USE OF LCA AS A DECISION METHOD IN THE OPTIMIZATION OF CONSTRUCTION PROCESSES

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ABSTRACT

The paper reports on the use of Life Cycle Analysis (LCA) as a decision method in the selection of construction materials and optimization of construction processes. The main features of the method and the LCA tool used are outlined. A case study of a reinforced concrete wall cast in situ is presented. A sensitivity analysis was conducted by selecting different concrete constituent materials. The results clearly show their major influence upon the environmental parameters, and, in particular, energy use and global warming. The study also addresses the impact upon the environmental parameters of different relative location scenarios; however, this impact for the transportation of the various materials to the construction site is minor, when compared to that due to the production of the constituent materials. Cement is the single most important component in terms of environmental impact.

KEY WORDS

Life cycle analysis, decision method, construction products, construction process, concrete.

INTRODUCTION

Increasing environmental awareness has forced the industries and businesses to start assessing the impact of their activities upon the environment. When the concept of sustainable development (Our common future, 1987) was introduced, attention was gradually being focused on issues related to natural sources depletion and environment degradation. Environmental performance has become a key issue, and many companies have begun to investigate ways to minimize the effects on the environment of their activities (EPA, 2006). As a consequence, life cycle analysis (LCA) has emerged as one of the preferred tools to assess environmental impact of a selected product. The method encompasses all stages of a product's life, including raw materials selection, production, use and disposal.

LCA is an objective procedure to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to identify and implement opportunities yielding environmental improvements.

LCA evaluates all stages of a product life from the perspective that they are all interdependent, i.e. each stage is strongly interlinked with all other stages of the product life. Therefore, it enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle. A comprehensive view of the environmental aspects of the

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product or process and a more accurate picture of the true environmental trade-offs in product/process selection can be provided.

An inventory of relevant energy and material inputs and environmental releases has to be compiled during LCA. Further, potential environmental impacts associated with identified inputs and releases have to be evaluated. Last, the results and their proper interpretation will help the producer make a more informed decision.

The term »life cycle« refers to the major activities in the course of the product’s life-span from its manufacture, including the raw material acquisition, use, maintenance to final disposal.

The method helps the decision makers select the products or processes that result in the least impact to the environment. This information can be used with other factors, such as cost and performance data, to select a particular product or process.

STEPS IN LIFE CYCLE ANALYSIS

The LCA became standardized with the introduction of the international standards ISO 14040 (1997), ISO 14041 (1998), ISO 14042 (2000) and ISO 14043 (2000). The standard analysis contains the following steps:

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Interpretation

Life Cycle Inventory (LCI) involves tracking of all flows in and out of the system of interest – raw resources or materials, energy by type, water, emissions to air, water and land by specific substance (Trusty and Horst, 2002).

LCA IN CONSTRUCTION

The LCA methodology had its origin in the metallurgical industry where large amount of energy and raw materials are used for the production of various metallic products. Over the years, it has been increasingly used in the production of consumer goods; however, it has not been widely used to analyse construction products and building production and use. In this area the research carried out is still embryonic, and the available has been limited and in this field and the published work is very limited in number (e.g. Schuurmans et al 2002; Josa et al, 2004; Schmidt et al, 2004; Nixon et al 2004; Treloar et al 2004), as revealed by an extensive literature search.

Worldwide, it is estimated that approximately 40% of the total energy consumed, 40% of all the waste produced, and 40% of all virgin raw materials consumed are associated with the building/construction sector. In today's world, only consumption of water is larger than the total production of petrous materials to be further used in construction. A rational method, such as LCA, leading to the minimization of the use of the above mentioned raw material resources and the inherent environmental impacts should be extremely beneficial to the final product of the construction industry, while ensuring sustainable development of the sector.

In contrast with the products for wide consumption, buildings are designed and constructed for a long service life, typically 50 years - the specified service life depends very much on the importance of the building. A building is a complex product that consists of many building products, which are permanently built in (Construction Product Directive, 1987) with a relatively long production period. Therefore, a life cycle analysis can be applied to a whole building, taking it as a product.

