Service life as main aspect in environmental assessment

0. Abstract

Building techniques are changing and the original 'constructing' becomes 'mounting'. This trend can be described as IFD building, in which IFD stands for Industrial, Flexible and Demountable. Changes can be made more easily as a consequence of this type of building, and building according to consumers’ wishes is possible this way. Making changes to buildings is often not taken into account when a Life Cycle Assessment (LCA) of a building is being made. Life Cycle Assessment's are still based on traditional buildings and components are taken into account for their complete technical service life. Especially this service life needs closer attention because the influence it has on the amount of materials used has also an enormous impact on the outcome of the environmental assessment.

By defining the role of service life within a LCA and indicating what can be achieved by a sound service life prediction, the environmental assessment of IFD buildings can be more accurate. This is necessary to point out the advantages IFD building have on the environmental impact of a building compared to traditional buildings. However, these insights are not only suitable for IFD buildings, but also for traditional buildings.

Aspects that will be looked in this paper at are the fixed service life within the current assessments, the different phases within service life and the rate of replacement of components. Currently fixed service lives are used, which originate from experience and practice. Another aspect that needs more clarification is the division of different phases within a service life. Upon now an environmental burden caused by a product is often regarded as a linear process, while distinctions can be made that can influence the entire outcome. A third aspect is the early replacement of components (before it’s technical service life is over). The assumption is that this aspect will more and more be responsible for replacements of components, while it is not being taken into account in a LCA. The role of service life in LCA is underestimated which results in inconclusive assessment values. One of the approaches to improve this is the factor method. This existing method needs some adjustments but is suitable for service life prediction in LCA's.

The outcome will be a service life of components that is more accurate in a given situation. Understanding the role of service life makes prediction of the environmental burden over time more accurate as well and choices between IFD buildings and traditional buildings can be well founded.

1. Introduction

This article describes preliminary results of research undertaken to develop a life cycle assessment method specifically for "flexible" buildings. This paper describes different aspects of the way to execute such an environmental calculation. The link between environmental burden and the building sector is elaborated and emphasis is placed on the differences between the environmental burden in the building sector and other sectors. Certain aspects related to environmental calculations are important when determining the environmental burden of a building are reviewed and further illustrated using three examples of LCA for a building. The use of the factor method is described when undertaking environmental calculations and additional information is given for enhanced calculations suggesting that the proposed changes make LCA calculations in the building sector more accurate.

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2. Building and the environment

2.1 Environmental burden

Building construction is a trade that probably will last as long as people need shelter and protection. But comfort and an own place are also qualities that ensure construction as an ongoing need. The construction of a building always gives a certain emission of substances with the accompanying environmental burden. What is considered to be an environmental burden? Every material has an effect on the environment. Extracting raw materials, transporting them to a factory, producing the product, mounting it in the project, dismounting, discarding and so on. If we know that building is an ongoing process and that this ongoing process will keep on putting a strain on the environment the current situation is evident. The goal for the building sector is to minimise the burden on the environment caused by construction. This is one of the fields the Kyoto protocol has had some influence on.

The Kyoto protocol only mentions the exhaust of CO₂ equivalents. However there are additional environmental aspects. Different methods are available and they discern different environmental aspects. Common aspects are ozone depletion, exhaustion of raw materials, human toxicity, eco-toxicity, global warming, acidification and so on. The literature (Goedkoop et al., 2003) provides descriptions of the various methods and the corresponding environmental aspects for environmental calculation. Every part of society causes an environmental burden. Solutions for each of them are possible but the building sector has some aspects that are specific for this sector and need particular attention.

2.2 Environmental burden and the building sector

The environmental burden caused by building (construction) has some aspects that differ from environmental burden in general. Klunder (2002) mentions the three main environmental effects of building to be caused by material flow, energy and water. This study reached a conclusion that the aspect related to water to be less important; hence from this it follows that energy and materials are the most important. The average weight of a European building is about 100 ton. That is 100 ton of materials that are used in construction, but also (after the period is over) have to be discarded. It is therefore not surprising to see that solid waste is responsible for a large part of the environmental burden in building. As an example, in the Netherlands in 2001 a waste stream of 19550 kton was produced, compared to 12680 kton in 1990 representing an increase of 54% in 10 years (AOO, 2003). The other effect is the energy use during the service life of the building, but this study is limited to the material aspects within environmental assessments. However the existing methods for calculating the environmental burden (of the materials) are not developed for the building sector and cannot cope with the long total service life of a building.

