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# OPTIONS OF MODELLING REFURBISHMENT IN LCA: CONTINUOUS IMPROVEMENT STRATEGY AND NEXT LIFE CYCLE APPROACH

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Abstract. Compared to other goods, buildings have a long lifespan. It is therefore the norm and not the exception that adaptation will be needed at some point in their life cycle to changing environmental conditions, technical progress and new/additional user requirements. The adaptation of existing buildings to future challenges in the form of refurbishment contributes to sustainable development. The proportion of refurbishments is increasing in both absolute and relative terms in the building sector in Europe. It is therefore surprising that the modelling particularities of refurbishment in the context of a life cycle-based environmental performance assessment are still neglected in the EN-standards. The paper deals with these particularities. Specifically, it presents a typology of approaches starting with a distinction between planned refurbishment as B5 and unforeseen refurbishment as an independent design and construction task / next life cycle, as well as the status of the discussion in selected countries. Recommendations for action for the life cycle assessment are given for specific decision-making situations.

Keywords: Sustainable development, buildings, refurbishment, re-purposing, life cycle assessment.

## 1. Introduction

Compared to other goods, buildings have a long lifespan. This can be between 20 and over 100 years, depending on the building type and pattern of use. Maintenance during a building's lifetime is necessary to keep the building in a usable condition. This includes activities such as maintenance, repair work, as well as replacement of components whose service life is shorter than the service life of the building. In a life cycle assessment (LCA), these processes correspond to modules B2, B3 and B4, respectively. The aim of these processes is to maintain the technical and/or functional performance of the building in use.

However, over a comparatively long building service life, changes may arise in social, legal, climatic and/or economic boundary conditions, changes in user requirements and/or technical progress. In addition to maintaining the technical and/or functional features, there is a need to explore whether a building will be usable, rentable and marketable also in the future. The need may arise to go beyond maintenance at some point in a building's life cycle and apply technical and/or functional improvements to adapt to technical progress (better products are entering the market) and/or to new user requirements. Such improvements can be realized by refurbishment measures. Major building refurbishments usually take place after a 20–30 year's period of use of a building and are possibly combined with maintenance, repair and/or replacement measures.

Refurbishment may extend the service life of buildings. A longer building lifespan can slow down the material cycles, reduce the energy and mass flows as well as negative impacts on environment. While many new buildings will have to be constructed in parts of the world in the coming years, in Europe adapting and further developing the existing building stock is a major priority [1]. To establish environmental performance assessment methods of refurbishment options would be needed to support design and decision-making processes in this context. The application of the environmental performance assessment is therefore becoming more important on the one hand, but has not yet been sufficiently methodologically penetrated, on the other, especially in contrast to LCA methods for new design / new buildings [2]. This impedes the effective use of LCA to quantify and understand the environmental benefits of refurbishments in practice.

The aim of this paper is to increase understanding of the subtleties of the use of LCA for modelling refurbishment, either as (1) a scenario in a new building design or as (2) an option for a further use phase (expressed as a next life cycle / next reference study period (RSP)) of an already existing building. This discussion is useful for clarifying the methodological context, especially given the fact that life-cycle-based benchmarks for refurbishment projects will be needed in future, although not yet the norm.

It is important to note that within the professional and scientific literature, the terms refurbishment, renovation, retrofit and modernisation are often used interchangeably. The international standard ISO 21931-1:2010 and European standard EN 15978:2011 both use the term refurbishment, which represents a "large scale (substantial) modification and improvements to

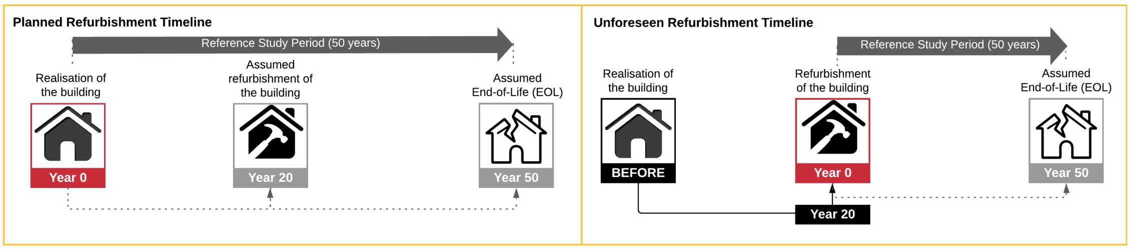


Figure 1. Timeline for planned and unforeseen refurbishment.

