



THE FACTOR OF TIME IN THE LIFE CYCLE ASSESSMENT OF HOUSING

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Abstract

Conducting life cycle assessments, or LCAs, involves many uncertainties, including those related to the factor of time. Time is very important in the environmental assessment of housing, because of the relatively long service life of houses. During a house's service life many changes occur, which are not usually considered in today's LCAs. Nevertheless this is of major importance in order to be able to make complete and accurate environmental assessments of housing. The aim of this article is to identify and classify the aspects belonging to the factor of time and to select solutions to handle these aspects in LCAs. On the one hand a difference is made between a static and a dynamic approach. On the other hand construction, demolition and frequency are distinguished. Six aspects of the factor of time resulted: design, production technology, re-design, waste treatment technology, technical service life and functional service life. So far only static factors are taken into account in LCAs, and only partly. To involve all the static aspects as well as to include the dynamic aspects, relationships between the six aspects of the factor of time have been defined and the most suitable solutions are assigned to the different groups of aspects, including scenarios, sensitivity analyses, turning points and potentials.

Keywords: LCA, housing, time, uncertainty, service life, environmental burden.

1. INTRODUCTION

Life cycle assessment, or LCA, is a widely accepted method to assess the environmental burden of products from cradle to grave, including the extraction of raw materials, the production of materials, product parts and products, and discard, either by recycling, reuse or final disposal. A framework for LCA has been internationally agreed upon (CEN, 1996). LCA-based calculation models are available to determine the environmental impacts (i.e. global warming, human toxicity and acidification) caused by houses. With the exception of service life predictions the factor of time has not been dealt with in LCA until now. Changes over time, being changes in the house and changes in technology, are not mentioned. In the case of simple products with a service life below 10 or 15 years incorporating the factor of time makes LCA an unnecessarily complex task. However, as a particular characteristic of houses is that they have a

long service life, neglecting the factor of time in environmental assessment of housing introduces major shortcomings and inaccuracies. The aim of this article is to identify and classify the aspects comprising the factor of time and to seek solutions to handle these aspects in LCAs. This should improve the accuracy of calculations on the environmental impacts of housing.

The article is structured as follows. Section 2 gives an introduction to environmental problems and presents LCA as a tool to measure environmental impacts. Some general gaps in the LCA methodology are indicated, and the factor of time is introduced. In section 3 specific characteristics of the construction industry are addressed which have implications for carrying out building-related LCAs. The differences between a house and a consumer product are explained. Section 4 divides the factor of time into six aspects. How to handle these aspects is the subject of section 5. Finally, conclusions are drawn in section 6.

2. DEVELOPMENT OF THE LCA METHODOLOGY

2.1 Knowing the environment

A growing awareness of the environment is a development of the last decade. Although the first serious signs became known several decades ago, the awareness of the need to take real action appeared later. Environmental problems were first mentioned in 1972, in a report called 'The limits to growth' (MEADOWS et al., 1972) written under the authority of the 'Club of Rome'. It gave a picture of the world within 30 years, if nothing changed. This is the first study that indicates the future of the environment. In this report, the world economy plays an important role in the increase of the environmental burden.

In 1987 the World Commission on the Environment and Development (WCED) published the report 'Our common future' (WCED, 1987). This report, the so-called 'Brundtland-report', again mentioned economic aspects, but also introduced social (UN, 1982) and ecological aspects. The Brundtland-report anticipated economic growth, but for the first time a disconnection between the growing economy and the decline of the environment was seen as a possibility. According to Brundtland, economic growth did not automatically have to involve environmental decline, but that new techniques and increased responsibility for the existing techniques were required.