METHODOLOGY

LCA tool developed by the European Ready-Mix Concrete Association (ERMCO) was employed to assess the applicability of the LCA for production of reinforced concrete structures. Several LCA methodologies are embedded in the program: CML2001 (Guinée, 2001), EDIP (Wenzel et al, 1997) and Eco-Indicator (Goedkoop et al, 2001). All these methodologies meet the ISO 14042 requirements, and although they are still in their development stage, they are becoming recognized throughout Europe.

The tool was developed specifically for analysis of concrete and reinforced concrete elements, which are incorporated in the building. It is not intended for the analysis of the building and its performance during its use. Consequently, data regarding the building type, design, service life planned and environmental performance are not a part of the tool's input. Even so, different end-of-life scenarios and levels of recycling can be projected in the analysis.

Material and energy flow in the Life Cycle Analysis is schematically presented in Fig. 1.

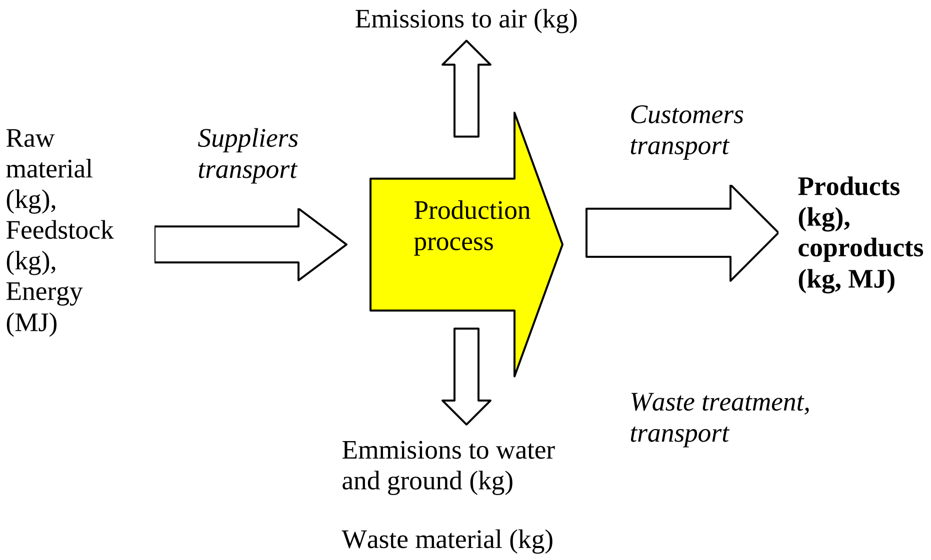


Figure 1: Materials and energy flow according to the CML2001 methodology (Meijer, 2003)

CASE STUDY

The Procedure

As an illustration of the procedure, a cast in situ reinforced concrete wall was analyzed by using the CML2001 methodology (Guinée, 2001). The production of the wall is schematically presented in Fig. 2.

The concrete plant supplying concrete to the construction site, where the wall is being constructed, is 100 km away from the site (distance B, Fig. 2). Reinforcement is supplied from a plant also 100 km away from the site (distance A, Fig. 2). Trucks with varying capacities are employed to transport the constituent materials to the concrete plant, and reinforcement and fresh concrete to the construction site. The distances from the concrete plant to aggregate producer (quarry), production of cement and additives (plasticizers) and other data defining the reference case, such as concrete mix design, end-of-life scenario and final waste treatment are collected in Table 1.

The complete results obtained by using LCA are presented in Table 2. It can be seen that the largest environmental impact emerges from the cement; 48% of all used energy and 68% of CO_2 emitted stems from its production. The results also indicate the second largest environmental impact is generated by the transportation by truck, when taken as a single group.