an existing construction work to bring it up to an acceptable condition". To be in line with the standards, the term refurbishment is used throughout the rest of the paper as an umbrella term. Furthermore, the term re-purposing is here also used to denote a special form of refurbishment where an existing building of particular type of use is transformed to a new kind of use (i.e. change of function), e.g. an office building to an apartment block. Re-purposing involves the same type of system boundaries with refurbishment, but with a changed function and – as a result – a new functional equivalent as object of assessment.

## 2. Options for modelling "Refurbishment"

### 2.1. Refurbishment as part of a first or start of a next reference study period

In this paper a distinction is made between: "planned" (anticipatory) refurbishment and "unforeseen" / not according to initial plan (re-active) refurbishment (Figure 1). In a planned refurbishment a new building still under design becomes the object of assessment. In this option refurbishment is represented by module B5 as part of the life cycle model of a new building design and the related impacts are calculated and assessed. In such a case the option for planned refurbishment becomes part of the functional equivalent. Examples are the repurposing of exhibition and Olympic game buildings, the refurbishment of a building to make it net zero in a prepared second step, etc. In the case of building concepts without refurbishment already planned at the time of design, module B5 becomes irrelevant, but modules B2, B3 and B4 must still be processed. In an unforeseen refurbishment, at first an existing building, later the design for refurbishment and at the very end the refurbished building become the object of assessment. This means that the type and time of refurbishment was not yet known during the initial design and the need for improvement (and/or adaptation to a new type of use) emerged during use.

### 2.2. Reflections in existing standards

Standards (e.g. EN 15978:2011, which is currently under revision) already offer module B5 (refurbishment) to serve as an option to document the impacts of a planned future refurbishment of buildings during the initial reference study period (RSP) in the sense of an upgrade of their technical and/or functional performance at some point during their lifetime.

What distinguishes planned replacements according to the initial plan (B4) from a planned refurbishment (B5) is that, in the present authors' interpretation, B4 only corresponds to replacements of like-for-like materials, building components and technical systems. Finally, refurbishment may also include the installation of entirely new components which are not present from the start, such as PV panels in the case of a planned net zero refurbishment.

This approach comes with implications. In future standards (and/or national guidelines complying with the standards) how to forecast technical progress of building components shall be addressed. Less problematic is the variant in which the best available technology is not yet used in the new building, e.g. for cost reasons, but is already known. In this case, the impacts and benefits associated with the re-placement of components with better ones in the context of B5 can be estimated without any problems.

A particularity of the case of addition of new types of components is that the building must be designed from the start to include them. This also may involve additional impacts, which are present before the refurbishment (B5) itself occurs. For example, in the case of solar systems planned to be installed at a later stage, empty pipes may be already defined and incorporated during design that can then accommodate components of the system to be installed at a later stage. Impacts associated with the pipes should be part of overall LCA. Therefore, it would make sense to document any additional efforts taking place at the time of refurbishment/repurposing as part of B5, while additional efforts in relation to the future use incorporated already in the initial design are part of A1-5, later also B4, C1-C4 and, in addition, B1. This is also an aspect not currently mentioned in the standards.

As seen, the inclusion of B5 necessitates complex assumptions. Furthermore, depending on the depth of the refurbishment/adaptation and type of building, its magnitude in the whole life embodied impacts can be nearly as important as A1-3 impacts [9]. It also significantly influences post-refurbishment operation

| Country ISO code / method guidance | | New components [A–C[3]] | Retained components Initial [A–B] | Retained components New [B–C[3]] | Removed components Initial [A–B] | Removed components Current [C[3]] |
|---|---|---|---|---|---|---|
| FI/national method [3][1] | | X | - | X | - | X |
| UK/professional guide RICS [4][1] | | X | - | X | - | - |
| DE/certification BNB [5] | | X | - | X | - | - |
| NL/addendum to national method [6] | | X | X[2] | X | X[2] | X |
| FR/certification HQE [7] | | X | X[2] | X | X[2] | X |
| CH/SIA 2032 [8] | Approach 1 (main) | X | - | X | - | - |
| | Approach 2[4] | X | X[2] | X | X[2] | - |
| | Approach 3[4] | - | X | - | - | - |

[1] Document applicable to both new buildings and refurbishments (only generic rules for refurbishment).
[2] Proportional to the remaining service life.
[3] The same considerations apply to recycling, recovery, reuse potential (i.e. D1), if considered.
[4] Approaches proposed for existing buildings, but some principles can also be applied to refurbishments.

