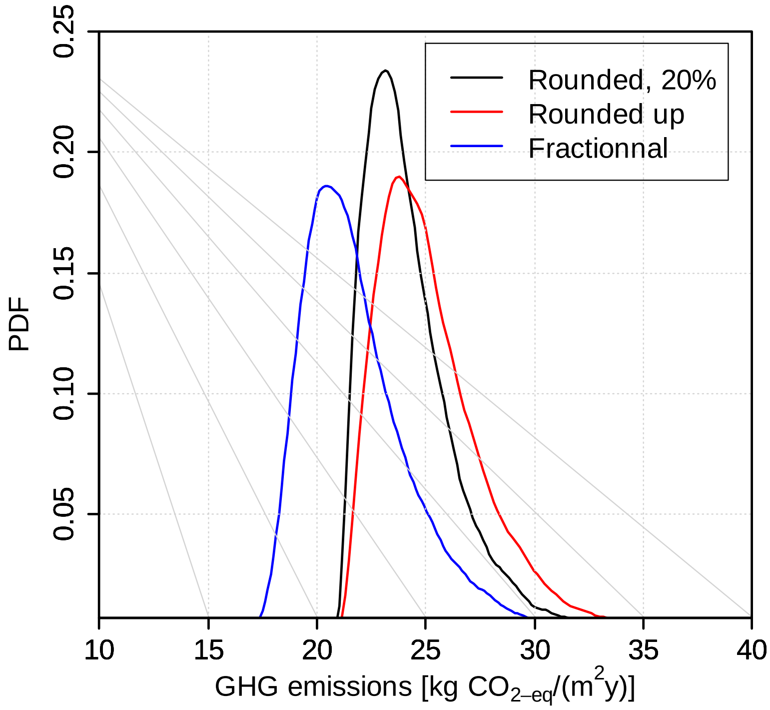

Figure 3.6: PDFs of the probabilistic LCA of the B1 case study, using the three calculation modes taken from Goulouti, Padey, Galimshina, Habert & Lasvaux (2020)

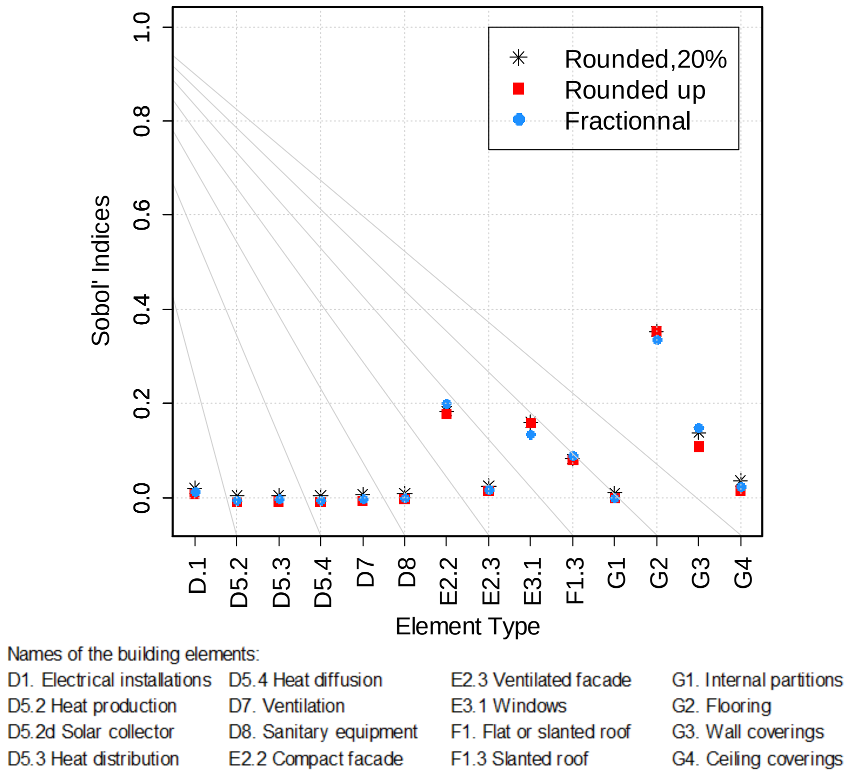

Figure 3.7: Fractional, rounded up, rounded 20% influence on the Sobol' Indices for the GHG emissions and the B1 case study, taken from Lasvaux et al (2020) and Goulouti, Padey, Galimshina, Habert & Lasvaux (2020)

The outcomes of the sensitvity analyses for different RSP for one building (B1) are the following:

- The same element types can be identified as presented in the Swiss case study in Section 3.1.
- The LCA uncertainty is not influenced by the calculation mode of the replacement rate, i.e. fractional according to Swiss SIA 2032 / SIA 2040 standard or rounded up according to SN EN 15978 standard. Hence, both modes could be used in further LCA analysis.
- The results show that the tendency of the sensitivity indices remains the same, independently of the chosen calculation method. As a result, even if rounded up and rounded (20%) may better reflect the physical reality of replacement rates, the use of a fractional rate does not change the sensitivity of the LCA.

