Tools for environmental assessment of the built environment

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Abstract

During the last decades there has been an increasing interest in environmental assessments of the built environment. As a result, we can find several qualitative and quantitative assessment tools. With an increasing understanding of cities and the built environment as systems metabolising matter and energy, the use of quantitative tools are expected to increase, making it relevant to ask for their status of development. Aiming to give an overview of the present status of quantitative tools, as a basis for further research and development, this paper describes and compares five different tools for quantitative environmental assessment of the built environment.

Keywords: Environmental assessment; Life cycle assessment; LCA; Built environment; City district

1. Introduction

A major issue in contemporary policy, planning and management is the need to account for the potential environmental impacts of different investments and for monitoring the environmental impacts of ongoing activities. This counts not the least for the planning of our future cities, and thus for the case of built environment planning and management. The built environment provides us with the most direct, frequent and unavoidable images and experiences of everyday life [1]. It plays an important role in the society of today, being a result of a number of social and economic processes that are central to, and determine the rate at which we proceed in the direction of, sustainable development. However, society and its built environment of today use large amounts of energy and materials, affecting the health of humans and the natural environment in negative manners. Thus, it is relevant to ask: “How ‘green’ is our built environment, and how could it be made ‘greener’ and more sustainable?”

With the rising interest and demand from policy makers to achieve a sustainable society the need for environmentally related information is increasing. There has been an increasing interest in environmental assessments of the built environment and today we can find a great number of tools for environmental assessment of the built environment, focusing on energy use in buildings, the sick building syndrome, indoor climate, building materials containing hazardous substances, and/or many other aspects in fragmented or integrated manners. Reijnders and van Roekel [2] have made a rough division of assessment tools into two classes: qualitative tools based on scores and criteria, and quantitative tools using a physical life cycle approach with quantitative input and output data on flows of matter and energy. In both groups there exist a diverse variety of concepts all over the world. Examples of widespread and well-known qualitative tools are GBTool, BREAM, LEED and EcoProfile [2,3]. Qualitative methods are often based on auditing of buildings, putting a score to each investigated parameter, resulting in one or several overall scores of a building. Some parameters investigated are quantitative, like energy use, while others are entirely criteria based. Various actors on the market have applied these tools during the past ten years. Within the second group of tools, all are based on quantitative data pending from life cycle inventories (LCI) or production data of material or energy flows. These tools have only existed for the past six years on the official market and as a result they have not yet been applied as extensively on various objects as the tools mentioned above. With an increasing understanding of cities and the built environment as systems metabolising matter and energy [4], the use of quantitative tools are expected to increase,
making it relevant to ask for their present status of development.

With the aim to give an overview of the present status as regards quantitative tools, this paper describes and compares five different tools for environmental assessment of the built environment, all of which are based on a life cycle approach. The purpose is not to rank the different tools and state which is the most appropriate one, but to produce a better picture and indicate profits and shortcomings for the tools as a group; thus providing important cognisance for potential decision-makers as well as further research and development of this group of tools.

2. Method

For the comparison of different tools, this paper uses the evaluative framework for conceptual and analytical approaches used in environmental management proposed by Baumann and Cowell [5], and earlier used in a related study where Jönsson [6] compared tools for environmental assessment of building products. However, the framework has been modified for the purpose of this study. The following aspects are adopted from the framework for conceptual and analytical approaches used in environmental management by Baumann and Cowell [5]: type of decision maker; overall purpose; object analysed; investigated dimensions; basis of comparison; and system boundaries. Aspects added to the framework to favour the aim of this study are: specific objective/primary type of building; type of environmental parameters investigated; presentation of results; and top level aggregation of results.

For this paper we have selected the following five tools for comparison:

- The Environmental Load Profile (ELP) [7,8].
- Eco-Quantum [9,10,17].
- BEE 1.0 [3,11].
- BEAT 2000 [12,13].
- EcoEffect [14–16].

The main reason for selecting these tools for comparison is that they all use a life cycle approach, and are computer-based bookkeeping methods with an emphasis on mathematical modelling as opposed to procedural modelling, thus aiming to find (or at least progress towards finding) the best decision for an intended user (cf. [5]). Who the intended users are in this case is discussed below. Other reasons taken into account are that they all have been developed in Northern Europe and that central or local governments have been the main financing bodies for the development.

This comparison is based on the authors’ evaluation of the likely use of the different tools. A relevant potential source of error is consequently the lack of primary information on the actual or intended functionality of the tools. The authors have had access to primary information on ELP (as they have personal experience of developing the tool) and received comments on text written about EcoEffect in this paper, but have only had secondary information via reports and articles on the others. This might have led to some misinterpretations in connection to the comparison of the aspects taken into account. An additional potential source of error is the method used for the comparison, as it might not consider all the relevant characteristics of the five tools, which could have lead to incorrect conclusions.