Table 1. Overview of selected methods.

processes (B6 and B7) if one carries out an energy-efficient and water-saving refurbishment. Therefore, when included in an assessment the question naturally arises as to the credibility of the assumptions made and the probability of their actual realization. There is a risk of manipulation. It would be helpful to develop the basis for voluntary commitments or contractual guarantees. For example, Level(s) system in its rules for scenario development of future refurbishment/adaptability requires that, if LCA results are to be publicly reported, an independent critical review of the assumptions shall be carried out by a property market specialist with knowledge of the local and regional conditions and his or her opinion appended to the reporting [10]. It is expected that the call for extending the life of buildings through adaptable/flexible designs will lead to upgrade the importance of module B5.

When it comes to unforeseen refurbishment (action of its own), EN 15978:2011 standard states that "if a building is refurbished and the refurbishment was not taken into account at the outset, i.e. in any previous assessment, a new assessment should be carried out, particularly where the refurbishment changes the functional equivalent, ... In the new assessment of the refurbished building, the environmental impacts and aspects of the refurbishment materials and reconstruction/installation processes are allocated to modules A1 to A5".

Although the standards resulting from ISO TC 59 SC17 and CEN TC 350 deal in principle with both new building and refurbishment projects, the peculiarities of the assessment of refurbishments have hardly been discussed in detail so far. Despite the reference above it is not made clear how to treat the environmental impacts of the initial building, whose parts are being further used in the next life/RSP, among other peculiarities of applying LCA to refurbishments of existing buildings. Special rules and guidance are needed. Such rules are expected to be added in the new version of EN 15978-1, as well as the results of the work of the CEN TC 350/ WG 8 Sustainable Refurbishment remain to be seen.

### 2.3. Reflections in existing national methods

Up to now only a few countries provide special guidance on how to calculate the life cycle environmental performance of refurbishment projects (Table 1), and even less provide benchmarks for their assessment. However, the inclusion of mandatory calculations and legal binding benchmarks also for refurbishments, along the requirements for new buildings, is currently examined in some countries (e.g. Sweden [11]).

Table 1 shows the difference of existing methods surrounding the treatment of (a) new components installed in the building (replacing old components or not); (b) the retained components of the initial structure continued to be used post-refurbishment; the removed components. What all methods include are the life cycle impacts of the new components and the life cycle impacts of retained components (i.e. maintenance, replacements, etc) occurring during the next life cycle/RSP (post-refurbishment). This already necessitates the determination of an additional parameter compared to a method for new buildings: the residual / remaining service life of retained components so that to be able to define the next replacement in the next building life. Most methods do not yet provide calculation rules for this.

What makes the methods differ is how to treat the "past" impacts of all initial building, either retained or removed. This leads to various modelling approaches as defined in the next section.

## 3. Typology of options in modelling of refurbishment activities

In the case of refurbishment of an existing building as a starting point of a next service life / RSP, different modelling and inclusion/exclusion possibilities exist for: (1) parts of the initial building structure that are removed and processed (for recycling, reuse, recovery) or disposed and (2) parts of the initial building structure that remain for further use. The implications are discussed below.

### 3.1. Treatment of initial structure further used

There are three main approaches. Their appropriateness is dependent on the decision-making situation.

#### 3.1.1. Approach "zero"

This approach represents a time-related allocation of environmental impacts / resource consumption; impacts occurred in the past are allocated to the past, i.e., embodied impacts of the initial structure are neither calculated nor considered in the LCA of refurbished building. Up to now, in literature studies and in LCA tools and methods, this has been the most used approach to determine the life cycle-based environmental performance of major refurbishments (see Table 1).

