Abstract

The building sector is a vital part in the progress towards environmental sustainability, because of its high potential to decrease the environmental impact. However, the building industry remains one of the most critical industries for the adoption of environmental sustainability principles, because of several unique characteristics in terms of e.g. long-lived products and many stakeholders involved. Environmental assessment tools have an important role to play in implementing environmental sustainability in the building sector, as they provide a clear declaration of what are considered the key environmental considerations and also provide a way of communicating these issues. The Environmental Load Profile (ELP) is a Swedish Life Cycle Assessment (LCA) based tool for the built environment, originally developed as an instrument for evaluation of the environmental performance of Hammarby Sjöstad (HS), a new city district in Stockholm, Sweden. The ELP is facing implementation, aiming to be established as an instrument of common acceptance. Experiences and results from the ELP has revealed that it can be applied to give a comprehensive picture of the environmental performance of a city district, but also that the tool has a number of weaknesses and there is much to improve in the practical procedures for the use of the tool in environmental assessments.

This research project has the overall goal of making the ELP a stakeholder-accepted methodology for LCA-based assessment for the built environment. The overall goal includes two subgoals: (i) a research goal is to find an acceptable compromise in the design of the ELP tool between a natural science and technology based scientific accuracy and a social-science based acceptance of the tool and (ii) an implementation goal is to study and report experience from the use of the tool as developed today. The thesis consists of three papers: (i) the first is a study of two Swedish LCA-based tools for the built environment, which is based on comparative assessments using the ELP and EcoEffect (EE), (ii) the second is based on a questionnaire and interview study, in which we have investigated responses on LCA-based tools for the built environment among stakeholder representatives of Sweden's building sector, with the purpose to identify barriers and opportunities for increased use of such tools and (iii) the third is based on case studies in HS using the ELP. We have identified the dominant environmental aspects in the ELP and also investigated the accuracy of the results. The study is completed with a development of a simplified version of the ELP, which also is applied in HS.

Findings show that despite applying the comparative parts of the ELP and EE on an equal basis (i.e. the object specific data), differences in results were found. The following factors give rise to the differences: (i) differences in material grouping and life expectancy for the construction materials used, (ii) diverse Life Cycle Inventory (LCI) data and (iii) different impact assessment. The required level of knowledge to compare, analyse and evaluate assessments made with the ELP and EE, is relatively high, which creates an educational barrier towards increased tool use. A number of other barriers that could mitigate a fruitful implementation of LCA-based tools in Sweden's building sector have also been identified. We have found barriers between: (i) the current and the desired environmental work within the sector, (ii) the knowledge of and the use of LCA-based tools and (iii) the developers of the tools and the potential users. Other barriers further identified are especially connected to: (i) data (availability and credibility), (ii) costs, (iii) time, (iv) customer pressure, (v) knowledge and (vi) incentives. We have also identified the following opportunities for increased use of the tools: (i) different design of the tools for different actors and situations, (ii) combine LCA with LCC, (iii) involve environmental assessment in the implementation of the EU Directive on energy performance of buildings, (iv) develop reference values, (v) simplify input-data collection, (vi) improve environmental labelling and (vii) provide incentives. In the development of a simplified ELP we have noticed that the most important aspects contributing to the environmental load at a city district level (50 % of the total amount), covers 91-99 % of the total environmental load. The thesis shows that different simplifications of the ELP-tool are required for different purposes, actors and situations. A simplified version of the ELP, "ELP-light" was developed and applied in HS. In the development of ELP-light, we have used some of the identified opportunities and bridged some of the identified barriers.

Sammanfattning

Den byggda miljön spelar en stor roll i arbetet mot en ekologisk hållbar utveckling, eftersom byggsektorn har en stor möjlighet att minska vårt samhälles totala miljöbelastning. För att nå en ekologisk hållbar utveckling krävs åtgärder från såväl samhället som industrin. Byggbranschen är en av de mest kritiska branscher att implementera ekologiskt hållbara principer i, på grund av ett antal unika karakteristika såsom att de produkter de tillhandahåller har en lång livslängd samt att det sällan är samma aktör som bygger som sedan äger och förvaltar byggnaderna. Miljövärderingsverktyg har en viktig roll att spela i miljöarbetet inom byggsektorn, eftersom de ger tydliga riktlinjer om vad som är vikigast att fokusera på samt att de förenklar kommunikationen av miljöarbetet. Utvecklingen av metoder för att miljövärdera den byggda miljön är en relativt ny företeelse inom byggbranschen, men sedan 1990-talet har ett flertal miljövärderingsmetoder utvecklats. Miljöbelastningsprofilen (MBP) är en svensk livscykelbaserad (LCA) miljövärderingsmetod för den byggda miljön, från början utvecklad för uppföljning av miljömålen i Hammarby Sjöstad (HS) (ett nytt stadsdistrikt i Stockholm). MBP står idag inför ett skede då den ska börja implementeras i olika projekt. Erfarenheter från tidigare studier har visat att verktyget kan användas för att ge en omfattande bild av miljöbelastningen från ett stadsdistrikt, men även att det har en del svagheter samt att det finns en del att förbättra i rutiner kring den praktiska arbetsprocessen.

Det här forskningsprojektet har ett övergripande mål att göra MBP till en vedertagen modell vid LCA-baserade miljövärderingar av den byggda miljön. Detta övergripande mål inkluderar två delmål: (i) ett forskningmål är att utveckla en förenklad MBP som bygger på en kompromiss mellan att vara vetenskapligt förankrad och socialt accepterad och (ii) ett implementeringsmål är att använda och dra erfarenheter av användningen av MBP som den är utvecklad idag. Avhandlingen består av tre artiklar: (i) den första är en studie två svenska LCA-baserade miljövärderingsverktyg för den byggda miljön, baserad på en jämförande värdering av en kontorsbyggnad mellan MBP och EcoEffect (EE), (ii) den andra är baserad på en enkät och intervjustudie i vilken vi har undersökt olika aktörer i Sveriges byggsektors åsikter kring LCA-baserade verktyg för den byggda miljön, med syftet att identifiera barriärer och möjligheter för ökad användning av denna typ av verktyg och (iii) den tredje är baserad på implementeringsstudier i HS, i vilka vi har identifierat de mest dominerande parametrarna som ger upphov till miljöbelastning i MBP, samt jämfört resultaten med andra studier genomförda inom området. Studien är avslutad med en utveckling av en förenklad version av MBP, vilken sedan är använd i HS.

Resultaten visar att det är svårt att jämföra resultat mellan MBP och EE, men trots en värdering av jämförbara delar ger metoderna olika resultat. Det som ger upphov till skillnaderna i resultat är: (i) skillnader i gruppering av olika materialtyper och skillnader på materiallivslängder, (ii) skillnader i LCI-data och (iii) olika klassificerings och karakteriseringsmodeller för miljödata. Den erforderliga kunskapsnivån för att genomföra värderingar med MBP och EE är relativt hög vilket skapar en barriär mot ökad användning. Ett antal andra barriärer mot implementering av MBP och andra typer av LCA-baserade verktyg i Sveriges byggsektor har även identifierats. Vi har funnit barriärer mellan: (i) det befintliga och det önskade miljöarbetet inom sektorn, (ii) kunskapen och användningen av LCA-baserade verktyg och (iii) utvecklarna och användarna av verktygen. Ytterligare identifierade barriärer är särskilt kopplade till: (i) data (tillgänglighet och trovärdighet), (ii) kostnader, (iii) tid, (iv) kundtryck, (v) kunskap och (vi) incitament. Vi har även identifierat ett antal möjligheter för ökad användning av denna typ av verktyg: (i) olika design av verktygen för olika aktörer och syften, (ii) kombinera LCA med LCC, (iii) använd miljövärdering i kombination med energideklaration av byggnader, (iv) utveckla referensvärden, (v) förenkla insamling av indata till modellerna, (vi) använd som underlag till miljömärkning och (vii) tillhandahåll incitament. I ett förenklingsarbete av MBP har vi sett att de viktigaste parametrarna som ger upphov till miljöbelastning i MBP på distriktsnivå (50 % av möjliga) ger upphov 91-99 % av den totala miljöbelastningen. Avhandlingen visar att olika typer av förenklingar av MBP är efterfrågade av olika aktörer för olika syften. En förenklad version av MBP ”MBP-light” har utvecklats och använts i HS. I utvecklingen av MBP-light har vi använt en del av de identifierade möjligheterna samt överbryggt en del av de identifierade barriärerna.

