Building use and asset management in environmental assessments
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Abstract
Little is known about the environmental consequences of using a building and managing its technical performances. This paper presents a theoretical framework for research on the environmental impacts of the use phase in the building life cycle. Four actors in the use phase are considered. First, the designer of the building who influences the amount and kind of management needed and, to a lesser extent, the behaviour of the occupant. Second, the builder that delivers work of a certain quality. Third, the owner of the building who decides on actual management activities. Fourth, the occupant of the building who is responsible for the amount of resources consumed and, to a lesser extent, the need for certain management activities.

The research aims to provide tools for the owner and user of a building which enable them to make decisions that are better for the environment. Also, it aims to provide a tool for the building designer in his role of developer of the building and its management requirements.

1. Introduction
In recent years, many researchers have worked on methods to quantitatively assess the effects of buildings on the environment with a view to eventually reducing the environmental burden caused by buildings (Reijnders and Huijbregts, 2000; Annex 31, 2001; Erlandsson and Borg, 2003; Forsberg and Malmborg, 2004; Peuportier and Putzeys, 2005). These methods are based on an analysis of the life cycle of the building, which starts at the extraction of resources for products and energy from the earth and ends when the demolition waste has been processed. This kind of analysis is called a Life Cycle Assessment (LCA).

The focus of current environmental assessment tools for buildings is on the building as a product, consisting of materials and components, and on the energy demand for climate control during the use
phase. The latter does not fully take into account the influence of occupants on the performance of climate control and therefore on the energy use, because too little is known about occupant behaviour. Furthermore, little is known about the impact on the environment of other processes and activities in the use phase of a building, such as maintenance and renovation. Klunder (2005) indicates that little research has been done on the subject of the influence of occupant and management behaviour on the total environmental burden of buildings. Building management is defined as the preservation and improvement of the technical and functional performances of the building. Borg (2001) and Paulsen (2001) did consider the use phase of building products in order to compare alternatives, taking into account maintenance needs and the influence of the products on energy consumption, but they did not consider the use of the building as a whole.

The objective of this research is to develop an environmental assessment model of the use phase of a building, in which all relevant use and management activities are represented. The model explicitly does not aim to determine the environmental impact in the use phase as precise and complete as possible, but considers only those factors in the use phase that account for the biggest part of the total environmental impact. Subsequently, the activities that are found to be dominant contributors can be replaced by alternative activities with less impact. Initially, a use or management activity is considered to be relevant when it either occurs frequently throughout the entire use phase or when it most likely causes a significant part of the total environmental impact in the use phase, even though it occurs only occasionally.

In the following section, this paper argues for the separation of the environmental assessment of the three major phases in the life cycle of a building: the construction phase, the use phase and the deconstruction phase. Subsequently, the use phase is split into smaller, manageable parts. Additionally, the role of the four actors in the use phase is discussed. In the ‘limiting conditions’ section, the research is narrowed down to the use phase of social housing. In ‘research methods’ the traditional sequential life cycle thinking is replaced by scenario thinking and the course of the research is explained. The last part of the paper discusses the kind of knowledge and products that will result from this research.

2. Research outline

The life cycle of a building can be divided into three major sequential phases: the construction phase, the operation or use phase and the deconstruction phase. The construction phase contains all activities that are undertaken until the building is ready for initial use. In this phase, the environmental impacts are mostly due to the extraction of resources and the emission of substances during production processes and transportation. The impacts take place on several locations spread across the globe and at different periods in time. The deconstruction phase starts when the building is no longer suitable for use by technical, economic or functional standards. The end of the technical service life of a building is defined as the time at which technical requirements can no longer be met. The economical service life of a building is over when another building can perform just as well or even better than the existing building, but at lower costs. Finally, the functional life of a building ends when the building cannot fulfil the function that users demand of it (van Nunen, Hendriks and Erkelens,
The deconstruction phase ends when all demolition waste is either reused, recycled or disposed of. The environmental impact consists mainly of emissions of substances during the transport and processing of waste. The use phase is the phase in between, which starts when the building is ready for initial use and ends when the building is no longer of use. In this phase, the building is occupied and needs to be maintained to keep performing well. The course of this phase is hard to predict, because the activities that take place are influenced by social and economic factors. The environmental impact in this phase consists of the impact caused by energy use (resource extraction and processing), maintenance of the building which consists of the replacement of building components, and major changes to the building, such as renovation and transformation. In addition to the three mentioned phases in the building life cycle, a preceding development and preparation phase can be mentioned. This phase is not a part of the building life cycle itself, nor does it have an environmental impact, but the decisions made in this phase do strongly influence the environmental impact in the building life cycle.