This approach makes particular sense in the context of setting a specific allowable budget for environmental impacts (including GHG emissions) for a time period. All building construction and maintenance activities carried out in the past have already been charged to a budget of a past time period. According to budget-approach, assigning effects that occurred in the past to future time periods (here to a current, subsequent life cycle) in the sense of a remaining "load" could be a double-counting. Furthermore, in practice, what has already been "spent" cannot be influenced retrospectively.

#### 3.1.2. Approach "remaining load"

This approach involves the determination of the "remaining environmental load" at the time of refurbishment, with straight-line depreciation hypothesis. This means that the environmental impacts of the initial parts of the building are divided over their planned service life and then allocated proportionally to the service life that has already taken place. The remainder corresponds to the remaining load at the time of consideration. This allocation approach acknowledges that when observing a building at a specific point of time during its life cycle, some materials are already at (or close to) the end of their service life and some still have a large remaining service life, because either they have a very long service life, or they were recently exchanged. This is a perspective towards the past.

This approach is more complex as it requires the definition of at least two additional parameters/inputs: the materialisation of the components retained (type and quantity of each product/material) and their environmental impacts (LCA data). The following variants occur based on the type of LCA data this is calculated:

(1.) **Historical data** – This presupposes that the original environmental impact data during the construction of the initial building as well as past repair and replacement measures are still known or can be reconstructed. In most countries, the application of LCA and the provision of life cycle-based environmental information of products has not been around for more than twenty years, which makes the retracing of the "environmental" history of already long-standing buildings very difficult or unfeasible. However, this will be less of a problem long-term with increasing digitalisation of environmental information and calculations in the construction sector.

(2.) **Present-day data** – Original components can be calculated as they were built today (i.e. by choosing the environmental values of equivalent products in current databases), although material efficiency in production and use significantly improve decade after decade.

(3.) **Dynamically modelled data** – There are examples of already-existing LCA datasets being remodelled to account for the influence of the dynamic development of electricity mix models and an increase in production efficiencies on environmental impacts of products to get the "future" environmental impacts [12]. In the same way, re-modelling of current LCA datasets can be done to correspond with the electricity mix used at the time of the production of the products constituting the existing building.

The methods that currently follow the remaining load approach exclusively (Table 1) do not clearly specify what type of LCA data shall be used for the original structure. It can be assumed that the data found in their national tools apply (present-day-data). In general, from a practical point of view, variants 1 (when feasible) and 2 make sense and can be part of an official approach. Variant 3 is a theoretical possibility for science.

#### 3.1.3. Approach "fictive replacement of components"

Structural parts continued to be used can be assessed based on current LCA data. This results in a "fictive replacement of building components" if existing components continue to be used in the sense of "as if newly constructed". In other words, this approach measures the impacts that are assumed as avoided by continuing to use existing parts of the building, i.e. not entirely constructing a new identical building (same functionality, size, operational energy efficiency, etc.). This is one of the approaches in SIA 2032 in the case existing buildings (Table 1). While the primary intention of

| Variant for removed products with considerable residual life | Approach zero | | | Approach remaining load | | |
|---|---|---|---|---|---|---|
| | IB | RB | AB | IB | RB | AB |
| 1 – removed and finishes its EoL | Full allocation | Zero | n/a | % allocation | % allocation | n/a |
| 2 – removed, sold & reused in another building | Full allocation | n/a | Zero | % allocation | n/a | % allocation |
| 3 – reused in the same building | Full allocation | Zero | n/a | % allocation | % allocation | n/a |

Table 2. Different ways of allocating removed elements with residual service life. Note: 'IB' = initial building; 'RB' = refurbished building; 'AB' = another building outside the system; '%' = proportional to remaining service life; 'n/a' = not applicable.

this approach in early studies has been to understand the environmental value of existing buildings, this can also be seen as additional information/metric to demonstrate the benefit of refurbishment compared to building entirely new (i.e. additional information to a zero approach A-C result). For example, if one maintains only the structural system of an existing building for further use post-refurbishment, while the rest is demolished and replaced by new components, then the "fictive replacement ..." equals the impacts of demolishing the existing structural system (if C1-4 is included at all) + rebuilding a comparable structural system under the precondition of fulfilling same technical requirements for the next RSP.