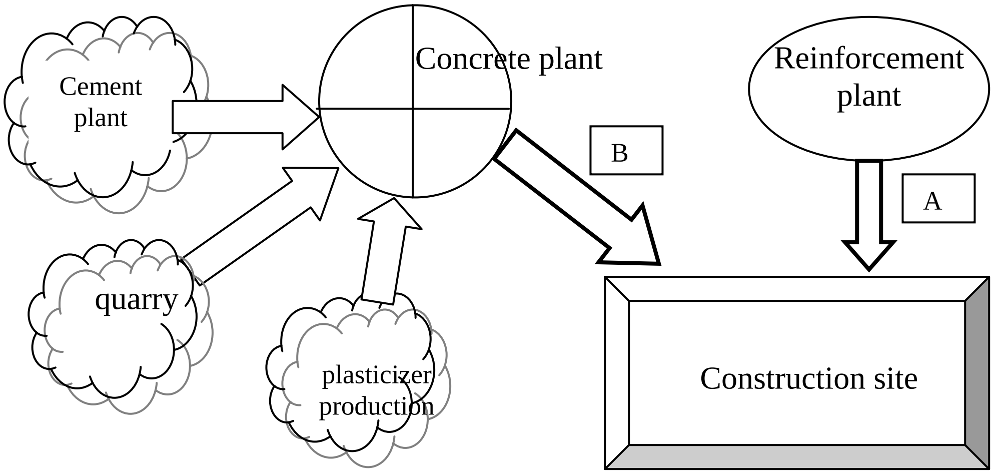


Figure 2: Schematic presentation of cast in suit reinforced concrete wall production

Table 1: Input data for the life cycle analysis of reinforced concrete wall cast in situ

Functional unit	**Quantity**	**Quant. / m^2**
Area	1 m^2	
Corresponding mass	0.508 t	
Concrete mix		
CEM I 52.5	**365** kg/m^3	73 kg
Cement transport (truck)	**100** km	
Coarse aggregate	**800** kg/m^3	160 kg
Fine aggregate	**1200** kg/m^3	240 kg
Plasticizers (truck 28 t)	**80** km	
Plasticizers	**3.3** kg/m^3	1 kg
Transport of plasticizers	**250** km	

Reinforcement	**45** kg/m^3	9 kg
Reinforcement transport	**100** km	
Water	**125** l/m^3	25 kg
Truck 28 t (transport)	202 t km/m^3	40 t km
Life cycle - construction		
Reinforced concrete wall	1	508 kg
Transport to site		
Truck 40 t	**100** km	
Truck 40 t	50.8 t km	50.8 t km
Demolition		
Demolition		508 kg
Final waste treatment		
Waste concrete	**5** %	0.025 t
Recyclable concrete	**95** %	0.474 t
Waste steel	**5** %	0 t
Recyclable steel	**95** %	0.009 t
Truck 28 t (transport to	**25** km	12 t km

Table 2. Contributions of individual processes and materials upon environmental impacts during the life cycle of a reinforced concrete wall

	Energy (MJ)	**Human toxicity (kg 1.4 DB)**	**Abiotic source depletion (kg Sb)**	**Acidification (kg SO_2)**	**Climate change (kg CO_2)**
Cement	456.250	2.365	0.424	0.134	65,554
Aggregate	12.200	0.074	0.054	0.004	0.596
Plasticizers	4.244	0.055	0.026	0.006	0.256
Reinforcement	83.430	5.922	0.338	0.028	4.266
Water	0.000	0.000	0.000	0.000	0.000
Transport – constituent materials	83.959	1.025	0.848	0.054	6.337
Production	65.996	0.376	0.640	0.017	3.807
Transport to site	64.473	0.782	0.650	0.042	4.858
Construction	12.336	0.151	0.125	0.008	0.934

Maintenance	0.000	0.000	0.000	0.000	0.000
Demolition	104.070	1.005	0.985	0.047	6.701
End-of-life scenario	58.379	0.566	0.515	0.022	3.512
Total	945.337	12.321	4.605	0.361	96.822

The indicator results presented in Table 2 are expressed in conformance to the methodology of CML2001 ((Guinée, 2001). The units employed are therefore kg of the reference resource antimony (Pb) for abiotic depletion potential, kg 1.4 DB (dichlorobenzene) equivalent for toxicity, kg SO_2 equivalent for acidification, and kg CO_2 equivalent for global warming potential.