2.3 Application of environmental burden calculation

The environmental burden can be calculated with the use of a Life Cycle Assessment (LCA) programmes. Examples of these programs are Sima Pro, Eco Quantum (NL), Envest (UK) and OGIP (CH). In this article

![FIGURE 1. Layout of a Life Cycle Assessment according to the ISO 14000 standard](image-url)
some particular aspects of these calculations will be discussed. To get a better hold of the calculation the layout of LCA is given in Figure 1. This layout is according to the ISO 14000 standard (ISO, 1966). A LCA consists of a goal and scope phase in which the aim is set. In the inventory analysis the building is looked at closely to determine the amount of materials. It is in this phase that the input for a LCA is retrieved. The third phase is the impact assessment. The materials from the inventory phase are calculated into the environmental burden. In all these three phases the interpretation of the effects is of importance: how are these effects when compared to other situations.

The way of using LCA can influence the interpretation. According to Guinée et al. (2001) there are six different objectives to using LCA:

- Exploration of options
- Company internal innovation
- Sector driven innovation
- Strategy determination
- Comparison (i.e. legislation)
- Comparative assertion disclosed to the public (development)

Looking at the construction sector, the sector driven innovation, strategy determination and comparison are the most important reasons to conduct LCA. Special attention must be given to the possibility of comparison. This stands for comparison between products as well as the comparison (better to say check) to legislation. Some countries are considering an obligatory environmental standard that for every (new) building has to be met. However at this moment the calculation according to such a standard will raise some problems because of a lack of consistency in its application (this will be discussed in section 4).

A calculated comparison between environmental burdens makes it possible to vary in materials or design solutions and see the results of the variations. An optimisation of the burden with the specific design is possible. The question is whether such an optimisation should be legislation, a kind of trademark or just a voluntary aspect? In case it becomes legislation, it has to be applicable for all buildings and no blanks or errors can be allowed in the method. This can be difficult because no general agreement has been reached on the calculation methods. When it is used as a trademark or even voluntary then some remarks or comments can be made. Then it can be used as a quality mark rather than an obligatory item.

3. The role of service life prediction in LCA

3.1 Characterisation

Life Cycle Assessment is material based. The general thought is that when more materials are used in a building, the higher the strain on the environment will be. This is not completely true, the kind of material and the accompanying processes are of importance too. Each material (or process) has emissions to one (or more) environmental aspect(s), and each environmental aspect can be measured by an amount of equivalents. So for each emission there are factors to convert emissions into equivalents. An example: for the environmental effect of 'greenhouse' gases, the CO2-equivalents are normative. CO2 is chosen to be the leading indicator and as a consequence 1 kg CO2 has the equivalent of 1. Another substance, CFC-13 has a characterisation factor of 13000. This means that 1 kg CFC-13 causes 13000 times more pollution than 1 kg CO2. Turning it the other way, 77 mg CFC-13 is as polluting as 1 kg CO2 (see Table 1). This step is called characterisation. This example shows that just a fraction of some material can cause a huge impact on the environmental burden when performing an LCA. This is the reason why in a LCA, the inventory phase is crucial. Incorrect data about materials can cause a lack of information or a redundancy of information.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Amount [kg]</th>
<th>Characterisation factor [CO2-equivalents]</th>
<th>Characterised amount [CO2 eq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CFC-13</td>
<td>1</td>
<td>13000</td>
<td>13000</td>
</tr>
<tr>
<td>CFC-13</td>
<td>0.0000769</td>
<td>13000</td>
<td>1</td>
</tr>
</tbody>
</table>

TABLE 1.
Using characterisation factors to give the same names to emissions
3.2 Replacements