All sectors of the economy have to contribute to improving the environment. The need for a global environmental policy is obvious. Because of the conflicting interests of some countries this has not yet come into being. The construction industry is co-operating at an international level, for instance in the PRESCO project (Practical Recommendations for Sustainable Construction), which seeks to facilitate the exchange of experience and the transfer of knowledge (PRESCO, 2002). Currently, buildings and their inhabitants are estimated to consume approximately 40% of the total energy, to be responsible for about 30% of CO₂ emissions and to generate around 40% of all man-made waste (BOURDEAU, 1999). Due to the constant need for buildings, eco-efficiency within the construction industry could have a huge impact, but what it needs is the environment to be brought out of obscurity and defined in measurable terms.

2.2 Making environmental impacts measurable

In 1996 SETAC (Society of Environmental Toxicity and Chemistry) formed a working group on Life Cycle Assessment (LCA). This term had already existed for a long time, but became well known in about 1990. It stands for 'the compilation and evaluation of the inputs and the potential environmental impacts of a product system throughout its life cycle' (CEN, 1996). The complete field of LCA is described in the ISO 14000 series, so the methods to produce environmental figures are defined. However, different assessment methods are available, the guides of CML (Leiden Centre for Environmental Studies) (HEIJUNGS, 1992; GUINÉE et al., 2001), Eco-indicator 95 and 99 and EDIP are all examples of widely-used methods (GOEDKOOPT et al., 2001), each of which has been initiated independently. With the ISO standards, aspects like functional units, processes and boundaries are taken into account in every method. However, as the ISO standards are still open-ended regarding standardisation, there are differences in methods dealing with certain issues. This has consequences for the outcomes of LCA.

Further research has to be conducted to address these shortcomings in the LCA methodology, which include allocation, weighting, data reliability, bio-diversity and nuisance. Firstly, there are different opinions about allocating energy and material flows to a process, especially in processes that are sequential. Do materials that come out of a product have any value, economic or otherwise, and if so, does the environmental burden shift from the original product to the next (VÖGTLANDER et al., 2001; BORG et al., 2001)? Secondly, weighting remains a widely discussed issue. The advantages of putting everything into a single score are opposed by the discussions of defining the weighting factors or losing information within an eco-profile (SCHMIDT and SULLIVAN, 2002). Thirdly, data collection for Life Cycle Inventories (LCI) is still a critical factor for successful work in the area of LCA (HUIJBREGTS et al., 2001). Without reliable data there is no possibility of achieving a reliable assessment. Then there is the discussion about bio-diversity and nuisance. The aspects that are implemented in LCA can be measured, but how is it possible to measure bio-diversity or nuisance and make it part of LCA? All these aspects are currently being researched. They might be called general problems of LCA, because they

occur in a wide range of assessments, whether it is a coffee machine, aeroplane or a building. Besides these general issues still to be solved in the LCA methodology, some problems relate specifically to the use of LCA in the building industry, and these are discussed in the next section.

3. USE OF LCA IN THE BUILDING INDUSTRY

LCA studies of building components are comparable to LCA studies of many other products. In the building industry LCA studies were carried out on, among others, window frames (HOEFNAGELS et al., 1992), insulation products (SEIJDEL, 1995) and concrete floors (FLUITMAN and DE LANGE, 1996). However, application of LCA on whole buildings entails major difficulties. There are three important reasons for this.

Firstly, each building has its own characteristics and contains a very large number of components and materials. Stuip (1993) compares buildings to consumer electronics. The latter concerns mainly mass-produced products, while buildings are, to a much larger extent, unique. This makes it rather complicated to draw general conclusions on building design and construction and their environmental consequences.

Secondly, buildings have extremely large service lives in comparison with, for example, electronic equipment such as computers. Differences in the order of magnitude of a factor of ten are no exception (STUIP, 1993). As a result of the longevity of buildings one of the problems is that the end-of-life stage is hardly predictable, as this will take place in the distant future. Kortman et al. (1996) conducted a study to estimate the environmental impacts of the end-of-life stage of long-cyclic products, namely water pipes, crash barriers and gutters. These are relatively simple products. Whole building assessment introduces an accumulation of uncertainties regarding end-of-life scenarios.