3. Comparison of tools for assessment of the built environment

As mentioned, the following comparison is made according to a framework slightly modified from Baumann and Cowell [5], covering contextual aspects (i.e. type of decision maker, overall purpose, specific objective/primary type of building and, object analysed) as well as methodological aspects (i.e. investigated dimensions, type of environmental parameters investigated, basis of comparison, system boundaries, presentation of results and, top level aggregation of results). It should be noted that the aim of this comparison is not primarily to compare how the tools are actually performing in practise; the tools are instead compared according to their intended use. For the reader’s benefit, the comparison is made with an emphasis on the main differences in the five tools.

3.1. Contextual aspects

The main types of decision makers intended to use the different tools can be defined as controlling authorities, architects and designers, researchers and consultants. Other potential user groups can also be the building owners, investors and contractors. These decision makers are more or less the same for the different tools. However, ELP also defines urban planners as a target group. An obvious difference looking at the object analysed with each tool (Table 1), is that ELP includes an area or a city district while the other tools only include the building or the real estate.

The overall purpose for the tools can commonly be summarised into acting as strategic decision support and as an aid in communication with third parties. However, there are differences in the emphasis of the purpose of the tools. As mentioned earlier, the primary purpose of the existing version of EcoEffect is not to give suggestions of remediation measures but to evaluate a real estate from an environmental point of view [16], while BEAT 2000 and Eco-Quantum have the common primary goal of providing the building sector with tools to optimize new and refurbished buildings from an environmental point of view. The primary purpose of BEE 1.0 is to analyze entries to an architectural competition in Viikki, Finland. This can be compared with the primary purpose of ELP, which was to gain a tool to follow
up and evaluate the environmental performance of the city district Hammarby Sjöstad in Stockholm, Sweden. Common for ELP and BEE 1.0 is that they had highly specified objects involved in their purpose, which is not true for the other tools. Concerning the primary type of building activity the tools ELP, Eco-Quantum, BEAT 2000 and BEE 1.0 are all developed for new buildings, while EcoE/V=ect primarily is developed for existing buildings. Though these are the primary building activities all the tools except BEE 1.0 can be applied for both new and existing buildings.

The object analysed, as defined by Baumann and Cowell, identifies the focus of the decision and the approach can be categorised as either having an ecosphere or technosphere focus. Following from this, all the tools analysed in this study have a technosphere focus, implying a focus on technological systems rather than ecological, although there is a significant difference in the ambitions in terms of which parts of the technological systems are included in the object analysed with the different tools, and at what different levels. This is illustrated in Table 1.

The levels of individual and household only concern the environmental load directly related to activities in the household and not the total environmental load from an individual or a household. In this case, the object analysed also defines at what levels data can be presented, except for EcoEffect where data is gathered and calculated for those objects marked in Table 1, but the results are presented in the five main areas: energy use, material use, indoor environment, outdoor environment and life cycle cost.

### 3.2. Methodological aspects

The types of effects studied (investigated dimensions) with the tools can be classified into environmental, economical or social categories [5]. The environmental category is the main group used by all the tools analysed in this paper. However, there are two tools also investigating economical dimensions: EcoEffect by applying life cycle cost calculations and ELP by applying societal economics through estimations of remediation costs. The types of environmental parameters investigated with the tools are presented in Table 2.

In order to compare alternative solutions with each other, there has to be a basis for comparison, which is strongly related to the specific object analysed. In LCA vocabulary this is called functional unit, meaning the quantified performance of a product system for use as a reference unit. For ELP, BEAT 2000 and EcoEffect the functional units can be per capita or m² floor surface area depending on the purpose of the conducted assessment. Eco-Quantum varies the basis of comparison between per unit building material/component, a life cycle stage, per m² floor surface area, per m³ of content, or per person depending on the object analysed [16]. BEE 1.0 calculates the environmental performance per unit building.

The system boundaries for the environmental assessment tools can be divided into temporal and spatial boundaries. The temporal boundaries are boundaries in time and those can vary between the core system and the extended system. The core system in this case characterizes the physical boundary of the largest object analysed, e.g. a building or an area, while the extended system includes activities occurring outside and far away from the actual site but is due to needs and activities in the core system. The temporal boundary for the core system of BEE 1.0 is set to 50 years, for Eco-Quantum and EcoEffect it is set to 50 years but can be changed, for ELP it can be changed to a maximum of 100 years and for BEAT 2000 the time is variable. The temporal
Table 2
Comparison of five methodological aspects between five different assessment tools for the built environment