Acknowledgements

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Karolina Brick
April 29, 2008

List of papers

Paper I
Brick, K., Frostell, B. A comparative study of two Swedish LCA-based tools for practical environmental evaluation of buildings

Paper II
Brick, K., Frostell, B., Svanberg, C. Barriers and opportunities for increased use of LCA-based tools for the built environment – Stakeholder responses

Paper III
Brick, K., Frostell, B. Towards simplification of the Environmental Load Profile

The thesis is based on three papers. The first paper is a study of two Swedish LCA-based tools for the built environment. The study is based on comparative assessments of an office building made with The Environmental Load Profile (ELP) and EcoEffect. The second paper is based on a questionnaire and interview study, in which we have investigated responses on LCA-based tools for the built environment among stakeholder representatives of Sweden's building sector. The purpose with the study was to identify barriers and opportunities for increased use of such tools. Paper three is based on case studies using the ELP in Hammarby Sjöstad (HS). We have identified the most important aspects contributing to the environmental load from a life cycle perspective at a city district level and at a building level. We have also investigated the accuracy of the result in the HS case compared with literature data from assessments by use of similar tools. The third paper was completed with a case study using a simplified version of the ELP-tool.

List of abbreviations

IE	Industrial Ecology
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
ELP	Environmental Load Profile
EE	EcoEffect
GWP	Global Warming Potential
AP	Acidification Potential
POCP	Photochemical Ozone Creation Potential
EP	Eutrophication Potential
RW	Radioactive Waste
NRE	Non Renewable Energy Sources
HS	Hammarby Sjöstad
SU	Sickla Udde
SK	Sickla Kaj

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1. Introduction

Sustainable development was defined in the Bruntland report 1987 as *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*. The field of sustainable development can be broken into three parts: (i) environmental sustainability, (ii) economic sustainability and (iii) social sustainability (United Nations, 1987). The building sector is a vital part in the progress towards environmental sustainability, because of its high potential to decrease the environmental impact. The building sector consumes approximately 50 % of material resources taken from nature and approximately 40 % of generated energy in most industrialized countries (Roodman et al, 1995; Anink, et al, 1996; STEM, 2004; BYKR, 2001). To achieve environmental sustainability, great efforts are required from the government as well as from industry and municipalities. Intensive efforts of co-operative branch organisations, such as the Swedish Ecocycle Council for the building sector have raised a general environmental awareness among practitioners (Gluch, 2005). Despite powerful arguments on the importance of environmental issues and evidence on the multiple benefits of early adoption of higher performance standards, the building industry remains one of the most critical industries for the adoption of environmental sustainability principles (e.g. minimize environmental degradation and to halt and reverse the processes they lead to). This is because of several unique characteristics in terms of its size, activities, number of employed, services and products provided, waste generated etc., which all create specific barriers against improvement of the environmental performance of buildings and building activities. However the experience of leading construction companies in different sectors shows that there is a strong business argument for more environmentally sustainable constructions (OECD, 2003; Khalfan, 2006).

The processes involved in a building project in Sweden are complex and for the project to be completed successfully, several different types of professionals with different skills are needed (e.g. architects, designers, suppliers and engineers). A building project is composed of several phases (i.e. programming and planning, design and engineering, construction, operation, and dismantling) and different levels of construction (i.e. construction of materials, components and technologies, whole buildings and the wider built environment). At each level and phases, different professionals are at work, different stakeholders are involved and different decision-making processes are crucial (Bakens, 2003; Naaranoja, et al, 2007). The complexity of interactions among these participants is one of the greatest barriers against the environmental sustainability work. Figure 1 presents the life cycle of a building and some of the different professionals in each phase in Sweden's building sector (note that several of the actors can possess several roles and be active in several of the phases).

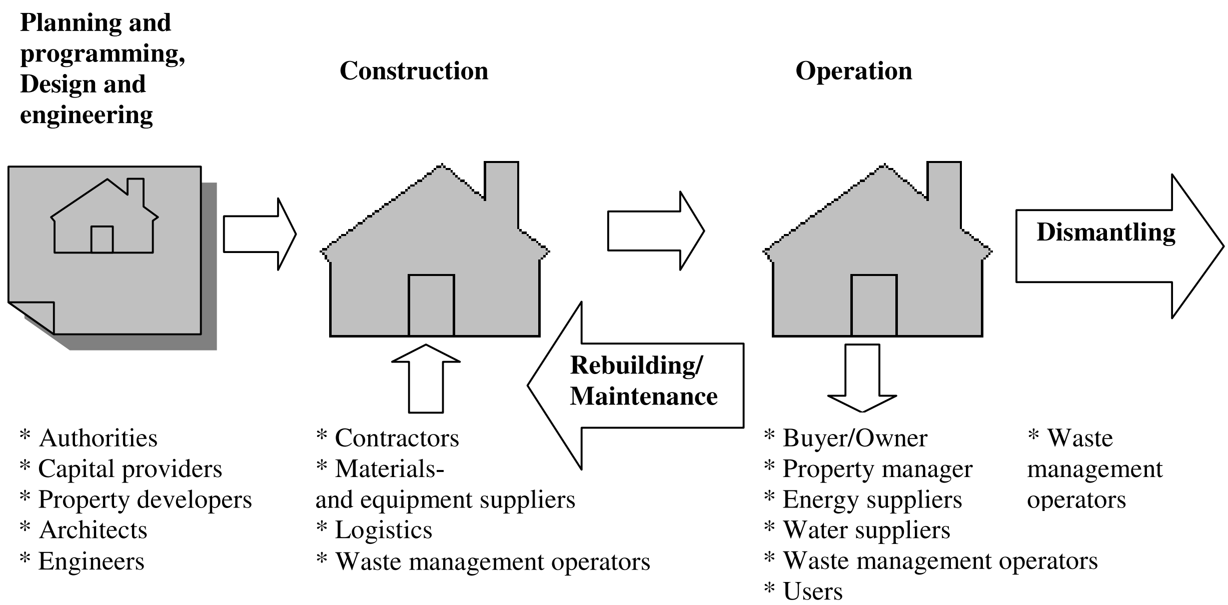

Figure 1. *The life cycle of a building and some of the different professionals involved in each phase in Sweden's building sector*

Environmental assessment tools have an important role to play in implementing environmental sustainability in the building sector, as they provide a clear declaration of what are considered the key environmental considerations and their relative priority and also provide a way of communicating these issues (Chang et al, 2007). However this will only be possible when these tools effectively influence the decision-making processes occurring at every level and phase of the construction process. Environmental assessment of the built environment is a relatively new phenomenon. The public and private sector are increasingly becoming more interested in being able to look holistically at the environmental consequences of their operations (Lindfors et al, 1995) and interest from public policy makers means that the need for a clearer environmental picture is rapidly growing (Swedish Ministry of Environment, 2000; Swedish Environmental Objectives, 2008; The Dialogue Project, 2008; BYKR, 2008; City of Stockholm, 2008; UN, 2008; Commission of the European Communities, 2001; European Commission, 2006).

A number of environmental assessment tools for the built environment have been developed since the first developments started in the beginning of 1990s. Historically, different types of checklists and criteria systems have been used, such as the Green Building Challenge (IISBE, 2008), Environmental Status (MFB, 2008), LEED (USGBC, 2008) and BREEAM (BRE, 2008a). More recently, tools based on Life Cycle Assessment (LCA) have begun to emerge. The standardization of LCA-methodology (ISO 1997; 1998; 2000a; 2000b) has strengthened its status as perhaps the most important tool for assessing a project's overall environmental impact (Malmqvist, 2004). Many researchers have illuminated the importance of using a life cycle perspective when evaluating the built environment (e.g. the operation phase is the highest point of a building's environmental impact) (Adalberth et al, 2001). Examples of LCA-based tools for the built environment are: EcoEffect (EE) (Glaumann et al, 2004), Envest (BRE, 2008b), Athena (Athenasmi, 2008), EcoQuantum (IVAM, 2008), LEGEP/LEGOE (Universität Karlsruhe, 2008), Sustainable Buildings (Erlandsson, 2005) and the Environmental Load Profile (ELP) (Forsberg, 2003).

2. Theory

The research is conducted within the framework of Industrial Ecology (IE), a concept for environmental sustainability. IE is a rapidly growing field that systematically examines local, regional and global materials and energy flows in products, processes, industrial sectors and economies (Journal of Industrial Ecology, 2008). IE is a rather young scientific discipline, in which the sustainable relationship between environment and society is the core issue (Universiteit Leiden, 2008). IE is a cluster of concepts, tools, metaphors and exemplary applications and objectives. So far there is no standard definition of IE (Ayres, et al, 2002). However, whatever the definitions may be, all authors more or less agree on at least three key elements of the IE perspective:

1. *"It is a systematic, comprehensive, integrated view of all the components of the industrial economy and their relations with the biosphere.*
2. *It emphasizes the biophysical substratum of human activities, i.e. the complex pattern of material flows within and outside the industrial system, in contrast with current approaches which mostly consider the economy in terms of abstract monetary units, or alternative energy flows.*
3. *It considers technological dynamics, i.e. the long term evolution (technological trajectories) of clusters of the key technologies as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem."* (Erkamn, 1997).