The factors that cause the biggest part of the environmental impact in the three major sequential life cycle phases are very different, which is why the environmental burden of the three phases should be considered separately (Blom, 2006). This research focuses on the use phase. In particular the influence of user and management behaviour on the environmental impact has not been considered by many researchers yet (Klunder, 2005). There are some indications that a reduction of the environmental impact of buildings might more effectively be achieved by changing the way buildings are used and managed than by changing the building itself (Fay et al., 2000; Treloar et al.; Klunder, 2002 and 2005). A big step in reducing the environmental impact of buildings might be made by changing the way buildings are used and managed.

As stated above, the entire life cycle of a building can be divided into three sequential phases. The use phase can be further divided into smaller pieces, but there is no standard sequence of sub-phases that can be distinguished. Rather than into sub-phases, the use phase can be divided into stages, such as initial and following use, renovation and transformation. The various possible stages do not all necessarily occur and they do not follow a specific order. For example, a building might be used by several different users, after which the technical performance of the building can be upgraded (renovation). After the renovation it is again used by several different users. Finally, the building might be renovated again or even be transformed, which means that the functional as well as the technical performance of the building is upgraded. In these cases, another use stage will commence after the second renovation or the transformation. However, the owner can also decide to deconstruct the existing building and build a new one.

In each stage, certain activities are undertaken, for example the consumption of resources or maintenance. These activities occur throughout the different stages. The activities are either iterative and interdependent or more or less random. For example, the building requires maintenance in the initial and following use stages in order to keep performing adequately. Maintenance activities repeat regularly and the kind of activity needed depends among other things on user behaviour, previous maintenance activities and the surroundings of the building. User related activities are for example the replacement of wall, ceiling and floor finishing, the kitchen or the bathroom whenever they feel the
need. Activities can further be divided into specific tasks, which consist of the use of materials and energy. For example, a maintenance task can be the cleaning of masonry for which water, a cleaning product and the energy for high pressure cleaning equipment is needed.

Alongside the before mentioned building life cycle levels, four actors can be distinguished who influence the environmental impact of the building. First, the designer of the building who can partly influence the management need of the building by making sure that building components are protected from rapid deterioration. For example, window frames can be protected from rain by designing an overhanging roof (Fig. 1). The designer might also be able to influence energy use by designing low energy houses or making use of passive solar energy. Second, the builders who influence the environmental impact by the delivered quality of work. The third actor is the manager of the building, who is responsible for the maintenance of the building and decides on major changes to it. Fourth the occupant of the building, who is responsible for certain maintenance activities and the energy use in the building. Energy is used for energy demanding consumer equipment, such as kitchen utilities and computers, and for climate control. The amount of energy needed to keep the indoor climate comfortable is partly building related, and thus influenced by the building and installation designers. The actual energy use is determined by the way occupants handle the indoor climate system. The manager and the occupant are combined in a single actor when the owner of the building lives in it himself, in other cases they are separate actors.