In section 2.3 the structure of a LCA is explained. The inventory analysis is the phase in which data about the amount of materials is retrieved. Within the building sector the total service life of a building is often set at 75 years. In these 75 years materials have to be maintained and/or even replaced. The question is: what is the service life of a component? This is significant because this establishes how many replacements have to take place, and consequently the total quantity of materials used throughout the overall service life of the building. A building that is well maintained with limited use will last longer than a building with a lot of activity. An example: a simple interior door of a family dwelling has a Reference Service Life of Component (RSLC) of 25 years. (Huffmeijer et al. 1998; Wornell et al. 1992). With a total service life of 75 years, the initial door and two replacements is the average situation. But imagine whether a family will use this door with two little children. The in-use conditions are much higher and the demands for replacements are larger as well. It is possible that the RSLC of 25 years will not be met and that 20 years is the maximum period (Estimated Service Life of Components, ESLC). More doors will be needed and the amount of materials used in the building is raised. Because the amount of materials is higher (inventory analysis) the impact assessment changes as well. Figure 2 shows the differences in output for a 20-year RSLC and a 25-year RSLC. The dark bars represent a service life of component of 20 years. The light bars represent a service life of a component of 25 year. The overall service life of the building is 75 years. Combined with the characterisation as mentioned in 3.1 the influence of the amount of materials and consequently the environmental strain becomes increasingly evident.

3.3 Three kinds of service life

The service life of a product will end at the moment the product reaches its End Of Life (EOL). There are many ways in which a product can reach its EOL. Van Nes et al. (1998) mention up to six different ways of obsolescence for consumer products (technical, economical, ecological, esthetical, functional and psychological). In the ISO standards (2000) three kind of EOL for the building sector are discerned. Concentrating on the building sector the following three EOL scenarios will be distinguished: technical, economical and functional EOL. The best-known type (and most easy to comprehend) is the technical service life. When looking at the reference service life published by SBR (Huffmeijer et al., 1998), it is the technical service life that is displayed. This is because for centuries this was the aspect that determined the replacement. However, looking at Figure 3 technical service life will in (most cases) last longer and be leading...
The technical service life is over when the component can no longer fulfil the performance it needs to (i.e. a leaking roof, a broken window). Another type of EOL is the economical EOL. This occurs when another component can fulfil the same (or better) function but with lesser costs. (i.e. central heating system, maintenance). In this case the economical criteria are indicative. The EOL that probably occurs first is the functional End Of Life. This occurs when the component does not fulfil the function people demand of the component. In this case the functional criteria can be a very wide range: the door doesn’t open any more, the living room isn’t large enough or the colour of the tiles does not please the user anymore. These three EOL’s define the moment that a component will be replaced. Regarding the three EOL’s the following can be concluded: at his moment it is no longer the product that indicates the end of (technical) service life of a product, but it is the occupant who decides that the (functional) service life of the product is over, so functional obsolescence is normative.

3.4 Conclusion

The outcome of LCA depends highly on the reliability of the input. To obtain a LCA that is as accurate as possible the input must be close to the actual situation. The aspect that is most important in this case is the service life. At this moment most assessment methods that are carried out regard the service life as a fixed item. As a consequence the outcome of the LCA will differ from the actual situation. In the example of the interior door, used by a family with children, the average LCA will be based on a RSLC of 25 years, although it is known that the actual service life is 20 years (Figure 2). To calculate an accurate LCA the inventory phase is crucial. Key issue in LCA is service life prediction. If the ESLC is known, the exact amount of material used throughout the overall service life is known as well. With the amount of material known, the assessment is more correct than most LCA’s, and a better judgement can be made.

4. Current problems in LCA

The previous section describes LCA and the importance of correct inventory analysis. Within LCA in the building sector there are some irregularities that can cause problems when performing calculations. In a previous paper (Nunen van and Hendriks, 2002) three problems are discussed:

1. Premature replacement; replacing products before it is a technical necessity;
2. Sequential use; replacement of (identical) products within the overall service life of the building;
3. Subdivision of environmental burden; regarding environmental burden as a linear process, instead of dividing it in different phases.