IE is rooted in systems analysis and is a higher-level systems approach to framing the interaction between industrial systems and natural systems. A systems approach provides a holistic view of environmental problems making them easier to identify and solve; it can highlight the need for and advantages of achieving environmental sustainability, (Garner, 1995). There are a number of Environmental System Analysis tools (ESA) available (e.g. EIA Environmental Impact Assessment, SEA Strategic Environmental Assessment, LCA, LCC Life Cycle Costing) (Moberg, 2006). Tools are operational methods supporting the concepts for environmental sustainability (e.g. IE, EcoEfficiency, Life Cycle Thinking) (Wrisberg et al, 2002). They enable to plan and organize activities, to identify, evaluate and implement environmental improvements and to evaluate progress in reducing environmental impacts of products and processes (Van Berkel, 1997).

2.1 Life Cycle Assessment (LCA)

LCA is a tool for assessing environmental impact of a product, process or activity through all stages of its life cycle (i.e. from the extraction of raw materials through to processing, transport, use, reuse, recycling or disposal). LCA shall include:

1. *Definition of goal and scope*
2. *Inventory and analysis*
3. *Impact assessment*
4. *Interpretation of results*

Goal and scope definition includes a description of the goal of the study, strategy for capture of data, decision of which functional unit to use and definition of system boundaries. The inventory includes data collection, i.e. inputs of e.g. materials, energy, chemicals and outputs in the form of air emissions, water emissions or solid waste. The impact assessment, is divided into three sub phases: (i) classification, where material and energy inputs are classified into impact categories, (ii) characterisation, where the contributions to each impact category are assessed by quantiatative or qualitative methods and (iii) valuation, where the impact of each impact category is addressed and related to each other and the total impact assessed. The valuation process includes a certain amount of subjectivity depending on how the weighting criterions are created and what weight different impact categories receive. The interpretation contains e.g. analysis of major contributions and sensitivity analysis which leads to conclusions whether the ambitions from the goal and scope can be met. The procedures of LCA are part of the ISO 14000 environmental management standards (ISO 1997; 1998; 2000a; 2000b).

2.2 The Environmental Load Profile (ELP)

Hammarby Sjöstad (HS) is a new city district in Stockholm Sweden. It is Stockholm's biggest ongoing urban development project. Once fully built, HS will have approximately 9 000 residential units for just over 20 000 residents. The city of Stockholm already at the beginning of the project in the early 1990´s declared that HS would serve as a fore runner for ecologically sustainable construction and living, with tough environmental requirements on buildings, technical installations and the traffic environment. The overall environmental goal is that the environmental load from HS shall be 50 % lower (*"twice as good"*) than the corresponding level for recently constructed housing areas from the early 1990:s (Forsberg, 2003; Hammarby Sjöstad, 2008). The Environmental Load Profile (ELP) was originally developed as a tool to follow up the environmental goal *"twice as good"* in HS. The ELP enables e.g. comparison of alternative solutions of building constructions and infrastructures in connection with city planning. The ELP holds two levels of life cycle perspective: (i) the life cycle stages: construction, operation and dismantling and (ii) the life cycle of e.g. building materials and electricity which are flowing in and out of the life-cycle stages of a building, a real estate property or a city district. Figure 2 illustrates the different levels in the ELP (i.e. building level, estate level and district level), the life cycle perspective (e.g. the life cycle of the building: construction, operation and dismantling) and the inputs and outputs to a building, an estate or a district (e.g. electricity and heat) (Forsberg, 2003).

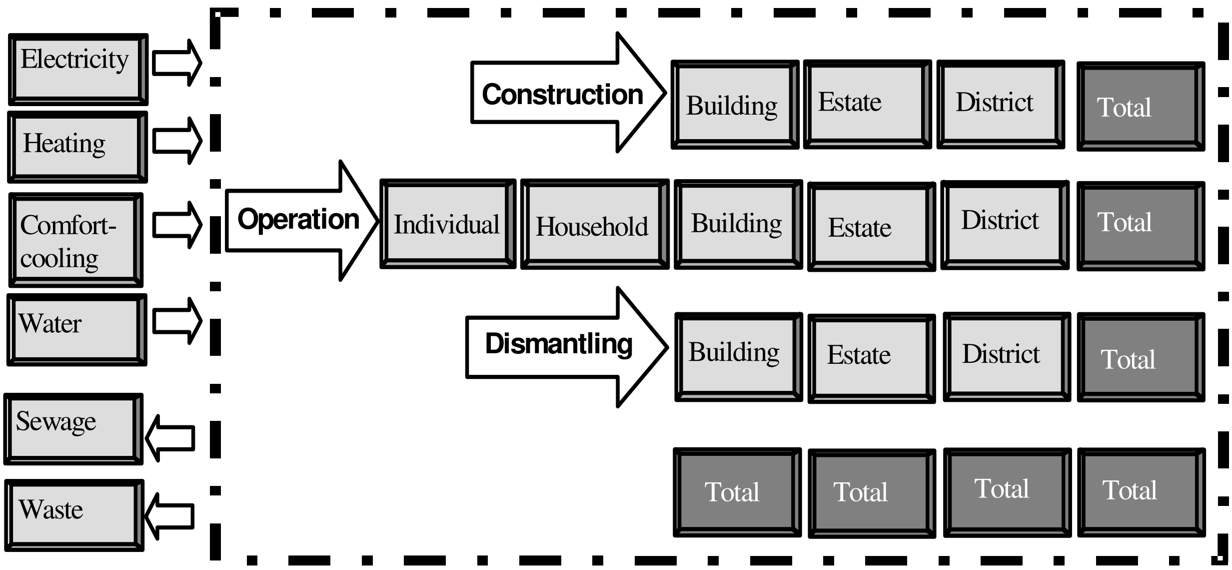

Figure 2. *The different levels in the ELP (i.e. building level, estate level and district level), the life cycle perspective (i.e. construction, operation and development) and the inputs and outputs to a building, an estate or a district (e.g. electricity and heat).*

The most important activities from an environmental aspect are defined and their emissions to air, ground and water are quantified. The parameters analysed are emissions such as CO_2, HC/VOC and NOx, which are presented as the following environmental impact categories: global warming, eutrophication, acidification and photochemical ozone creation. The ELP also quantifies radioactive waste, extraction of renewable and non renewable energy resources. Figure 3 illustrates the activities included at the different levels (building, estate and district) and life cycle phases (construction, operation and dismantling) of the ELP.

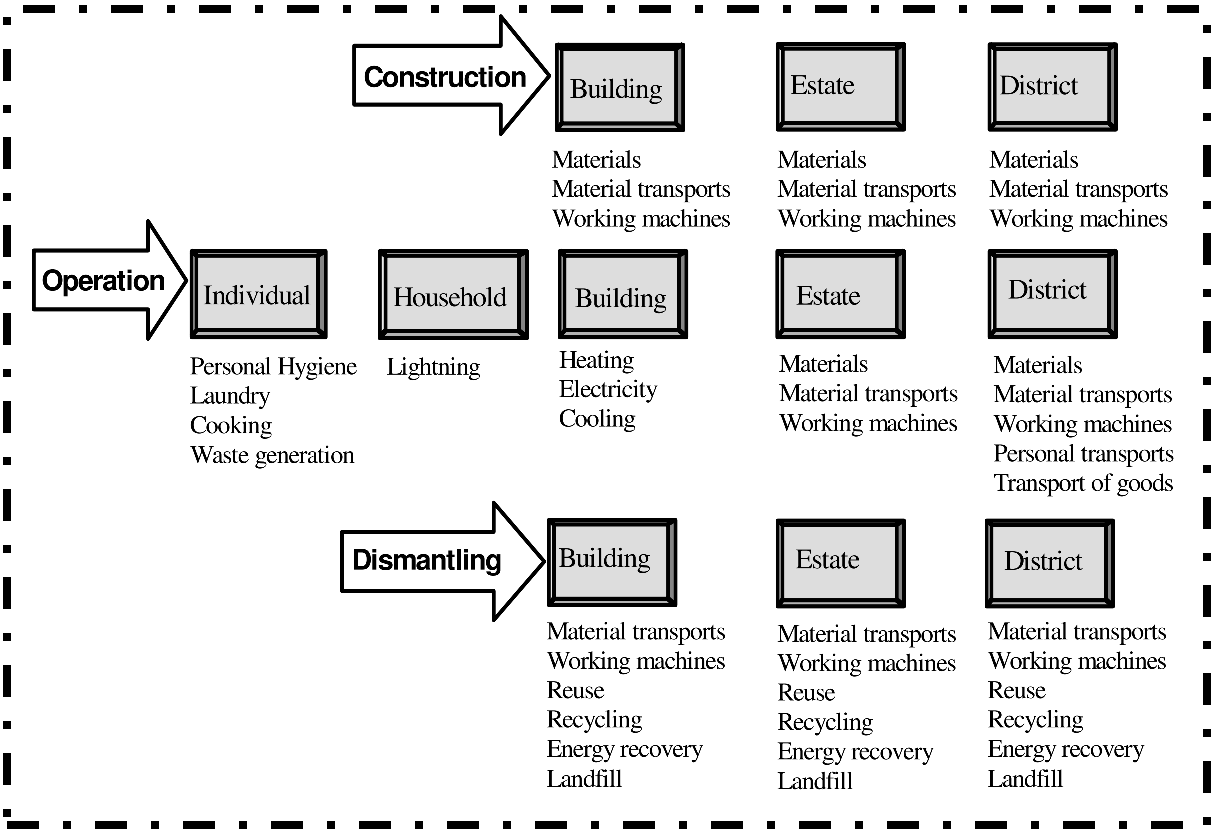

Figure 3. *The activities included in the ELP within the different levels and life cycle phase.*

3. Aim and objectives

Experiences and results from the ELP has revealed that the tool can be applied to give a comprehensive picture of the environmental performance of a building as well as a city district but also that the tool has a number of weaknesses and there is much to improve in the practical procedures for the use of the tool in environmental assessments (Forsberg, 2003).