<table>
<thead>
<tr>
<th>Methodological aspects</th>
<th>ELP</th>
<th>Eco-Quantum</th>
<th>BEE 1.0</th>
<th>BEAT 2000</th>
<th>EcoEffect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigated dimensions</td>
<td>Environmental, Economical (society, remediation costs)</td>
<td>Environmental</td>
<td>Environmental</td>
<td>Environmental</td>
<td>Environmental, Economical (real estate, LCC)</td>
</tr>
<tr>
<td>Type of environmental parameters investigated</td>
<td>Water use, Material and energy flows, Env. impact potentials, Nuclear waste, Hazardous waste, Indoor comfort and health. Indoor environment.</td>
<td>Resource depletion, Material and energy flows, Env. impact potentials, Human toxicity, Ecotoxicity, and land use</td>
<td>Material and energy flows, Global warming, Acidification, Eutrophication</td>
<td>Resource depletion, Material and energy flow, Env. impact potentials, Human toxicity, Ecotoxicity, Nuclear waste, Solid volume waste, Hazardous waste, Slag and Ashes</td>
<td>Resource depletion, Material and energy flows, Env. impact potentials, Human toxicity, Ecotoxicity, Nuclear waste, solid volume waste, hazardous waste, slag and ashes, Health effects (in and out) and vegetation (out)</td>
</tr>
<tr>
<td>Spatial system boundaries</td>
<td>Product and service life cycle</td>
<td>Product and service life cycle</td>
<td>Product and service life cycle</td>
<td>Product and service life cycle</td>
<td>Product and service life cycle</td>
</tr>
<tr>
<td>Temporal system boundaries</td>
<td>Core system: up to 100 years</td>
<td>Core system: 50 years but variable</td>
<td>Core system: 50 years Extended system: Not defined</td>
<td>Core system: Variable Extended system: Not defined</td>
<td>Core system: 50 years but variable Extended system: Not defined</td>
</tr>
<tr>
<td>Top level of data aggregation</td>
<td>As parameters investigated</td>
<td>Validation to five parameters</td>
<td>As parameters investigated</td>
<td>Not defined</td>
<td>Validation to five parameters</td>
</tr>
</tbody>
</table>

Environmental impact potentials is here an abbreviation for the parameters: global warming; acidification; eutrophication; ozone layer depletion, and ground ozone.

boundaries for the extended system of all five tools can vary for each material or energy flow included and has not been defined for any of the tools (as known by the authors). The spatial or geographical boundaries are here defined as the product or service life cycle of more or less all flows included in the assessment. This definition is valid for each and every one of the compared tools.

Resulting data presentation varies between the tools depending on the top level of data aggregation. As shown in Table 2, Eco-Quantum and EcoEffect have the highest level of data aggregation when weighting the final results into a few environmental indicators. EcoEffect presents the final results in a table with the results weighted against a reference building for the parameters: energy and material use; indoor and outdoor environment; and life cycle cost. The results are presented on a five level scale ranging from much worse than the reference building to much better than the reference building. For Eco-Quantum the final results are weighted into four environmental indicators: resources; energy; emissions; and waste. These are presented in bar charts compared to a reference building given a normalised value of 100. Concerning BEAT 2000 the highest aggregation level of results is presented in bar charts with the following environmental parameters: resource depletion; global warming; acidification; eutrophication; ozone layer depletion; ground ozone; human toxicity; ecotoxicity; nuclear waste; solid volume waste; hazardous waste; slag and ashes. BEE 1.0 presents the final results in tables with a smaller amount of environmental parameters: material and energy flows; global warming; acidification; and eutrophication. Finally, the highest level of data aggregation used in ELP is a presentation in bar charts with the following parameters: use of non renewable energy sources, renewable energy sources, global warming, acidification, eutrophication, ozone layer depletion, ground ozone, volume nuclear waste, volume hazardous waste and water use.

4. Discussion and conclusion

The five tools compared all have a common ambition, namely to increase the knowledge about the built environment by giving quantitative information. However, there is a great difference in the level of development of the different
The environmental parameters considered in all the tools are within the range of parameters normally accounted for while performing life cycle inventories. This is quite logical, as all the tools studied have used a life cycle approach as the base of development. On the other hand, there are some important parameters which the life cycle methodology has difficulties to consider when it comes to environmental impacts from the built environment. An example of such a parameter is land use, the amount of used land and the quality of the land being used, when new buildings are constructed. These factors are to some extent lacking in all the tools studied. EcoEffect handles outdoor environment but not the quality of land being used for new settlements. Eco-Quantum handles the parameter land use in the unit m² footprint surface per space coverage but not the quality of the land being utilized. This factor may not have such big influence if the object studied is the building or real estate only. On the other hand, one could question if it is useful to have a tool only looking at the building or a real estate when considering built environment planning and management.