Thirdly, incremental changes feature in the building industry. The building industry mostly follows technologies developed in other branches of industry. Thus, it is not so much the building industry itself that directs new developments and innovations, but, for instance, the plastics industry and the computer industry (STUIP, 1993). This implies that there are many influences on the development of the building

and construction industry, and it is difficult to predict what will be adopted and how they will be implemented.

Environmental information on construction products and tools for the environmental assessment of buildings is available. In many countries whole-building assessment tools have been developed or are being developed, including Eco-Quantum in the Netherlands, Envest in the United Kingdom, EcoFoot in Germany and ESCALE in France. These tools have been designed for use in the determination, analysis and improvement of the environmental performance of buildings (KNAPEN and BOONSTRA 1999). Furthermore, the amount of environmental information on construction products is growing. Various countries have introduced LCA-based environmental declaration systems, such as the Environmentally Relevant Product Information (MRPI) in the Netherlands and Environmental Profiles of Construction Products in the United Kingdom (CEPMC, 2001). This enhances the uniformity in the methodology of data collection and precision, making environmental information more unambiguous, reliable, accurate, transparent and harmonised. The Netherlands is even preparing to include environmental performance requirements for materials used in buildings in the Dutch Building Decree (SCHOLTEN et al., 2000). This strengthens the need for making the factor of time manageable.

4. CLASSIFICATION OF THE ASPECTS OF THE FACTOR OF TIME

For identifying and classifying the various aspects of the factor of time, a single house is taken as a starting-point. Many changes occur in the features of a house over time, due to maintenance, replacement and renovation. In the operational phase new construction materials and components will be added and demolition materials and components will be discarded. Over time technological developments continue, which has consequences for the environmental efficiency of products and processes. The changes in the house as well as in technology introduce uncertainties when considering the factor of time.

Looking at changes in the house the factor of time has three kinds of uncertainty:

1. in-going materials and components;
2. out-going materials and components;
3. number of times materials and components will be going in or going out as a result of the end of service lives.

Looking at changes in technology we discern two kinds of uncertainty:

1. static approach, which means that assessment of a house is based upon extrapolating the current situation for the period of its service life.
2. dynamic approach, which takes into account innovations, changes and trends.

Figure 1 classifies the various aspects of the factor of time, according to the type of uncertainty. The columns represent the kind of uncertainty, related to three central questions: What goes in? What comes out? and How many times? The rows reflect the distinction between a static and a dynamic approach. In this way six different aspects of the factor of time can be distinguished. Each of them will be explained below, taking window frames as an example.

1. Design

The first aspect of the factor of time is design. This concerns in-going construction materials and components from a static point of view, which means that maintenance, replacements and refurbishment take place with current construction materials and techniques (extrapolation of present day techniques). Taking wooden frames as a starting-point, new frames can also be of wood, but there are two other possibilities, introducing uncertainties to this aspect of the factor of time. Firstly, new frames may be made of a material other than wood, such as plastic or steel. Secondly, refurbishment may result in new or adjusted components, for example the enlargement of window openings in the front of a house. These uncertainties are concerned with changes in the housing design.

2. Production technology

The dynamic point of view takes into account future developments in production technologies.