The overall aim with the thesis is to contribute to environmental sustainability for the built environment, by further developing the ELP, as a tool for assessing the built environment and broadening the environmental knowledge base for decision making. The objective is to make the ELP a stakeholder-accepted methodology for LCA-based assessment for the built environment. This objective includes two sub parts, one research based and one implementation based: (i) the research based part is to find an acceptable compromise in the design of the ELP tool between a natural science and technology based scientific accuracy and a social-science based acceptance of the tool and (ii) the implementation based part is to study and report experience from the use of the ELP-tool as developed today.

Five specific research questions have been identified for achieving the overall aim and the objectives:

1. *How do LCA-based tools for the built environment in Sweden work today?*

2. *Which are the main barriers and opportunities for LCA-based tools?*

3. *Which are the main aspects in a life-cycle perspective contributing to the environmental load at a city district level and a building level?*

4. *By what means can the ELP be simplified in order to facilitate the use of the tool and considering only a smaller amount of contributing environmental aspects?*

5. *Does a simplified version of the ELP give accurate results?*

4. Method

The research project contains two parts to overcome the weaknesses of the ELP and its use in practical assessments of the built environment: (i) one scientific part and (ii) one practically oriented implementation part.

The scientific part can be divided into six different sub-parts:

1. Case studies with the ELP for analysis and follow-up of newly built areas in the Stockholm region together with project owners and construction companies
2. Further knowledge registration of other tools with similar aims as the ELP
3. Evaluation of stakeholder responses to LCA-based tools such as the ELP
4. Evaluation of application results from new and existing buildings and investigate what modules of the ELP that may be simplified
5. Change, refine and simplify the ELP tool in accordance with stakeholder response and other experience gained in the project
6. Comparative evaluations of buildings from the full and simplified version of the ELP

The implementation part can be divided into four different sub-parts:

A. Use of the ELP to document progress with the environmental goals (e.g. national environmental goals such as a good built environment, reduced climate impact, natural acidification only (Swedish Environmental Objectives, 2008), local environmental goals (City of Stockholm, 2008) as well as project specific environmental goals (Hammarby Sjöstad, 2008))
B. Illustration of the importance of performing environmental load calculations as a means of information feed-back in the work to reach the national environmental goals
C. Make the environmental goals more clear for individual stakeholders
D. Illustrate the connection between the environmental goals and measures in the built environment (e.g. illustrate the value of changing the windows or the heating system of a building)

The first paper in the thesis is a study of two Swedish LCA-based tools for the built environment, based on Brick (2004). The work has been concentrated on the scientific part: (1) case studies with the ELP for analysis and follow-up of newly built areas in the Stockholm region together with project owners and construction companies and (2) further knowledge registration of other tools with similar aims as the ELP. The method used is practical evaluation of an office building using two different tools (the ELP and EcoEffect).

In the second paper we have identified barriers and opportunities for increased use of LCA-based tools. The focus in this work was the scientific part (3) to evaluate stakeholder responses of LCA-based tools such as the ELP. The study was based on Svanberg's ongoing Master thesis *"LCA-based tools in Sweden's building sector"*, which was part of the research work. In Svanberg's study we have established a dialogue with different stakeholders in Sweden's building sector. We used a combined approach using a questionnaire with oral questions and personal interviews as means to collect information. The questionnaire comprised 22 questions (both multiple choice questions and open questions) and was sent out to 76 different stakeholders. A few stakeholders stated that they didn't have time to answer the questionnaire and were given to answer five questions within the questionnaire by phone. To get a better information basis, we chose eight stakeholders to make additional personal interviews with.

In the third paper we have focused on the scientific part: (4) evaluation of application results from new and existing buildings and investigate what modules of the ELP that may be simplified, (5) changing, refining and simplifying the ELP-tool in accordance with stakeholder responses and other experience gained in the project and (6) comparative evaluations of buildings from the full and simplified version of the ELP. The paper is based on three case studies in Hammarby Sjöstad (HS), which are part of the implementation project (A,B,C,D): (a) *A follow up study of the environmental impact and economy in Sickla Udde.* (This report is earlier work and not done within this project) (b) *A follow up study of the environmental load in Sickla Kaj* and (c) *A follow up study on the environmental load in Lugnet*. Results from (a) and (b) were: (i) used to identify the most important aspects contributing to environmental load in a life cycle perspective at a city district level and at a building level, (ii) used to investigate the accuracy of the ELP-results and (iii) completed with a simplification of the ELP-tool (ELP-light) aiming for an increased use. Moreover, study (c) was used for a comparative evaluation between ELP and ELP-light.

Figure 4 summarizes all the applied studies in the research project and related work (i.e. Master theses and implementation studies).

RESEARCH PROJECT

Paper I, A comparative study of two Swedish LCA-based tools for practical environmental evaluation of buildings

Goal: To demonstrate that significant differences occur and that they are related to the way the tools have been modelled and especially to what input data have been used and how it is organised
Method: Environmental evaluation of a newly built office building, using the ELP and EE
Results: Differences in results appear when using the ELP and EE depending on detailed model figuration and data sources

Paper II, Barriers and opportunities for increased use of LCA-based tools for the built environment
- Stakeholder responses

Goal: Identify barriers and opportunities for an increased use of LCA-based tools to use in a further refinement of the ELP-tool.
Method: Questionnaire and interviews with stakeholders
Results:

- Identification, analysis and discussion of: practices, procedures and needs of the expected end users of LCA-based tools for the built environment.
- Barriers against increased use of LCA-based tools for the built environment.
- Opportunities for increased use of LCA-based tools for the built environment

Paper III, Towards simplification of the ELP

Goal: Find an acceptable compromise in the design of the ELP tool between a natural science and technology based scientific accuracy and a social-science acceptance of the tool
Method:

- Application of the ELP for analysis and follow up of newly built areas.
- Evaluation of application results.
- Development of a simplified version of the ELP.
- Application tests with the simplified version of the ELP

Results:

- Identification of the main aspects in a life cycle perspective contributing to the environmental load at a city area and a building area level.
- Development of a simplified version of the ELP to facilitate the use of the tool and considering only a smaller amount of important contributing aspects
- Analysis of results accuracy

RELATED WORK

Master Theses

Brick (2004) *Life Cycle Based Environmental Assessment of a New Office Building-a Comparative Study Using two Different Tools,* Master Thesis, Division of Industrial Ecology, Royal Institute of Technology, Stockholm

Svanberg, *LCA-based tools in Sweden's building sector,* Ongoing Master Thesis, Division of Industrial Ecology, Royal Institute of Technology, Stockholm

Implementation studies

(a) Levin et al (2004) A *follow up study of the environmental load and economy in Hammarby Sjöstad, Sickla Udde*

(b) Levin et al (2005) A *follow up study of the environmental load in Hammarby Sjöstad, Sickla Kaj*

(c) Brick (2007) *A follow up study of the environmental load in Hammarby Sjöstad, Lugnet*

Figure 4. *The structure of the papers within the thesis and related work (i.e. Master theses and implementation studies). The shaded box is earlier work and not done within the project.*

5. Results

The main findings from the appended papers and related work are presented in this chapter. The first paper concerns a comparison of two Swedish LCA-based tools for the built environment. The second concerns responses on the environmental work in the building sector in Sweden and on environmental assessment tools, especially LCA-based, among stakeholder representatives of the Swedish building sector. The third is an approach towards simplification of the ELP, by finding an acceptable compromise in the design of the ELP-tool between a natural science and technology-based accuracy and a social science based acceptance of the tool.

5.1 Paper I

Brick, K. and Frostell, B. (2007) A Comparative study of two Swedish LCA-based tools for practical environmental evaluation of buildings, *Journal of Environmental Assessment Policy and Management* Vol 9 no 3, ISSN: 1464-3332, Poster presentation, ISIE (International Society for Industrial Ecology) conference (Toronto, Canada, June 17-20 2007)

In this study the following research questions were analysed:

- *How do LCA-based tools for the built environment in Sweden work today?*
- *Which are the main barriers and opportunities for LCA-based tools?*

A number of different environmental impact assessment tools for the built environment are available. Each of the tools has focused on different environmental aspects, according to what is considered the most important. In Sweden two LCA-based tools have been developed during the last years: the Environmental Load Profile (ELP) and EcoEffect (EE). Both are facing implementation and it is therefore important that they may deliver credible and consistent results to end-users and facilitate a transition to more environmentally benign building construction and administration.