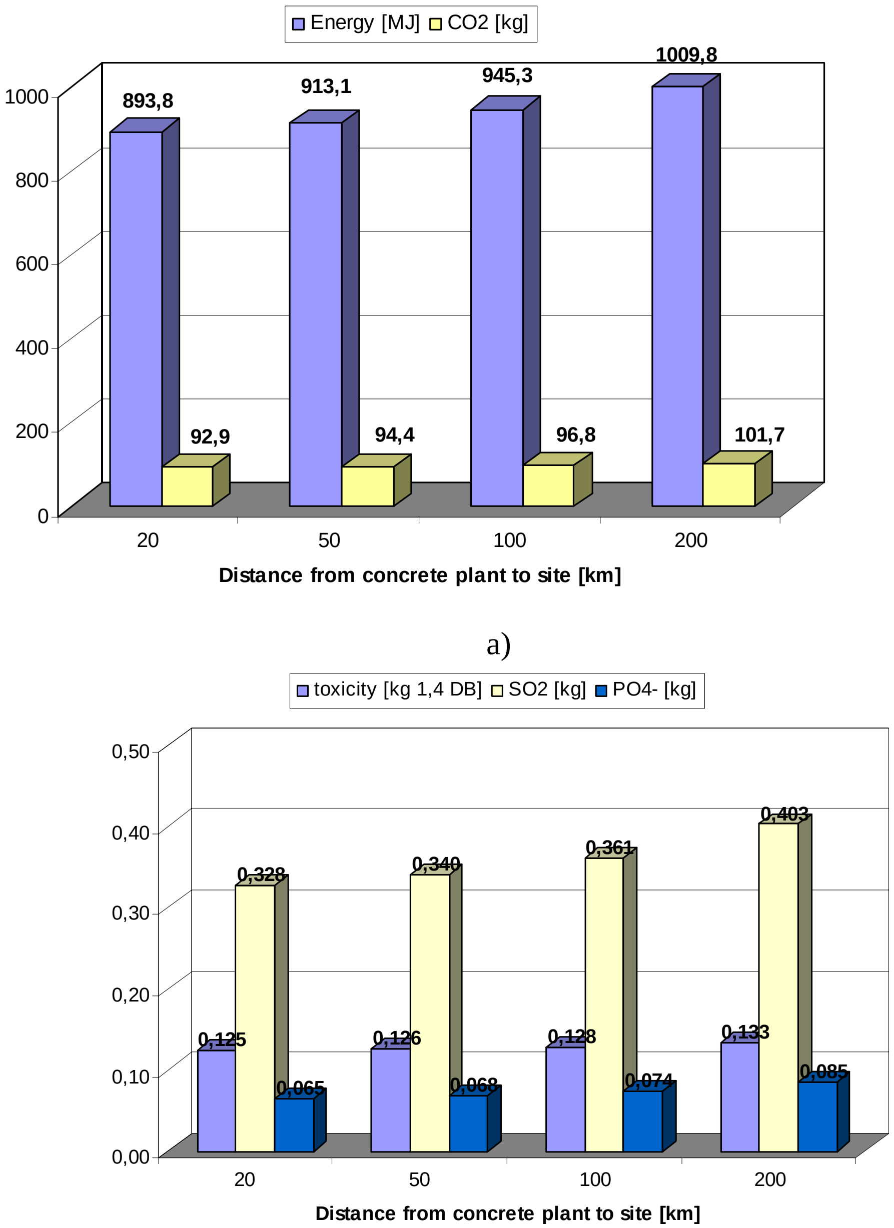
SENSITIVITY ANALYSIS

A sensitivity analysis was carried out for the following parameters: the distance between concrete plant and construction site (Fig. 2, distance B), concrete mix design, degree of recycling, and end-of-life scenario.

The influence of transport distance from the concrete plant to site was evaluated at 20, 50, 100 and 200 km. The last option, due to the hardening of concrete with time, is not desirable as it can lead to diminished quality of concrete placing. It was chosen just for the purpose of assessing the influence of the transport distance. The results obtained are reported in Fig. 3.

The results presented in Table 2 clearly show the dominant influence of cement on the overall environmental impact of the reinforced concrete wall. The sensitivity study was therefore conducted for two different concrete mixes containing different cement types in different quantities. Concrete mix design employed in the analysis is presented in Table 3. Cement Type I (CEM I) used in the reference mix is replaced by Type II (CEM II), which contains up to 20% of supplementary cementing materials. The two mixtures have approximately equivalent compressive strength of concrete; therefore, the bearing capacity of the wall does not change due to the concrete mixture design change.