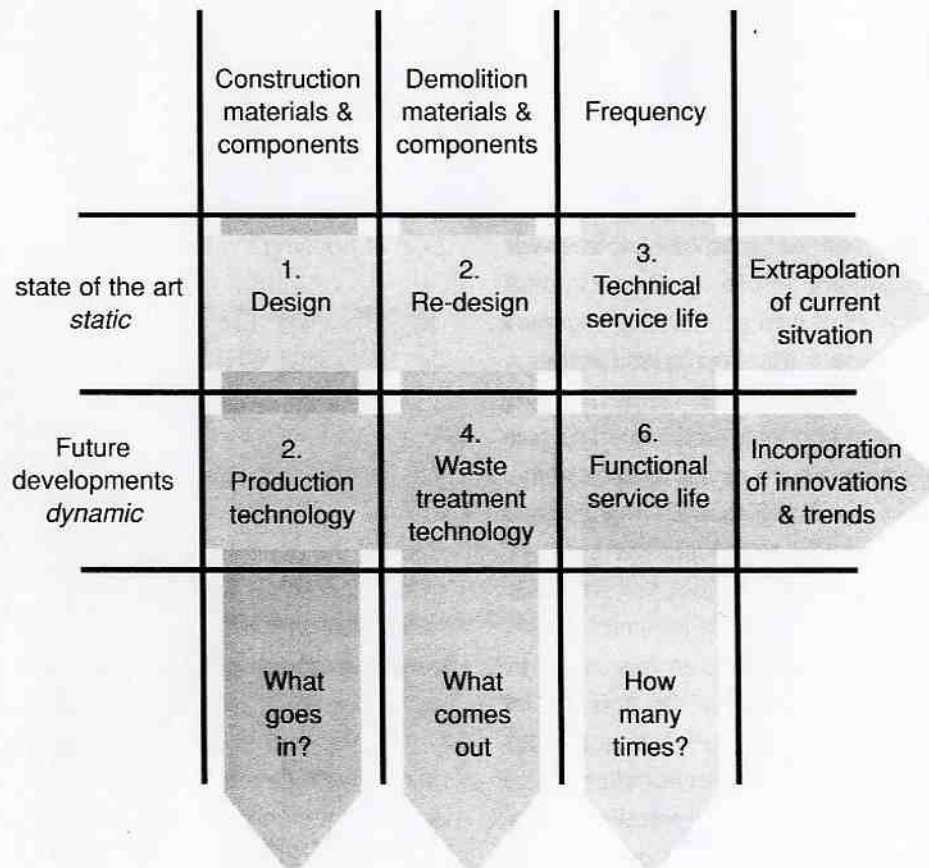


Figure 1. Classification of the aspects of the factor of time

Components do not keep the same characteristics during their service life, even though components are fabricated from the same materials. A wooden window frame today will be different from a wooden window frame tomorrow, due to modifications in material compositions and production processes (innovations). This is also the case if plastic window frames or a newly developed alloy replace the wooden window frames.

3. Re-design

The third aspect of the factor of time is re-design. This implies recycling and re-use of materials and components in a new house after their end-of-life in the original house or after the end-of-life of the whole house. A static point of view means that waste treatment scenarios, which is the division between dumping, incineration, recycling and reuse, are fixed during the service life of the house. Especially recycling and re-use cause uncertainties, because there are many reasons not to profit from technological possibilities. Among others, wooden window frames might not be appreciated any more in fifty years' time because they are considered too old-fashioned.

4. Waste treatment technology

From a dynamic point of view there are uncertainties regarding waste treatment technologies. Recycling and re-use have not reached their highest level yet, including the recycling and re-use of window frames, but it is expected that these ways of waste treatment will grow to the detriment of dumping and incineration. Waste treatment processes and repairing processes to make components and materials suitable for re-design also belong to this factor of time. So, waste treatment technology comprehends waste treatment scenarios as well as processes.

5. Technical service life

The technical service life indicates the period over which a certain product can fulfil its function. Service lives of products in practice can differ from theoretical values, due to house-specific conditions. For example, window frames last longer when protected by overhangs or when fitted in a house situated in a friendly climate zone. Besides, when the service life

of window frames is over but the remaining service life of the house is limited, the frames will often longer be replaced. These are uncertainties in technical service lives.

6. Functional service life

The functional service life is the period over which certain product can fulfil expectations. Often products are replaced before there is a technical necessity to do so. In the case of window frames, aesthetic and convenience reasons may influence the need for replacing wooden frames with plastic ones. The uncertainties of functional service lives concern the moment when people turn to technically unnecessary replacements.