The starting point for the study was Brick's Master Thesis (Brick, 2004) in which some of the questions were: (i) how much knowledge is needed for using the ELP and EE? (ii) does it matter which tool we choose to use? (iii) how much input data is needed to collect? and (iv) where to find this input data? One conclusion in Brick (2004) was that assessment results differed between the ELP and EE. However, the assessments were made independent of each other and therefore not fully comparable. The present study therefore looked more in detail on what differences in results may appear when using the ELP and EE tools and where do they come from. The purpose of the paper was to demonstrate that significant differences occur and that they are related to the way the tools have been modelled and especially to what input data have been used and how it is organised.

Comparative assessments of a new built office building were made with the ELP and EE. Because of the different approaches used in the ELP and EE, it was difficult to make a complete comparative assessment. This is because they model different areas, and hence give only few individual results that are comparable. Assessed were materials during building construction and energy (i.e. electricity and district heating) during building operation. The types of environmental impact potentials examined were: Global Warming Potential (GWP), Photochemical Ozone Creation Potential (POCP), Acidification Potential (AP) and Eutrophication Potential (EP).

Differences in results were found for all the environmental effect potentials. However, both tools pointed at energy use in the administration phase of the life cycle being the most significant factor for environmental impact, consistent with other studies. To examine the reasons for the diverse results on the environmental effect potentials for the tools, a deeper analysis of the factors behind was carried out.

There are some differences between the ELP and EE which give rise to diverse results: (i) differences in material grouping, (ii) different life expectancy for different materials, (iii) different classification[1] and characterization[2] models. However, the differences are small and have only a minor influence on the results. There are various LCI-data incorporated in the tools, which have a significant influence on the results. By using the same LCI-data expressed in equivalents of CO_2 (i.e. with the same impact assessment) for electricity and district heating in the ELP and EE, the GWP become equal. This proved that with the same LCI-data and the same classification and characterization model used, the tools give the same results for this environmental effect potential category (GWP).

The author's own experiences and reflections of working with the ELP and EE tools in an ongoing construction project are that: (i) it takes time to understand and use both tools and (ii) it was complicated and time demanding to collect input data to the assessments (e.g. where to find the data and how to choose system boundaries with respect for what to include and not).

Using different environmental assessment tools is an efficient way of broadening the knowledge base for improved decision-making. There are some difficulties (such as the required level of knowledge and collecting input data), but if the assessments are reported with full transparency, by showing the sources for uncertainty (such as background data) a higher credibility is reached. In the future there is need for more standardisation work (object specific data, LCI-data and calculation methods) to reach an even higher credibility and congruence between different tools.

5.2 Paper II

Brick, K., Frostell, B., Svanberg, C. (2008) Barriers and opportunities for increased use of LCA-based tools for the built environment – Stakeholder responses, Presented at the ISIE (International Society for Industrial Ecology) conference (Toronto, Canada, June 17-20 2007), Submitted to the Journal of Industrial Ecology.

In this study the following research question was analysed:

- *Which are the main barriers and opportunities for LCA-based tools?*

The development of the ELP as an assessment tool has so far been supply driven (rather than being demanded by stakeholders in the building sector), and therefore this important target group have participated only to a limited extent in the process. The next logical step in the research project was therefore to involve the expected end users in the further refinement of the tool.

[1] Classification: Assigning of substances to impact categories (ISO, 1997)
[2] Characterization: Modelling of the substances within impact categories (ISO, 1997)

In the study we have investigated: (i) the environmental work in Sweden's buildings sector (attitudes, driving forces and responsibility) and (ii) what knowledge of and attitudes towards environmental assessment tools (especially LCA-based) different stakeholders in Sweden's building sector have. The paper aimed at clarifying barriers and opportunities for increased use of LCA-based tools, such as the ELP for the built environment. The research is a step towards further refinement of the ELP-tool that will aid in establishing it as an instrument of common acceptance. For this purpose, we have established a dialogue with different stakeholders in Sweden's building sector: (i) actors who require change through e.g. laws, regulations and general advice (i.e. authorities, researchers and industry organisations) and (ii) actors whose assignment is to fulfil the requirements (i.e. property developers, property managers, consultants/architects and construction companies/contractors). A questionnaire and interviews were used as means to collect information.

The characteristics of the stakeholders contributing to the study are that most are property developers and property managers and that their knowledge about environmental issues and sustainable development in Sweden's building sector is high. For most contributors, environmental issues are part of their daily work.

In the study, the stakeholders consider that their company or organisation is positioned high in the environmental work in Sweden's building sector. However, it seems that the current environmental work only contributes to real environmental improvements to some extent. A large part (77%) of the stakeholders use different tools in their environmental work and according to themselves the knowledge about LCA-based tools is high (81%). Despite this, it seems that they only use their knowledge to a limited extent (i.e. only 42 % of those who know about LCA-based tools use them) considering that they: (i) are directly or indirectly involved with environmental initiatives within their respective organisations, (ii) consider themselves to have a high knowledge about sustainable development and (iii) are aware of their environmental responsibility within Sweden's building sector.

The stakeholders showed a strong commitment to an improved environmental work in that they: (i) desire to be positioned higher in the environmental work in the sector than they consider themselves to be today, (ii) realize their responsibility for the environmental work in the sector, (iii) realize that there is need for collaboration between the different stakeholders, (iv) consider it important to be visible in the debate of sustainable development and (v) consider that participation of environmental research is of high importance. However, the study also shows that to reach an improved environmental work in the sector, there is a need for a stronger pressure from the surroundings (e.g. laws, regulations or customer pressure).

The study shows that many of the stakeholders consider LCA-based tools for the built environment, such as the ELP, a good thing and they see many potential ways to use them (e.g. to compare energy solutions, to choose materials, to use in environmental annual reports, use in connection to the EU directive on energy performance of buildings and environmental labelling). At the same time, the preparedness to use them is relatively low (e.g. the tools are considered to be data and time intensive which is connected to high costs; there is a lack of standards on how to use the tools; a high level of knowledge is required to use the tools and their results). A reflective comment is that this is an educational process and the present work is part of that education.

A number of barriers that could mitigate a fruitful implementation and use of LCA-based tools in Sweden's building sector have been identified. We have found barriers between: (i) the current and the desired environmental work within the Swedish building sector, (ii) the knowledge of and the use of LCA-based tools and (iii) the developers of the tools and the potential users. Other barriers identified are especially connected to: (i) data (availability and credibility), (ii) costs, (iii) time, (iv) customer pressure, (v) knowledge and (vi) incentives. Our study has also revealed the following opportunities for increased use of LCA-based tools in Sweden's building sector: (i) different design of the tools for different actors and situations (e.g. focus on energy), (ii) combine LCA with LCC, (iii) involve environmental assessment in the implementation of the EU Directive on energy performance of buildings, (v) simplify input-data collection, (vi) improve environmental labelling and (vii) provide incentives.

The study shows that there are certain strong driving forces towards environmental sustainability in Sweden's building sector, but that altogether there is a need for a stronger pressure from the surroundings (e.g. laws, regulations or customer pressure) to drive the sector towards environmental sustainability. By establishing a dialogue with involved stakeholders, the value and importance of stakeholder participation has been highlighted, when developing a tool for assessing the environmental impact from the built environment. In this study, we have received many important opinions of LCA-based tools to take into consideration in the further development of the ELP.

5.3 Paper III

Brick, K., Frostell, B. (2008) Towards simplification of the Environmental Load Profile, Manuscript.

In the study, the following research questions were analysed:

- *How do LCA-based tools for the built environment in Sweden work today?*
- *Which are the main aspects in a life-cycle perspective contributing to the environmental load at a city district level and a building level?*
- *By what means can the ELP be simplified in order to facilitate the use of the tool and considering only a smaller amount of contributing environmental aspects?*
- *Does a simplified version of the ELP give accurate results?*

The study aimed at developing a simplified version of the ELP as a compromise between: (i) a natural science based demand of being accurate enough and (ii) a social science based demand of being user-friendly enough to become accepted and used in the construction area.

The paper is based on implementation studies in Hammarby Sjöstad (HS) (i.e. Levin et al, 2004; Levin et al, 2005; Brick, 2007), where the ELP has been used to follow up the environmental goals in HS and to illustrate the connection between the environmental goals and measures in the built environment (e.g. illustrate the value of changing the windows or the heating system of a building). In Levin et al (2005) and in Brick (2007) we have implemented a simplified input data collection routine for construction material data. The results in Levin et al (2004) and Levin et al (2005) were used to find by what means the ELP can be simplified in order to facilitate the use of the tool and considering only a smaller amount of important contributing aspects. The most important aspects to the environmental load in a life cycle perspective at a building level and at a city district level were identified and compared with values obtained for the full model, to secure that simplifications introduced would not distort the results in an unacceptable way.