This approach is useful when the main objective of an assessment is to decide whether a refurbishment project gives enough environmental benefits to balance the perhaps higher costs. However, this "benefit" is a hypothetical representation of the reality; developers do not often replace an existing structure with a similar one in terms of size and basic design. Therefore, other options and perspectives are possible. This will be discussed in next research activities.

### 3.2. Treatment of removed components

There are different reasons for refurbishing or repurposing buildings. There may be cases in which building parts are removed that have not yet reached the end of their useful life or of wear margin (early removal), i.e. they still have a potential for residual life. Like the maintained existing components for the second life, the treatment of removed components can follow a zero or a remaining load approach. One difference is that the residual service life of these products is not used in the specific next building cycle, but potentially in other construction activities. After removal, different courses of life for these products exist which lead to different modelling variants (Table 2). This can be discussed in relation to circularity of building components.

Variant 1: an advantage of remaining load approach over zero approach is that it "punishes" premature removal of products without possibility or intention of reuse. This can be a significant effect in the case of long-lived products and undesirable in view of circular economy [6]. On the other hand, this effect can be negligible for short-lived products since the moment of refurbishment will often not deviate that far from the regular replacement moment. Not all country methods have set rules of what early discarding/removal means, and therefore for what removed components the impacts can be overlooked, e.g. would a component replaced just two years before its EoL be considered early discarding? Country methods following the remaining load approach should clarify such issues. For example, HQE [7] allows overlook the remaining load of existing components when RSL $\leq 10\,\%$ technical service life (TSL).

Variant 2: According to the standards (e.g. EN 15978:2011) net benefits of potential reuse shall be considered under module D (renamed to D1 in latest versions). However, in the specific case of a (partial) deconstruction of an existing building, reuse is not far in the future but takes place (almost) at the same time as the refurbishment interventions. Therefore, issues arise on how to proceed with all processes concerning modules C1-4 and D1 of initial building parts being removed. Does the demolition of an existing building in the sense of clearing the property form the end of a previous or the beginning of a subsequent life cycle/object of assessment? The two life cycles are overlapping in reality; partial demolition, deconstruction, transport, etc. are activities happening during A5 of the refurbished building. For example, Anink [6] allocates impacts of module C2 to module A4, while assigns the impact of modules C1, C3, C4 and D1 to module A5. Here further discussions are needed, like in current activities of IEA EBC Annex 72.

### 3.3. Complete overview of differences in approaches

Below (Figure 2) the scope of the different approaches is visualized along the typical refurbishment timeline.

## 4. Discussion and recommendations

Table 3 provides an overview of options for action and assessment and creates a connection with typical decision-making situations. On how to deal with an existing building, three possible options exist:

(a) further preservation/maintenance (in this case, it is decided to not carry out any major intervention that deviates from the regular replacements and maintenance, but no action is not an option);

(b) refurbishment (with the same or changed function);

(c) deconstruct it and build a new similar one.

