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# Environmental footprint assessment of building structures: A comparative study

Rajib Sinha [a, *], Maria Lennartsson [b], Björn Frostell [a]

[a] Industrial Ecology, KTH Royal Institute of Technology, Stockholm, Sweden
[b] City of Stockholm, Stockholm, Sweden

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ABSTRACT

Following the failure to implement a rather sophisticated Excel-based environmental assessment tool, environmental load profile (ELP) in the Swedish construction industry, the City of Stockholm further developed a simplified version focusing on materials to make the tool user friendly and simple, aiming at educating stakeholders in the design phase of building construction. This study evaluated whether this simplified ELP of building structures (ELP-s) can be used directly or modified for use as a simple standard model for calculating the environmental footprint of building structures. ELP-s was compared with the two leading commercial LCA softwares, GaBi and SimaPro, based on two reference buildings: (i) a concrete and (ii) a wooden building, in order to examine the importance of material selection and the simplification of the tool. The results showed that the estimated energy footprint obtained using ELP-s was close in value to that produced by GaBi and SimaPro, but that carbon footprint was much lower with ELP-s. This great deviation in carbon footprint can be explained by the lower GHG emissions intensity per unit energy in Sweden compared with the world average or European average, the major data sources on which estimations in GaBi and SimaPro are based. These results indicate the importance of exercising care when applying commercial software tools to a specific situation in a specific country. They also indicate that the model should fit the purpose.



## 1. Introduction

Life cycle assessment (LCA) is a widely accepted analytical tool that provides a holistic environmental perspective on a product by assessing impacts and resources used throughout its life cycle [48,26]. Following a similar life cycle inventory (LCI) based approach as LCA, increasing use of *footprinting*, e.g., carbon footprint, has been observed [19,20,52]. Recently, the EU [18] proposed the environmental footprints of products, with the aim of harmonizing the LCA methodology. In the present study, environmental footprints were chosen in order to be semantically consistent with the EU proposal.

Environmental footprints of the built environment is an important issue for municipalities, developers and construction companies due to growing environmental awareness. The building sector, in Europe and globally, accounts for around 40% of the total energy use, more than one third of green house gas (GHG) emissions, 30% of raw materials use, 25% of water use, 12% of land use, and 25% of solid waste generation [5,50,51]. Therefore, the building sector needs to devote great attention to reducing its environmental footprints.

Life cycle thinking [22,30] in the building sector is increasing [7,11,17,31–33,35,44]. The life cycle of buildings can be divided into three important parts: construction, use/operational phase, and demolition. Many studies have found that the operational phase accounts for most of the environmental impact during a building's life cycle. For example, energy use in the operational phase of buildings is approximately 85% of the total [1,2,7].

Thormark [47] argues that the operational energy use in a building could be reduced by improving insulation and technical solutions and that with energy efficient solutions, the embedded energy in the building could account for 40% of the total life cycle energy. Since that study was published the construction sector has improved the energy efficiency of housing and, consequently, has

* Corresponding author. Division of Industrial Ecology, Department of Sustainable Development, Environmental Science and Engineering (SEED), KTH Royal Institute of Technology, Teknikringen 34, 10044 Stockholm, Sweden.
*E-mail address:* rajib.sinha@abe.kth.se (R. Sinha).
*URL:* http://www.kth.se

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significantly increased the share of embedded energy. Thormark [47] also estimates that substitution of materials used in buildings could decrease embedded energy use by approximately 17%. In addition, numerous studies report a significant effect on the environment of material choice during the construction phase [9,39,43,53]. Building materials – the materials used in a building body – are thus an increasingly important part of the overall environmental footprints of buildings.

In discussions on environmental footprints, a life cycle approach is increasingly used, i.e., taking into account all emissions to the environment, no matter where they occur. Historically, life cycle approaches to assessment of the built environment started in early 1990s [6], at that time generally in the form of different types of checklists and criteria analysis. More recently, a number of LCA based softwares/tools have been developed especially to assess the built environment, e.g., Athena [49], Building environment assessment tool (BEAT) [42], EcoEffect [3], Envest 2 [13], Environmental Load Profile (ELP) [21], Eco-Quantum [27], and Sustainable Building [15,16]. Several other softwares (e.g., SimaPro, GaBi) are available for calculating of environmental footprints/impacts in a life cycle perspective. A problem with these is that they require the purchase of costly licenses and involve much work to perform a life cycle assessment.