The most important contributing aspects at a district level (i.e. materials during building level construction, electricity, heating, water and sewage during building level operation, working machines during real estate construction, and district level construction, materials, material transports, personal transports and transport of goods during district level operation) cover approximately 91-99 % of the total environmental load for every impact category and resource use. By including the most contributing aspects at a district level (approximately 50 % of the total amount of aspects) over 90 % of the total environmental load at a district level is covered. The most important contributing aspects at the building level (i.e. materials during construction, electricity, heating, water and sewage during operation) covers approximately 91-100 % of the total environmental load for every impact category and resource use. By including the most contributing aspects at the building level (approximately 60 % of the total amount), over 90 % of the total environmental load at the building level is covered.

A calibration of the ELP results at a building level was made through a comparison with literature data from assessments by use of similar methods. The ELP results for HS coincide with other studies for most impact categories, life cycle phases and indicators. A common characteristic of the differences in results between the ELP applied in HS and other methods is that the environmental load from the operation phase is lower and the environmental load from construction higher. The differences in results can be explained by: (i) that different kind of buildings were investigated in the different studies (e.g. office buildings, multi family dwellings, single family houses), (ii) the buildings investigated were of different size, (iii) different constructions (e.g. framework of steel, wood, lightweight concrete) were investigated, (iv) there were different thicknesses of thermal insulation in external walls and thermal performance of windows for the investigated buildings, (v) there were different locations of the buildings, (vi) different system boundaries were used, (vii) different LCI-data e.g. for electricity was used, (viii) there were significant differences in energy use for the buildings and (ix) there were differences in heat supply methods for the buildings (e.g. gas condensation boiler and district heating). Moreover, HS is a project where the city of Stockholm has imposed tough environmental requirements on e.g. technical installation in buildings. The influence of different LCI-data for electricity (e.g. Nordic, Swedish, different years) and district heating (e.g. Stockholm, Gothenburg, different years) on the results is something that has been illuminated in several studies (Adalberth et al, 2001; Forsberg et al, 2003) and also in implementation studies in HS and in other projects when using the ELP e.g. for environmental annual reports.

In order to get a social acceptance, we have involved different stakeholders in Sweden's Building sector in the development of the ELP. In Paper II (Brick et al, 2008) we studied what knowledge of and attitudes towards environmental assessment tools (especially LCA-based) different stakeholders have in Sweden's building sector. The stakeholder opinions taken into consideration when simplifying the ELP-tool were: (i) decrease costs and time for assessments, (ii) develop different varieties of the tools for different actors and situations (e.g. one more simplified tool and one more detailed) and (iii) simplify input data collection.

There are many different stakeholders and users of assessment results, which means that the tools must be able to communicate different stories to different stakeholders. In Brick et al (2008), different simplifications of the ELP-tool were required for different purposes, actors and situations. This means that the ELP-tool can be intact and thereafter be tailored for specific situations. A simplified version of the ELP (ELP-light) was developed for the application situation Lugnet containing:

(i) Materials used during construction at the building level
(ii) Operational electricity and heating at the building level
(iii) Water and sewage used during operation at the building level

ELP-light applied in Lugnet covers 92-100 % of the total environmental load at the building level for the specific case by using 57 % of total possible aspects. In the development of ELP-light, we have used some of the identified opportunities and bridged some of the identified barriers.

5.4 Related work

In addition to the work presented in the section above, the author has worked in implementation projects with the ELP-tool in e.g. Hammarby Sjöstad, i.e.: Levin et al (2005) *A follow up study of the environmental load in Hammarby Sjöstad, Sickla Kaj*; Brick (2007) *A follow up study of the environmental load in Hammarby Sjöstad, Lugnet*; Brick (2008) *A follow up study of the environmental load in Hammarby Sjöstad, Sickla Udde, Sickla Kaj and Lugnet, a summary report.* The purposes with these studies were to: (i) illustrate the importance of making environmental assessments as a part of the work to follow up environmental goals (e.g. national environmental goals (Swedish Environmental Objectives, 2008), local environmental goals (City of Stockholm, 2008)) as well as project specific environmental goals (Hammarby Sjöstad, 2008) and (ii) to illustrate the connection between the environmental goals and measures in the built environmental (e.g. illustrate the value of changing the windows or the heating system of a building). We have also developed a simplified input data sheet for construction materials, which has been used for Sickla Kaj (Levin et al, 2005) and Lugnet (Brick, 2007).

The author has also participated in the work with the ELP in connection to the City of Stockholm's homepage for environmental accounts of energy use, in cooperation with Stockholm's programme for ecological sustainable construction (The City of Stockholm, 2005) and has also worked in other projects using the ELP-tool (e.g. environmental annual reports for real estate companies and evaluation of applications for the City of Stockholms "Environmental Billion fund" where municipal administrations and companies have been able to apply for funding for a variety of environmental projects (The City of Stockholm, 2008)) at the consultancy company Grontmij AB (former Carl Bro AB).

6. Discussion

The field of building environmental assessment has matured remarkably quickly since the 1990:s and the past years we have witnessed a rapid increase in the number of assessment tools in use worldwide. The idea of LCA has now been generally accepted within the environmental research community (Cole et al, 2005). Whilst international standards (ISO 1998; 1999; 2000a; 2000b) are available and the methodology of LCA is becoming more established, there are still the contentious issues of the system boundary setting, choice of impact categories, data selection and allocation (Urie et al, 2004). Meaningful LCA assessment methods are usually data intensive and can involve strong efforts of collecting data and keeping it up-dated, particularly in a period of considerable changes in material manufacturing processes (Cole et al, 2005). The choice of the assessment tool can be decisive for the result (IEA, 2001; Brick et al, 2007). Whereas the public eye might be confused by such results variety and regard it being a weakness of environmental assessments as such, there is a necessity for a variety of tools from an analytic point of view (Trinius, 1999). However, the required level of knowledge to compare assessments made with different tools is relatively high, which makes the barrier to use the tools on a routine basis higher (Brick et al, 2007). LCA-based tools for the built environment are generally associated with uncertainty since the way ecological systems as well as social systems change in the future need to be considered. The world is changing and issues that are not considered as problems today may well be in the future, in the same way as today's environmental problems were not anticipated yesterday. Buildings are long-term investments and there are many possible things that can happen during a buildings life cycle. Moreover, it is difficult to motivate the use of LCA-based tools in the building sector. The temporary perspective of construction projects sometimes conflicts with the long-term principles of environmental sustainability. It has also been proven to be difficult to convince the actors (e.g. the contractors and the customers) about the value of environmental assessment tools and their use is therefore not required yet (WBCSD, 2007).

However, it is apparent that there is much room for improvement and for reducing the environmental impact in the building sector, but various barriers stands in the way. As I see it, there are possibilities to make improvements either in: (i) the upstream system, (ii) the core system or (iii) the downstream system (Figure 5).

(i) Improvements in the upstream system can be made e.g. through improved energy production (electricity and heating) and improved raw materials production.

(ii) Improvements in the core system can be made e.g. through improved construction and maintenance. The property developers and the property managers have the opportunity to install solar cells or heat recovery systems. We have also the opportunity to change the human behaviour. We have got a great potential to save energy, just by using less of it (e.g. lights and electronic equipment).

(iii) Improvements in the downstream system can be made e.g. through improved waste and wastewater management.

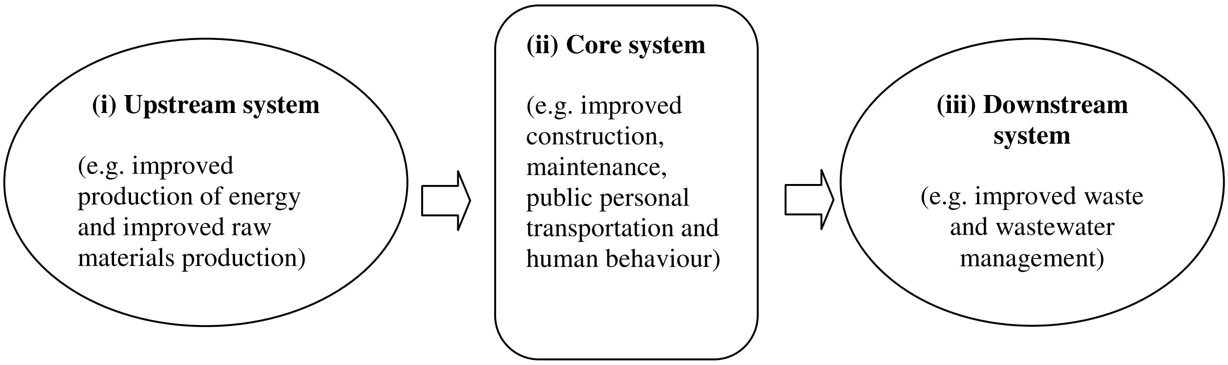

Figure 5. *Opportunities to reduce the environmental impact in the building sector in the upstream system, the core system and in the downstream system.*

Figure 6 shows the environmental load from the buildings within Sickla Udde (SU) compared to a reference scenario (Ref) in the beginning of 1990. The impact categories and resource use presented are: Extraction of Non Renewable Energy Sources (NRE), Water use, Global Warming Potential (GWP), Photochemical Ozone Creation Production (POCP), Acidification Potential (AP), Eutrophication Potential (EP) and Radioactive Waste (RW). The aspects analyzed were: Building Level Operation, Water and Sewage (BLO, W&S), Building Level Operation, Heating (BLO, Heating), Building Level Operation, Electricity (BLO, El), Building Level Dismantling, Materials (BLD, Mat.), Building Level Construction, Working Machines (BLC, Work. Mach.), Building Level Construction, Material Transports (BLC, Mat. Transp.) and Building Level Construction, Materials (BLC, Mat.). The environmental load profiles show improvements made in: (i) the upstream system (e.g. improved energy production), (ii) the core system (e.g. the property developers measures such as installation of solar cells, extra insulation, use of energy efficient windows with low U-values) and (iii) the downstream system (e.g. improved wastewater management).