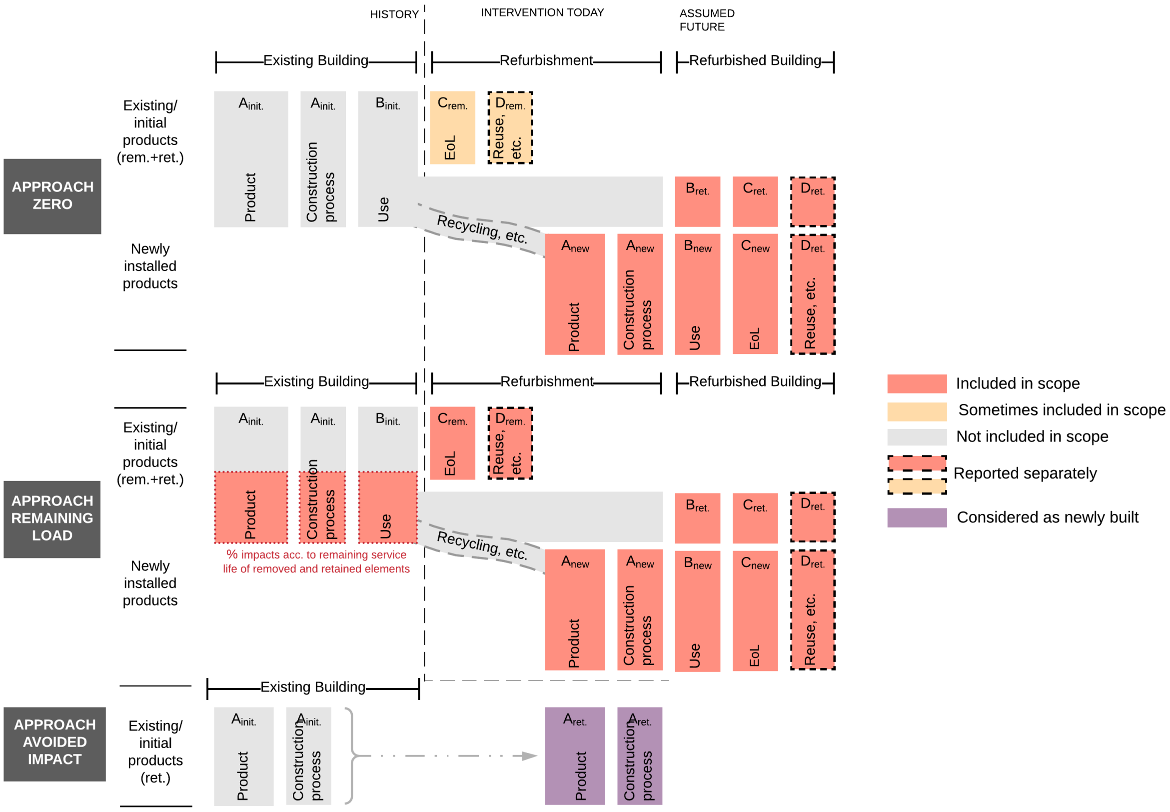


Figure 2. Visualisation of the three modelling approaches. Note: newly added is denoted as "new", removed is denoted as "rem." and retained as "ret.".

| **Typical cases for the application of LCA to major refurbishment** | Approach "zero" | Approach "remaining load" | Approach "fictive replacement . . . " |
|---|---|---|---|
| Guidance for a choice between refurbishment versus maintenance | X | (x) | (x) |
| Guidance for a choice between refurbishment versus demolition/deconstruction and rebuilding | X* | (x) | (x) |
| Support of design optimisation of the refurbished building | X | (x) | (x) |
| Sustainability assessment of the refurbished building for the purpose of certification | X | (x) | (x)** |
| Support of research to improve the modelling of the dynamics of changes in the building stock | X | (x) | (x) |

* To reduce the risk of manipulation, a minimum retention/use period of 5 years should be guaranteed.
** Recommended as additional information.

Table 3. Suitability of approaches for different typical decision-making cases.

The first two decision-making situations express these investigations. If refurbishment has been decided, the next two cases come into play.

It becomes clear that all approaches described are practically applicable for the respective decision-making situations. The authors recommend orienting in any case to the "zero" approach. This maps the points in time the energy and material flows occur more precisely, including the resulting impacts on the environment, and can thus be better combined with sectoral considerations. In an environmental performance assessment, it is possible and sensible to additionally (and separately) indicate the impacts avoided by continuing to use parts of the existing building fabric. This enables to communicate the advantages of slowing down material cycles. The quality and residual service life of the still-in-use structural parts must always be checked. The refurbished building RSP should correspond to the residual service life of the load-bearing structure. If not the case, there would only be a temporal shift in environmental impacts.

## 5. Conclusions

The refurbishment of the building stock to adapt to climate change and new user needs, is an essential element of sustainable development in Europe. It is necessary to develop methodological bases for the life cycle-based environmental performance assessment of refurbishment measures that lead to reliable results. These must also find their way into standardization in the short term. Scientific work must be intensified, and consensus-building accelerated. Too many variants inhibit transparency and traceability of the chosen approach. One solution is to assign specific models to specific decision-making situations. The present authors will contribute to IEA EBC Annex 72 in this direction.

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