For use in its eco-village Hammarby Sjöstad, the City of Stockholm previously developed the so-called Environmental Load Profile (ELP) for Hammarby Sjöstad [6,21], an Excel-based analytical model that provides the environmental footprints of a building in a life cycle perspective. The tool has been used in many pilot cases [6,7,21], but the City of Stockholm has been facing difficulties in implementing the tool in practice [6,29,38]. This is because the tool is perceived as complex and, in some cases, too detailed for users' actual needs. Thus, a previous attempt to simplify the tool (ELP-light) was made based on important contributing aspects to buildings that could capture 92–100% of the environmental footprints [6]. ELP-light has not yet been successfully implemented [29,38].

The main barriers to implementation of ELP and of LCA-based tools are complexity, reliability of the tool, time, and costs [6,24,32]. Based on the benefits of material selection discussed above, a second attempt to further simplify the tool was made, with the aim of educating designers (e.g., architects) about environmental footprints of material selection and related transport. The present study focuses on this simplified ELP of building structures model, which could possibly also be used as an approximate model for calculating the environmental footprints of the construction of building structures. For simplicity, the simplified ELP of building structures (Fig. 1) is referred to as ELP-s hereafter in this study.

The aim of this study was to investigate and evaluate whether ELP-s of building structures can be used directly or refined for use as a simple standard model for calculating the environmental footprints of building structures. Specific objectives of the study were to:

- Compare ELP-s with SimaPro and GaBi, by performing the same calculations for reference buildings in SimaPro and GaBi to compare the database and the algorithms
- Compare two reference buildings – a concrete frame building and a wooden frame building – to determine the importance of material selection
- Evaluate the results and determine whether ELP-s can be used for standard calculations of the environmental footprints of building structures, possibly with minor changes.

## 2. Hammarby Sjöstad and ELP

Hammarby Sjöstad is a newly developed residential city district in Stockholm, Sweden, containing approximately 11,000 apartments and housing for approximately 35,000 people [28]. The development plan for the city district was initiated in the early 1990s because of the increasing housing demand in Stockholm [6,28].

During mid 1990s, some leading politicians in Stockholm were strongly interested in hosting Olympic games in 2004 [28] and suggested Hammarby Sjöstad as the site for the Olympic village. The Olympic committee specified priority for the environment in its call and thus inspired by the call and the Brundtland Report [8], the politicians of Stockholm decided to develop Hammarby Sjöstad as a forerunner for an ecologically sustainable city district [6,28,37]. Although Stockholm was not successful with its Olympic application, it was decided to continue development of Hammarby Sjöstad with its environmental program [37].

The environmental goal of city development was to reduce the environmental load by 50% compared with the average value in the reference situation of the city of Stockholm in 1990 [6]. To make the city district *twice as good*, the ELP tool was developed to follow up/monitor the environmental targets for Hammarby Sjöstad [6,7,21]. Fig. 1 illustrates the different levels (i.e., individual, household, building, estate, and district) and activities (i.e., construction, operation, and demolition) included in the ELP tool. ELP for the built environment (ELP-full) includes all the levels and activities. The simplified version of ELP (ELP-light) is based on the sub-activities contributing most to the environmental load and limits the tool to the building level (c.f., lighter background in Fig. 1). The tool was further simplified to ELP-s with the aim of educating stakeholders associated with the design and construction of buildings – property developers, consultant and architects, construction companies, constructors, and engineers. The

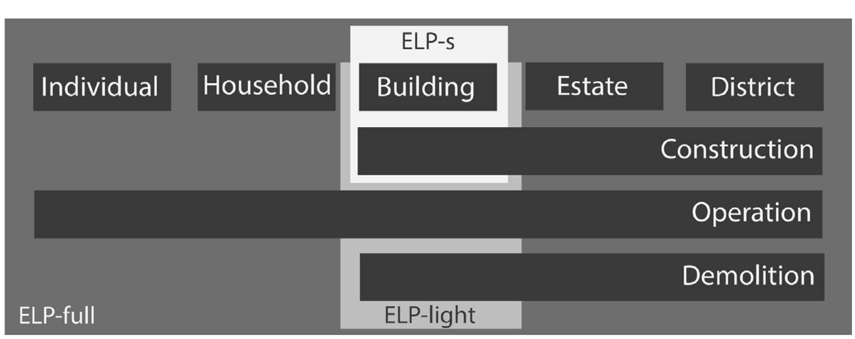


**Fig. 1.** The different activities and levels included in the ELP [6,7,21]. The dark background represents the full ELP, the lighter background the simplified version for building level, ELP-light. The white background represents the simplified ELP of building structures (ELP-s), which is tested in this study.