The first problem is already described in paragraph 3.4. In a LCA it is in most cases the technical service life that is normative for the calculations. Increasingly the economic and functional criteria are decisive for the replacement. Using only the technical service life in a LCA has a positive effect on the outcome of the LCA, because components in the calculation are supposed to have a longer service life than the actual situation. Calculating the full technical service life, fewer replacements will take place and the calculated results will be less than the actual environmental strain (figure 4).

Sequential use is the second problem and follows on the premature replacement. The LCA tool has not been designed for the building sector; it is more aimed at consumer goods. Looking at consumer goods
FIGURE 4.
Environmental burden divided in mounting use and dismounting.
The replacement criteria (Functional (Fc), Economical (Ec) and Technical (Tc)) are shown as well.

FIGURE 5.
Prolonging service life will only increase the environmental burden
replacements are not that big an issue and often not taken into account. Because of the long service life of a building, the replacement of components in a building is important. During the overall service life, several replacements have to take place. Given that the actual spread of service lives is not known, an assumption (as accurate as possible) has to be made in regard to a bandwidth, from which may vary the amount of material required.

The third aspect is the subdivision of the environmental burden. There is a relation between the environmental burden of a component and time. (Klunder and van Nunen, 2003) Three different phases can be distinguished: mounting, use and dismounting. Mounting a building will have a relative high level of environmental burden, partly because of the production of materials. In the use phase the environmental burden will only slightly increase because of maintenance (energy consumption by habitants is not taken into account). The last phase is dismounting and there the waste creates the highest strain. In figure 5 this subdivision is illustrated. In the use phase the increase of environmental burden is small compared to the prolonged service life. In the example this is shown by the light coloured graph. When prolonging the service life the average environmental burden will decrease. Most current LCA programs regard the environmental burden as a linear process (figure 5). If the environmental burden is regarded to be linear, prolonging the service life will cause this process to continue. The environmental burden will increase in time. In the actual situation, the environmental burden during the period of use will rise slightly, perhaps some maintenance, the rest (dismounting) will not increase. The actual environmental burden will not increase as much as most programs calculate at this moment. As a consequence the calculated burden (current methods) is higher than the actual burden (prolonged actual situation).

5. Factor method

5.1 Goal within LCA

To get a better grip on LCA there has to be more information on the service life of products. Service life prediction originates in 1950's when the first experiments with cyclical loads were done. Later on these tests were elaborated. In the 90's service life prediction became an expertise and guides and standards were developed. Even now a combined task group (CIB W80/RILEM 175-SLM, 2001) is studying service life prediction. Three different approaches are followed. First of all the research of the probabilistic design, second the so-called engineering methods and third the deterministic approach. The last approach is the simplest way to define the service life and therefore the deterministic methods are being studied. Defining the service life is an important part of LCA and an easy to use method must be available. Because buildings are not the same everywhere service life prediction varies from locations to location. In Japan a method to calculate a more specific method for service life planning was developed: The Factor Method (ISO, 2000).

5.2 Factor method

The factor method is a way to include several factors that influence the service life and come to a better estimated service life (Hovde, 2002). This method is described in an international standard ISO 15686 (ISO, 2000) At this moment parts 1, 2 and 3 are out, and parts 4 to 6 are to be published. The factor method consists of a RSLC and different factors (for different aspects mentioned below). The reference service life will be multiplied by the factors, some positive, others negative. The outcome is an ESLC, a specific service life for the given situation and product. The formula for the factor method is:

\[ \text{ESLC} = \text{RSLC} \times \text{factor A} \times \text{factor B} \times \text{factor C} \times \text{factor D} \times \text{factor E} \times \text{factor F} \times \text{factor G} \]

The Factor Method uses seven factors to compensate for specific situations. These factors are:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Quality of the component</td>
</tr>
<tr>
<td>B</td>
<td>Design level</td>
</tr>
<tr>
<td>C</td>
<td>Work execution level</td>
</tr>
<tr>
<td>D</td>
<td>Indoor environment</td>
</tr>
<tr>
<td>E</td>
<td>Outdoor environment</td>
</tr>
</tbody>
</table>