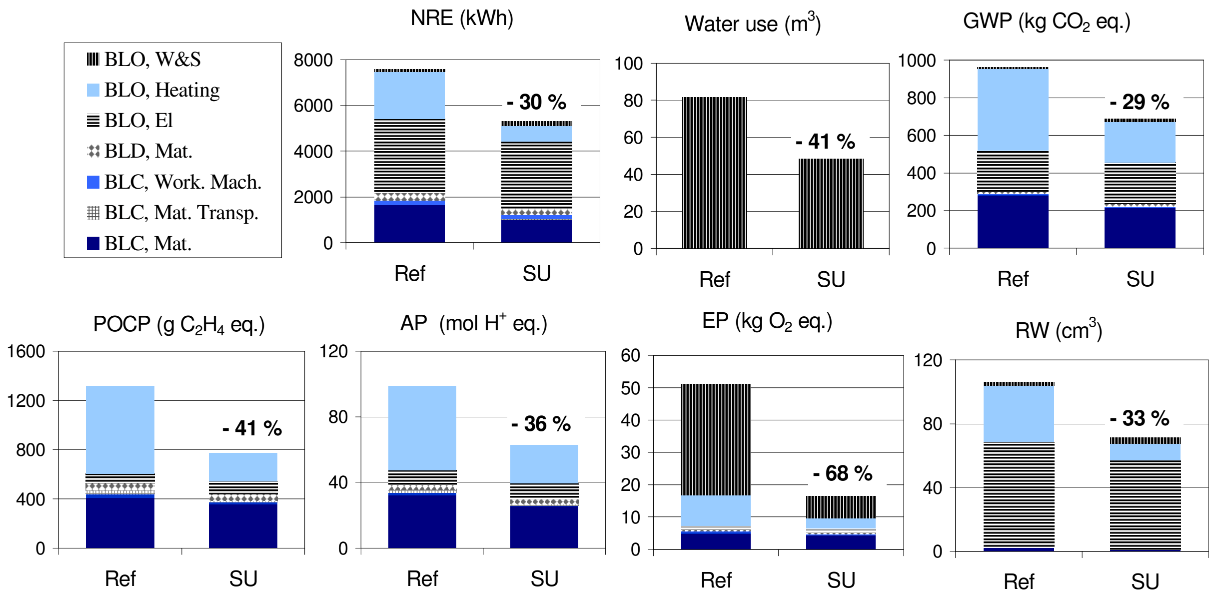

Figure 6. *Environmental load profiles per resident and annum for the buildings within Sickla Udde (SU) compared to a reference scenario (Ref), which should represent a recently constructed housing area from the early 1990:s. The environmental load profiles illustrate both the effect of the property developers measures and also the effect from e.g. improved energy production and wastewater management (Levin et al, 2004).*

Figure 7 shows the effect only from improvements made within the core system (i.e. the property developers measures). The improvements for Sickla Udde (SU) in relation to the reference scenario (Ref) is much better if we also take the improvements in the upstream system and the downstream system into consideration such as in Figure 6.

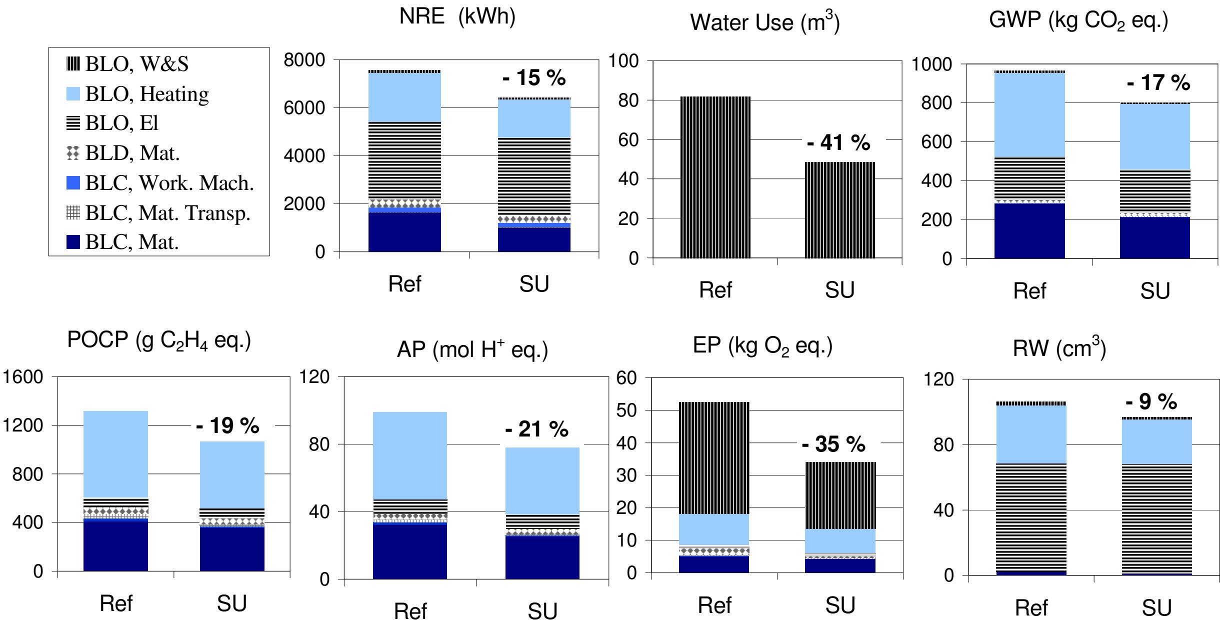

Figure 7. *Environmental load profiles per resident and annum for the buildings within Sickla Udde (SU) compared to a reference scenario (Ref), which should represent a recently constructed housing area from the early 1990:s. The environmental load profiles illustrate the effect of the property developers measures.*

When calculating the environmental impact from energy production (such as in Figure 6) it is important to be aware of the variations of fuels used for the production at different energy companies. Figure 8 shows the CO_2-emissions (LCI-data) from the district heating in southern Stockholm, for the reference scenario (average: 1988-1992) and for Sickla Udde (average 1998-2002) (Forsberg, 2003). This partly explains the much better improvement for GWP in Figure 6 (-29 %) compared to Figure 7 (-17 %).

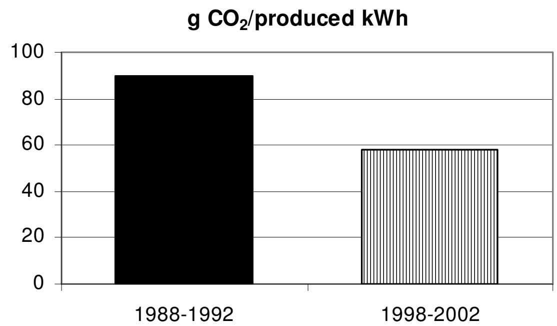

Figure 8. *CO_2-emissions per produced kWh district heating (LCI-data) for southern Stockholm (Fortum) average 1998-1992 and average 1998-2002.*

Figure 9 shows the variations of CO_2-emissions (combustion only) from six district heating producers in five different cities in Sweden year 2007 (Wikström, 2008; Andersson, 2008; Wågsäter, 2008; Zetterberg, 2008; Slovak, 2008; Lindqvist, 2008). There are differences in CO_2-emissions/kWh both between different years and different cities. One problem is that the different energy companies uses different system boundaries (e.g. Göteborgs energi calculates with zero CO_2-emissions for buying heat from burning waste and Eon Malmö calculates with CO_2-emissions from buying heat from burning waste (Andersson: 2008; Wågsäter, 2008)), Norrenergi calculates with their specific electricity supplier, Vattenfalls electricity mix (27 g CO_2/kWh) (Lindqvist, 2008; Vattenfall 2008) and Fortum uses a Nordic electricity mix (90,1 g CO_2/kWh) (Wikström, 2008). These variations have a significant influence on the results, when calculating the environmental load from buildings.