These six aspects of the factor of time have to be dealt with in LCA. As we already know much about the aspects, which in their turn influence technical service lives, we are therefore considerably able to predict technical service lives. However, exogenous factors, including legislation and economic growth, are also important and also change over time, though independently of the six aspects included in the classification. Although some aspects, in particular the uncertainties, are to some extent predictable, future developments as well as exogenous developments cannot be completely foreseen. The important question, however, is not the exact causes, but how to deal with the different aspects of the factor of time in LCA of housing?

5. DEALING WITH THE FACTOR OF TIME IN LCA OF HOUSING

5.1 Relations between the aspects of the factor of time

Each of the aspects of the factor of time states a significant aspect in which time can influence the environmental performance of a house and its components. To come to solutions for dealing with these aspects in LCA, we first describe several relationships between these. We have identified the following pairs which can be handled in a similar way: aspects design (1) and re-design (3), product technology (2) and waste treatment technology and technical service life (5) and functional service life (6). On the other hand, the aspects design (1)

design (3) and technical service life (5) have to be treated in a different way to the aspects production technology (2), waste treatment technology (4) and functional service life (6). This can also be said for the aspects design (1), production technology (2), re-design (3) and waste treatment technology (4) against technical service life (5) and functional service life (6). The relations, indicated by A through E, are illustrated in Figure 2 and explained below.

A) Design (1) and re-design (3) both handle materials, one constructing them, the other demolishing them. Currently, these factors are for a large part being taken into account, but aspects like refurbishment and use are not. Furthermore, new ideas, like adding flexibility to a building, cannot easily be calculated with the current tools. The result is a building that provides flexibility, but the environmental assessment shows a higher environmental burden because of specific material and design choices. The fact that this building can more easily be adapted is often not considered.

B) Contrary to design and re-design the aspects production technology (2) and waste treatment technology (4) are often not mentioned at all. These two factors indicate an advance in technology. The way these advances will develop over time depends on different aspects (i.e. economy, wealth, knowledge), and so the impact on the performances these products achieve cannot be predicted easily. These

aspects are often not accounted for when performing environmental assessments. Within a larger time span, common in the building industry, the developments can make a significant difference to the environmental burden.

C) Finally, technical service life (5) and functional service life (6) are comparable aspects. There are two reasons why working with standard service lives, which tools generally do, does not reflect the actual situation. Firstly, theoretical values on technical service lives do not often correspond to practical values. Secondly, the functional service life may be of greater importance than the technical service life.

D) Within the six aspects of the factor of time contrasting groups can also be examined. Until now, LCAs dealt with a static cradle-to-grave approach (aspects 1, 3 and 5), which means that assessment of a house is based upon extrapolation of the current situation for the period of its service life. Innovations and trends are not taken into account (aspects 2, 4 and 6).

E) Another difference within the factors of time can be found between the material related aspects (1, 2, 3 and 4) and the service life aspects (5, 6). The issue of uncertainties about service lives has already been recognised, while knowledge about the causes for differences in material related aspects is limited.

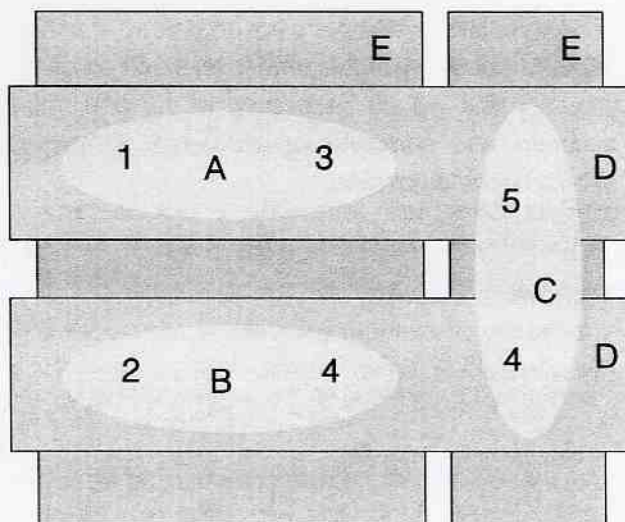


Figure 2 Relations between the aspects of the factor of time

5.2 Solutions for including the aspects of the factor of time in building LCAs

Splitting the factor of time into aspects and grouping them together again helps to explore which solutions suit which aspects best. Possible solutions are working with scenarios, turning points, sensitivity analyses and potentials.