![Figure 1: Design decisions influence the maintenance need of building components.](image)

Besides the four actors mentioned above, the government is an actor who is able to influence building related environmental impacts indirectly. By setting up building regulations, it can influence design possibilities. In the Netherlands, the government already requires a certain performance standard regarding energy efficiency. The occupant can be influenced by financial encouragements or discouragements through taxes and subsidies.
3. Limiting conditions

As stated above, the subject of this research is ‘the use phase of buildings’, which is a very broad topic that needs to be narrowed down. Buildings can be divided into four categories: commercial, industrial, public and residential buildings (Fig. 2). The use phases of these buildings categories are widely divergent. The use phase of commercial, industrial and public buildings is hard to model, because of the many changes during the life span of the building. Not only do the occupants of these buildings change frequently but the needs of these occupants are typically very diverse as well, which results in frequent remodelling of the building. Remodelling is defined here as applying changes to the floor plan and the interior of the building to meet the functional needs of the user, without improving the technical performance. A storage area can for example be changed into an office area. The use phase of dwellings is less dynamic, while the intended use of the building is basically the same for the subsequent users. Because of the higher predictability of the use phase, the larger amount of available data and the fewer external factors that influence the use phase, such as strategic economic motives, this research focuses on dwellings.

![Building Types Diagram](image)

*Figure 2: Building types.*

Dwellings can further be divided into three categories, based on the identities of the owner and the occupant of the building (Fig. 2). A dwelling can either be owned by the occupant or not. When the dwelling is inhabited by its owner there are only two actors in the use phase of the building, because the user and the manager are the same actor. The owner of the house decides on all the activities that take place in the use phase. However, the building will not be owned by only one owner/occupier during its use phase, but by several different owners. Each of these owners will have his or her own way of living and dealing with management activities, which makes it hard to model the use phase of privately owned houses. It is relatively easier to model the use phase of houses that are not owned by the occupant, because the occupant and the owner are two different actors. Although the frequent changing of occupants of rented dwellings will remain a modelling challenge, the management of these dwellings will be easier because the owner remains the same actor for a longer period of time,
which is not necessarily the entire use phase. The owner of the building can either be a private landlord or a non-profit housing corporation (social housing), of which the latter will most likely have a better described and documented management strategy than the former. Because of the separation between the user and the occupant of the dwelling and the greater data availability on management activities in the use phase, this research focuses on the use phase of social housing. At a later stage, the research can possibly be expanded to other types of dwellings.

4. Research methods

Life cycle assessment can be based on linear sequential life cycle thinking (Borg, 2001; Erlandsson and Borg, 2003), also called the waterfall model. In a waterfall model, each phase must be completed in its entirety before the next phase can begin. Phases do not overlap in a waterfall model and there is no feedback between the phases (Lewallen, 2005; Fig. 3).

Sequential life cycle thinking can only be applied to the major phases in the building life cycle, since the three phases can clearly be distinguished and do not overlap in time. However, the stages in a major phase cannot be considered using sequential life cycle thinking, because the stages do overlap in time and are related. In the use phase, for example, renovations can be carried out while the building is still in use and they are often combined with regular maintenance activities. Additionally, the activities and tasks in the use phase stages are interdependent. Therefore, this research introduces scenario thinking as a way to model the use phase (Pesonen et al., 2000; Treloar et al., 2000; Erlandsson and Borg, 2003).

As seen above, the building life cycle can be divided into five levels: major phases, stages, activities, tasks, and materials and processes. Similarly, it is possible to distinguish different levels of scenarios (Fig.4), which describes possible courses of events. In a use phase scenario, several stages are indicated, as well as the relationship between them and the actors involved. Similarly, a stage scenario consists of activities and an activity scenario consists of tasks. For example, a simplified use phase scenario might consist of a ‘first use’ stage, followed by a ‘renovation’ stage and then another ‘use’ stage. The building manager is involved in all stages, while the occupant is mainly involved in the use stages. The first use stage can further be divided into the activities of the actor, which are for example the consumption of resources and small maintenance indoors, and activities of the building manager, for example maintenance of the brick outer wall. A part of the scenario for the
latter activity might be applying protection to the openings in the wall, followed by high pressure cleaning with an abrasive grit. All the activities in a stage scenario have a certain following order and some activities repeat with a certain frequency. Finally, the task of 'high pressure cleaning' can be considered a combination of materials and processes used. In this case, this task will consist of the use of water and an abrasive grit, and energy for the use of the high pressure machine.