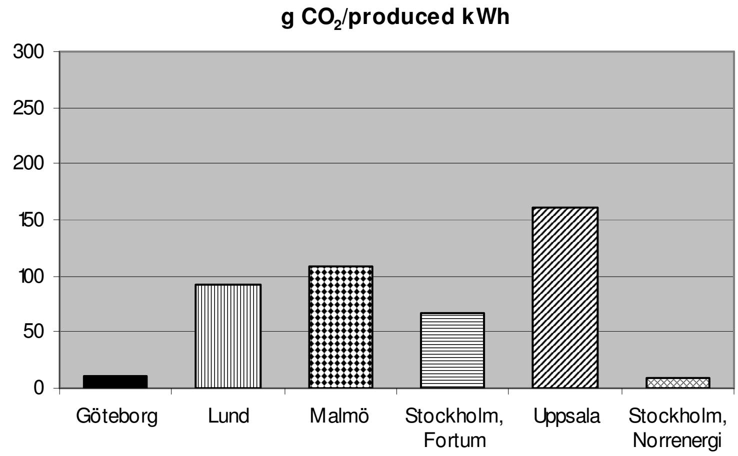

Figure 9. *CO_2-emissions per produced kWh district heating (combustion only) for six different production units in five different cities in Sweden, year 2007.*

In order to be better accepted, LCA-based tools must be better suited to different stakeholders. Different actors may need information at different parts of a building's life cycle. A distinction between active users of methods and tools and more passive users of the information generated by these tools can be made. While there are many different audiences and users of assessment results, different design of the tools are required for different actors and situations, simplifying communication of different stories to different actors (Cole et al, 2001). The widespread adoption of an environmental assessment method takes time. The requirement for stimulating demand may require some oversimplification at first in order to educate the market. After the market becomes more educated, a requirement for increased comprehensiveness can be introduced (Cole et al, 2001).

There are different ways to use LCA-based tools for the built environment and there are many different actors who can influence in different ways e.g. authorities through laws (Ministry of the Environment, 1987; 1998) and building policies (The City of Stockholm, 2005), architects and engineers in the programming and planning phase through choice of low environmental impact materials. The contractors can influence in the construction phase through the choice of locally produced materials. The capital providers (i.e. lenders or investors) should be concerned with the environmental risks and property developers should see the benefits with low operating energy costs. However, many developers are speculative developers which results in a short term focus on buildings financial value. On the other hand, developers who hold property to receive income from tenants have a longer term view and it is more likely that they will consider investments that may have paybacks over several years.

One aspect is to use environmental assessment tools to illustrate the aspects where the possibility to make changes are greatest, such as in Figure 6 and 7. These aspects are required to be highlighted, when using the tool as an indicator for improvements. If the tools are intended to be used as part of the environmental management system, as a help to set and to follow up environmental goals, it is important to highlight the sources to the main environmental impacts of the company.

If the intended user of the results are property managers, the essential issue is to illustrate the operational energy, because that is what the property manager has a great power to do something about and has the most significant contribution to environmental impact in a life cycle perspective (Adalberth, 2000; BYKR, 2001; Forsberg, 2003; Citherlet and Defaux, 2007). If the intended user is a property developer, it might be important to illustrate the connection between measures and the environmental impact from the built environment. The construction phase is also of high importance, e.g. by showing the environmental effects through a careful selection of low environmental impact materials (Cole and Kernan, 1996; Forsberg, 2003). However, the construction of new buildings only adds marginally to the total building stock (i.e. most buildings are already here). This means that the major improvements are going to come from existing buildings (Svane, 2006). The existing building stock in European countries accounts for over 40 % of the final energy consumption in the European Union member states (Balaras et al, 2007). End users are often in the best position to benefit from energy savings. However, tenants in Sweden do not pay for their own heating or hot water, which gives low incentives to save. Moreover, the tenants may not be in a position to make the necessary investments.

After working with the ELP for nearly four years, it seems to me that the awareness about: (i) the building sectors potential and responsibility to decrease the environmental impact, (ii) the life cycle thinking and (iii) environmental assessment tools is relatively high in Sweden's building sector. I consider that good environmental assessment tools already are available on the market today, but that they are not being widely used. There are a variety of barriers for an increased use in form of e.g. industrial structure and practices, incentives and costs. I believe that the kind of tools as illuminated in this thesis will get their greatest use in highlighting where in a project or a company the highest environmental impact occur, so that we make it possible to focus on the most important issues in our work. The tools will hopefully be used as part of environmental management systems in the work to set environmental goals. It is an easy way to get measurable goals and to priority the most important measures (e.g. where do our measures give the best result). I believe that there will be many tools such as the ELP on the market in some years and that these tools will be used in different ways by different actors in different situations. However, I believe that we have to be aware of the data quality within them so that we understand what we are assessing.

7. Conclusions

The overall aim of the thesis was to contribute to environmental sustainability for the built environment, by further developing the ELP. This was made by: (i) implementing the tool in different projects (e.g. construction projects) which increases the knowledge about environmental assessment tools and the life cycle thinking among different actors, (ii) involving stakeholders in Sweden's building sector in the refinement of the ELP, which also is broadening the knowledge base among those actors and which gives valuable input in the development of the ELP-tool and (iii) showing that it is possible to make a simplified environmental assessment of a building, by using less input data (e.g. less costs and time demanding) but to still get a truthful picture of the reality.

The five research questions as stated in section 3 can be answered as below:

1. *How do LCA-based tools for the built environment in Sweden work today?*

It is difficult to compare different environmental assessment tools with each other. Despite tackling the same analytical problem, there are limited parts that are comparable between the ELP and EE. The different approaches make it difficult to compare the results. Application of comparative parts on equal basis (i.e. the object specific data) give different results from the tools, because of different impact assessment and LCI-data. If the assessments are reported with full transparency, by showing the sources for uncertainty (such as background data) a higher credibility is reached. In the future, there is need for more data standardization work (both object specific-, LCI-data and calculation methods) to reach an even higher credibility and congruence between different tools. The required level of knowledge to compare, analyse and evaluate assessments made with the ELP and EE, is relatively high, which creates an educational barrier towards increased tool use.

2. *Which are the main barriers and opportunities for LCA-based tools?*

We have found barriers between: (i) the current and the desired environmental work within the Swedish building sector (ii) the knowledge of and the use of LCA-based tools and (iii) the developers of the tools and the potential users. Other barriers identified are especially connected to: (i) data (availability and credibility), (ii) costs, (iii) time, (iv) customer pressure, (v) knowledge and (vi) incentives. Our study has also revealed the following opportunities for increased use of LCA-based tools in Sweden's building sector: (i) different design of the tools for different actors and situations (e.g. focus on energy), (ii) combine LCA with LCC, (iii) involve environmental assessment in the implementation of the EU Directive on energy performance of buildings, (v) simplify input-data collection, (vi) improve environmental labelling and (vii) provide incentives.

3. *Which are the main aspects in a life-cycle perspective contributing to the environmental load at a city district level and a building level?*

The operation phase is the most significant phase for environmental load, for every environmental category examined at the district level. The most important aspects contributing to the environmental load in the ELP:s design, at the district level (i.e. materials used during building level construction, electricity, heating, water and sewage used during building level operation, working machines used during real estate construction, and district level construction, materials, material transports, personal transports and transport of goods used during district level operation) covers approximately 91-99 % of the total environmental load for every impact category and resource use.

The operation phase is the most significant factor for every impact category and resource use except for the POCP at the building level. The most contributing aspects in the ELP:s design at a building level (i.e. materials during construction, electricity, heating, water and sewage during operation) covers approximately 91-100 % of the total environmental load for every impact category and resource use.

4. *By what means can the ELP be simplified in order to facilitate the use of the tool and considering only a smaller amount of contributing environmental aspects?*

By including the most contributing aspects at a building level (approximately 60 % of the total amount), over 90 % of the total environmental load at a building level is covered. By including the most contributing factors at a district level (approximately 50 % of the total amount), over 90 % of the total environmental load at a district level is covered.

5. *Does a simplified version of the ELP give accurate results?*

A simplified tool (ELP-light) have been developed on the basis of: (i) the most important contributing environmental aspects in a life cycle perspective at a city district level and at a building level, (ii) results accuracy and (iii) different stakeholders in Sweden's Building sector responses on LCA-based tools for the built environment. In the development of ELP-light, we have used some of the identified opportunities and bridged some of the identified barriers in this thesis. The ELP-light is applied in Lugnet and covers 92-100 % of the total environmental load at a building level for the specific case, by using 57 % of total possible aspects.

8. Further research

There are different opportunities to reach environmental sustainability for the built environment (e.g. spatial planning, expansion of district heating, production and distribution of biogas, improved energy production (electricity and heating), improved construction and maintenance (e.g. install solar cells or heat recovery systems)). These different opportunities should be further investigated, in order to see which way the most effective way to decrease the environmental impact is, in building projects as well as for other projects. Finally, the interactions with the occupants are an important aspect to take into consideration in the future.

Establishing the ELP as a widely accepted tool for evaluation of environmental performance, requires more efforts such as: (i) improved help with collecting input data, (ii) further implementation studies using both simplified versions and the full version of the ELP in other city districts than Hammarby Sjöstad, (iii) implementation studies for different user situations in the building sector and (iv) a further dialogue with stakeholders.

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