Scenarios reflect possible futures, so they are a possibility to take changes over time into account. Working with scenarios seems especially appropriate when taking refurbishments into account. Refurbishments concern changes in time aspects 1 and 3 as well as 5 and 6. The scenarios define time, extent and quality of the changes. Although these elements are hard to predict, the choice of scenarios is important. After all, accurate scenarios make for accurate assumptions and form accurate input data for LCA.

Turning points can also support environmentally-sound decision-making. This can be seen as a spe-

cific form of scenario analysis. For instance, bringing more materials into a building to achieve a certain level of flexibility will increase the environmental burden. When the materials used and the materials saved during the adaptation have come to an equilibrium the turning point is reached. This turning-point can be assessed using probability. Turning points are related to all aspects of the factor of time.

Another way of interpreting the result of an environmental assessment is by using sensitivity analyses. When changes cannot be predicted easily it is more accurate to vary input data and important assumptions and calculate the consequences for the outcomes of the LCA. Varying input data is useful when considering unknown technological developments, identified by time aspects 2 and 4. Varying important assumptions includes service lives (time aspects 5 and 6). Sensitivity analyses give insight into the environmental consequences of deviations of the assumed service life.

The last method for dealing with the factor of time is working with potentials. This is important mainly within time aspects 1 and 3. The existing building stock can provide re-used materials, but there is no guarantee that materials will be used again or if enough materials will be released at the right time. For instance, at this moment the available amount of recycled steel is less than the demand, so despite the technological possibilities for recycling steel, virgin resources have to be added (LEY et al., 2002). So instead of incorporating the impacts of recycling and reuse, it might be a better idea to separate the potential impacts (THORMARK, 2000), because of the allocation problem mentioned in section 2. The choice of the allocation procedure clearly contributes significantly to the outcome of calculations on the environmental burden.

6. CONCLUSIONS

This study of the factor of time in life cycle assessment leads to the following conclusions.

- LCA is a suitable tool to make environmental issues regarding building measurable. Research is being carried out into several general kinds of uncertainty in LCA, which are independent of the products assessed. However, there is hardly any attention on the factor of time.

- Using LCA in the building industry is complicated because each building has its own characteristics. Buildings have extremely large service lives. Incremental changes are a feature of the building industry. Therefore, the factor of time is of more importance in whole building assessment.
- Six aspects of the factor of time have been identified, which cause uncertainties in the environmental assessment of housing. These aspects are design, production technology, re-design, waste treatment technology, technical service life and functional service life.
- Current LCAs comprise the assessment of design, re-design and technical service life. This assessment is not complete, while assessment of production technology, waste-treatment technology and functional service life is not taken into account at all. For dealing with the factor of time in LCA aspects have been grouped regarding solutions which are working with scenarios (time aspects 2 and 3 and time aspects 5 and 6), turning points (time aspects 1 to 6), sensitivity analyses (time aspects 2 and 4 and time aspects 5 and 6) and potentials (time aspects 1 and 3).

Further research on this subject will concentrate on estimates of the influence of the six aspects of the factor of time on the environmental burden of housing. Developing knowledge about the six time aspects will make designing an environmentally sound house an easier task, because more care is understood about the environmental consequences of design options, which are not addressed in current LCAs of houses. For this further research on all time aspects will be necessary. In the end, more accurate and complete assessments of housing should become possible.

ACKNOWLEDGEMENTS

This study is part of the PhD research of both authors, supervised by Prof.Dr.ir. H. Priemus, Prof.ir.N.A. Hendriks, Prof.ir.J. Westra and Dr.ir. P.A. Erkelens respectively.

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