The assembly of realistic scenario alternatives will be validated by the analysis of case studies. The building stock of housing corporations will be analysed to obtain typical use phase and stage scenarios. Typical activity scenarios can be composed by questioning occupants and managers. The next step in the research is to make comparisons between scenarios and single out factors that contribute considerably to the total environmental impact in the use phase. These factors will be identified by performing sensitivity analyses. The environmental impact will be calculated by using current environmental assessment methods, adjusting them to specific needs as the research progresses. This approach serves two objectives: to develop a general environmental assessment method that can be used to assess any use phase scenario and to keep the scenarios realistic, as opposed to pre-defining all possibilities. Based on the results of the comparisons between scenarios, alternative scenarios will be drawn up that might improve the environmental performance of a building in the use phase.

5. **End products**

   During the research, data will be needed to perform environmental assessments. First, data on activities and stages related to the use phase are needed to obtain a complete overview of the building use phase. These data can be gathered from an analysis of historic empirical data on the building stock of housing corporations. Second, data on the amount of materials and processes...
related to tasks, and data on tasks related to activities are necessary to assess activity scenarios. These data can be obtained in several ways. Data on activities and tasks performed by various actors can for example be obtained by questioning the concerning actor. A drawback of this data gathering method is the level of detail and accuracy in relation to the level of detail needed. A maintenance company will for example record the total amount of produced waste in a certain period, rather than waste fractions per task. A waste fraction is the amount of materials wasted compared to the amount of materials properly used. For example, of every litre of paint, 5% may be wasted because the canister cannot be emptied properly and some paint stays in the brush. Another possible way of gathering data on quantities of materials and processes is to obtain sales figures from suppliers of building products and appliances. If for example the annual sales figures of paint are known, the actual amount of produced paint can be used instead of the net amount of paint that is put on building products. This approach has similarities to input-output analysis, which can be used in environmental assessments (Suh et al., 2004). Finally, detailed data on extractions and emissions that relate to materials and processes is needed. These data are used to express the environmental impact of tasks quantitatively.

Currently available data are not always suitable, because they might be obsolete, incomplete or not gathered consequently. During the research, a database structure will be set up in which a data format will be defined for data on the different levels. Additionally, several possible sources of data, their availability and their accuracy will be examined.

The use phase model will contain the three scenario levels and a method to environmentally assess these scenarios. The model is not meant to describe an average use phase, but it is used to oversee the environmental consequences of adopting a certain attitude by assessing the accompanying scenarios. Assessments can be made on any scenario level for comparison purposes and the entire use phase can be assessed by assembling several scenarios. The model can be used to develop a use phase strategy.

The actors in the use phase of a building will not be using the model. They need comprehensible knowledge and specific actions that they can perform to contribute to a reduction of environmental impact. Part of the research is to examine the knowledge needs of the actors and the form in which they want to be able to access this knowledge. Additionally, the need for feedback systems to communicate the effect of changes in the behaviour of actors on the environmental impact will be considered and suggestions will be made.

In building practice, a change can be seen from designing a building as a finished product to total building concepts in which the building is designed, built and managed by one actor. This procedure is called DBOT: design – build – operate – transfer (van Bueren and Priemus, 2002). It is a possible way to overcome some of the barriers that stand in the way of a breakthrough of sustainable building by eliminating the division between the actors that decide on and invest in sustainable building measures and the actors that benefit from these measures. The environmental assessment model for the use phase of a building might be the basis for a design tool which can assist in creating total building life cycle concepts with great respect for the environment.
References


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