An interesting question to ask when working with the environmental assessment of the built environment is whether it is possible to isolate the buildings from the surrounding area and still get a good picture of the environmental performance of the built environment? This question cannot be answered by the authors but is a question of interest to future research, although ELP is one tool with the ambition to try to overcome the gap between urban planners and building designers.

The indoor environment, affecting the health and comfort of inhabitants, is another important environmental parameter in the environmental assessment of buildings. In EcoEffect and ELP this parameter is studied through inquiries answered by the building occupants. However, this cannot be done for not yet constructed buildings, meaning parameters for the assessment of the indoor environment in designed buildings are still waiting to be developed.

The object analysed and the results possible to obtain, clearly make a difference between the five tools. Eco-Quantum and BEAT 2000 give the opportunity to present top aggregated data for building materials, construction elements and the whole building while BEE 1.0 presents the results for a building. For ELP the structure of the tool is built in the way that top aggregated results could be obtained for each and every one of the levels illustrated in Table 3; e.g. personal hygiene, construction materials for the building and personal transports in the area. For EcoEffect the top aggregated results can only be obtained for a real estate but the user can, through the graphs provided in the software package, click down to the source of the environmental load, e.g. heating or material use.

The selection of system boundaries for environmental assessment tools is crucial when it comes to the results to be obtained. The temporal boundaries of the core system can be varied within four of the systems, though this puts demands on the user to be aware of the consequences while varying the lifetime of the object studied as it has a large influence on final results. In all the tools studied the temporal boundaries for the extended system is not defined except by saying that they use a life cycle approach for all products and services included. Here, the service life of products has a great influence on the results. However, it is hard to have good knowledge about the technical service life of products as it varies with e.g. the use of the construction, the climate and quality of the material. BEAT 2000 and Eco-Quantum give the user an opportunity to change the lifetime of constructions or building products if there are some project specific appliances. Another issue related to selection of system boundaries is the definition of functional unit, the reference unit for which the environmental performance of different buildings or different changes in a building are estimated and compared. Eco-Quantum uses different functional units for different parts of the building depending on the object analysed, and BEE 1.0 uses the building as such as a functional unit. While the former gives a lot of freedom in the final assessment, the latter inhibits comparison of different buildings. One of the functional units suggested for Eco-Quantum (i.e. m² floor surface area) is used also by the three remaining tools. This seems to make sense initially as it enables comparison of different buildings, but the floor surface area is not really the function of a building. Taking a two bedroom flat as an example, the functional unit would also cover a given inner climate, a set of basic facilities for cooking, personal hygiene etcetera. However, this is very hard to express quantitatively. If defining of a relevant functional unit is anything but straightforward in LCA in general, it is indeed very tricky when it comes to buildings and the built environment as the study object of the LCA.

Clearly there is more work to be done on the development of quantitative life cycle oriented environmental assessment tools for the built environment. If the environmental assessment tools are extended to sustainability assessment tools a further development of economical aspects are essential as well as an addition of social aspects. Other aspects the tools have not managed to handle so far are the cumulative environmental effects. For these effects there is in addition an extensive lack of scientific knowledge, which has to be covered before including such parameters in environmental assessment tools.

To conclude, the tools studied have the same base but different ambitions on what objects to analyse. They have reached different stages of development and there is still a great need for further development of quantitative tools for environmental assessment of the built environment.
Table 3
Principle layout of ELP with life-cycle stages, organizational areas and activities taking place in a city district (Source: Fyrhake et al., 1998)

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>1</td>
<td>Building level</td>
<td>Real estate level</td>
<td>Area level</td>
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<tr>
<td></td>
<td>construction</td>
<td>construction</td>
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<td>Materials</td>
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<td>Transports</td>
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<td>2</td>
<td>Individual level</td>
<td>Household level</td>
<td>Building level</td>
<td>Area level</td>
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<td>operation</td>
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<td></td>
<td>Personal hygiene</td>
<td>Personal hygiene</td>
<td>Heating</td>
<td>Green areas</td>
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<td></td>
<td>Cooking</td>
<td>Cooking</td>
<td>Lighting</td>
<td>Hard areas</td>
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<tr>
<td></td>
<td>Washing</td>
<td>Washing</td>
<td>Other electricity</td>
<td>Wires and piping</td>
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<tr>
<td></td>
<td>Lighting</td>
<td>Lighting</td>
<td>Cooling</td>
<td>Electricity</td>
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<td>Waste production</td>
<td>Waste production</td>
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<td>Storm water</td>
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<tr>
<td>3</td>
<td>Building level</td>
<td>Real estate level</td>
<td>Area level</td>
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<td>demounting</td>
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<td>Landfilling</td>
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