ESLC Estimated Service Life of Components
RSLC Reference Service Life of Components
For each factor a value must be used whereas the mean is 1.0. An example: a product consists of high quality raw materials it will be more resistant to influences from the outside. In order to award the better quality, factor A (quality of the component) will be 1.2 instead of 1.0. Another example can be the location of the building. With a building near to the sea the outdoor environment (factor E) will be more severe than the average outdoor environment. Factor E will become lower than 1.0, for example 0.8. When these factors and the reference service life are all multiplied a specific service life, more accurate for the specific situation can be predicted.

$$ESLC = 25 \times 1.2 \times 1.0 \times 1.0 \times 1.0 \times 0.8 \times 1.0 \times 1.0 = 25 \times 0.96 = 24 \text{ years}$$

The RSLC is 25 years, but when the quality (A) and the outdoor environment (E) are taken into account the ESLC is 24 years.

5.3 Adding factors

The Factor Method consists mainly of indicators for the technical service life. In section 3.4 two other criteria are mentioned: functional and economical criteria. To include these criteria two factors are added: Trends and Related components. With the Trend factor (T), the likelihood of a component to conduct changes not indicated by the designed service life is taken into account. The sensitivity to (fashion) trends will reduce the functional service life of the component. This indicates a replacement before the technical service life is over.

Looking at the Related components factor (R), two aspects are considered. The first one is the accessibility of a product to be replaced. When a wall panel can be replaced by just clicking four pins it will be done with much more ease than in a situation where a lot of nails and cement have to be removed. The first situation causes much less trouble and therefore will occur more often. As a consequence, the service life will be short. The second aspect is in combination with the replacement of components. When a single component has to be replaced, it sometimes is easier to replace a complete building part, although the service life is not yet completed. An example is a window frame. When the frame has to be replaced, in most cases the glass will be replaced as well, although it is not necessary in functional or technical way. Both factors trends and related components are not mentioned in the ISO standard. Adding these two factors will bring the ESLC closer to the actual service life and not only representative for the technical service life.

5.4 Distribution in the factor method

To come to a service life prediction that is even more accurate the factor method can be evaluated with a statistical approach. Aarseth and Hovde (1999) use a statistical approach on the outcome of the multiplication (ESLC). In their approach the entire outcome is judged on its variation and the predicted service life is given with boundaries. Moser (1999) uses a statistical distribution on every factor. The factors all have different distributions, because not all factors act in the same way. All these separate factors, with their boundaries are multiplied and the result is a mean (ESLC) with boundaries. This last approach, in which every factor gets its own distribution, is most suitable because deviations from the normal situation can be given a place in this method. The only difficulty is defining which distribution fits best to which factor. Moser (2002) used a recursive Delphi method to obtain these figures. By using experts he defined percentiles and a mean and derived the statistical distributions for the factors. By adding two new factors to the factor method, new distributions have to be defined and in doing this, the existing distributions of factors can be reviewed.

6. Discussion

This paper presents Life Cycle Assessment for the building sector. It is clear that although LCA for buildings is possible, most LCA tools are not specifically developed for the building sector. Typical problems between LCA and the building sector are discussed in this paper. One of the problems is that the most polluting aspects (waste and energy) are not taken into account in most of the existing LCA methods. Using these methods, a LCA will show a gap of important impact assessments. Another crucial problem for using LCA in
the building sector is the service life of a component. A building has a long overall service life and replacements have to take place. But the service life used in a LCA is a fixed one, although we know the actual service life to be shorter. Without knowledge of the predicted service life it is also impossible to take sequential use into account, and as a consequence determine the exact environmental burden.

In order to use LCA in the building sector it is necessary to define the service life. Only when the service life of components is estimated as close as possible, the effort to calculate the environmental burden by means of a LCA has a value. To come to a method in which all the specific aspects of a situation are mentioned the Factor Method (extended with two factors) can be used. To enhance the reliability of this method statistical distributions have to be added. This method calculates a better estimated service life without the need of huge data about deterioration of components.

Based on a service life that is as close as possible to the actual situation a LCA will also give results that are close to the actual situation. This is not the case in most current LCA calculations. It will be necessary to optimise the current methods in order to use LCA as a decision tool. Using the elaborated Factor Method provides in this optimisation.

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