3.5 Case Study's Limitation and Conclusions

This case study concerns only one LCA indicator (GHG emissions), tested for one system boundaries (Swiss LCA method from SIA 2032 & SIA 2040 technical books), and for one building case study. The complete research study supporting this project's report can be found in the DUREE project final report[16] and associated papers[17,18].

Last but not least, this case study helps to better understand the consequences of uncertain service lives values, uncertain reference study period for buildings but does not contain yet rules and guidance for a better modelling of module B4. The next chapter presents the rules and guidance.

[16] Lasvaux S. et al 2019. "DUREE Project: Analysis of lifetimes of building elements in the literature and in the renovation practices and sensitivity analyses on building LCA & LCC case studies", Swiss Federal Office for Energy (SFOE), Final report, June 2019, available online: https://www.aramis.admin.ch/Dokument.aspx?DocumentID=50999.

[17] K. Goulouti, P. Padey, A. Galimshina, G. Habert, S. Lasvaux 2019. "Uncertainty of building elements' service lives in LCA & LCC of buildings: what matters?", Building & Environment, Volume 183, October 2020, available online: https://www.sciencedirect.com/science/article/pii/S0360132320302638?via%3Dihub .

[18] K. Goulouti, P. Padey, A. Galimshina, G. Habert, S. Lasvaux 2019. "Dataset of service life data for 100 building elements and technical systems including their descriptive statistics and fitting to lognormal distribution", Data in Brief, Volume 36, June 2021, available online (Open Access): https://www.sciencedirect.com/science/article/pii/S2352340921003462

4. Conclusions and Guidance on How to Handle Replacements (Module B4)

The following conclusions, rules and recommendations come from the main A72 report by Lützkendorf, Balouktsi and Frischknecht et al. (2023).

Module B4 makes a significant contribution to the results of a building LCA. Components and systems that are either replaced very frequently or cause high environmental impacts (initially and when replaced) are important. For the modelling of B4, there are different methodological questions for which methods need to provide answers. First, the definition of the service lives for different types of building elements is unavoidable. Special attention should be given to building elements whose uncertainty may have an important impact on the final LCA result. Second, there are several approaches to calculate the replacement rate based on components' service lives. Third, a matter of question is at what level of detail the service life of a component comprised of several layers of varied service lives must be fixed. Rules and recommendations for action are provided below to support the handling of such calculations in building LCAs (Table 4.1 and gray box below).

Table 4.1: Rules on how to model replacements

ISSUE(S)	RULE(S)	
How to deal with the uncertainty of building elements' service lives?	1.	Default values for the service lives of all possible construction products and technical equipment shall be provided
	2.	For fixing the default values for the most influential service lives of building elements on the total LCA result, uncertainties shall be handled, robustness of results shall be checked (through ranges)
How to calculate the replacement rate of building elements?	3.	It shall be clearly stated whether Approach A (Annualised impacts per building element), approaches R1, R2 or R3 (rounded up approaches) or S (simulation) shall be followed when calculating the replacement rate. Particularly, for approach R3, it shall be made clear for which components, products and equipment the number shall be always rounded up (never rounded down) including a justification.
At which level of detail shall the service life of a building element be defined?	4.	If two products/layers are typically replaced at the same time, the two components shall not be distinguished in the view of their service lives even if literature sources provide different service live for these two products. At least, the lowest service life shall be used for both materials (layers).

Recommendations for action

National standardisation bodies (application / use case: C, see Table 1.2)

a. Develop and provide tables with default service life values for building elements and construction products

b. Provide service life ranges for influential building elements based on empirical evidence to assist designers to examine the robustness of the LCA results following a probabilistic approach

Developers / providers of sustainability assessment systems (application / use case: C, see Table 1.2)

c. use the default service life values for building elements provided by your national standards.

Researchers (application / use case: B, see Table 1.2)

d. run sensitivity analyses to investigate the significance of effects of various service life ranges for different components on the final LCA outcome

e. provide empirical evidence on the actual service life of building components under different conditions of use

Construction product manufacturers (application / use case: F, see Table 1.2)

f. provide different default values for service life according to different conditions of use

5. References

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