The comparison between the two concrete mix designs, CEM I and CEM II, respectively, is presented in Fig. 4 for energy usage, CO_2 and toxic substance emissions. The results of the simulation reveal a significant reduction of energy consumption in the production and disposal of the concrete wall, when built with CEM II cement type; this is due to the increased content of mineral additives in this cement that do not require high temperature kiln-burning. In what concerns climate change impact, i.e. CO_2 production, CEM I and CEM II yield practically identical results; however, CEM II has lower terrestrial ecotoxicity (0.087 vs. 0.128 kg 1.4 DB) and slightly higher acidification (0.411 vs. 0.361 kg of SO_2) than those of CEM I.



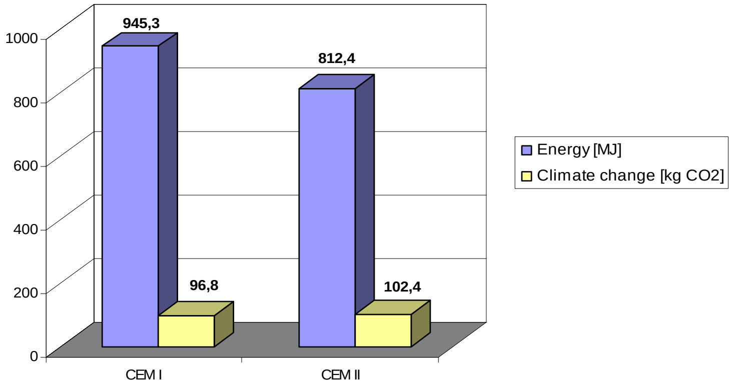
a)

b)

Figure 3: Influence of the transport distance from the concrete plant to the construction site upon a) used energy and CO_2 production, b) toxic substance emmission to the ground, water and air.

Table 3: Concrete mix design used in sensitivity analysis to assess the influence of cement type.

	Reference case mix design (CEM I 52.5 Europe)	Changed mix design (CEM II/A-L 32.5R Europe)
Cement	365 kg/m^3	410 kg/m^3
Coarse aggregate	800 kg/m^3	960 kg/m^3
Fine aggregate	1200 kg/m^3	790 kg/m^3
Plasticizers	3.3 kg/m^3 (plastifikator)	6.1 kg/m^3 (superplastifikator)
Water	125 l	175 l



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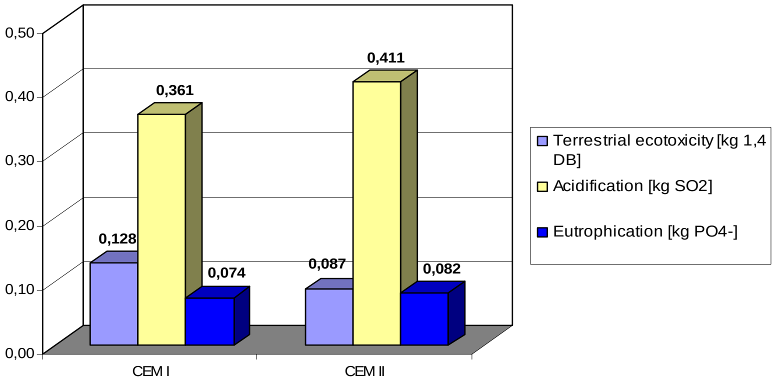

b)

Figure 4: Influence of concrete mix design upon a) used energy and CO_2 production, b) toxic substance emmission upon ground, water and air.

DISCUSSION AND CONCLUDING REMARKS

The analysis for the base case of a cast in situ reinforced concrete wall using the CMLCA methodology reveals that cement is the leading single component in what concerns environmental impact in all categories considered, namely: energy usage, human toxicity, abiotic resources, acidification, and climate change. It is interesting to note that in terms of energy usage demolition is second only to cement (104.1 vs. 456.2 MJ). The combined transport component is, when all the categories are considered and after the cement, the one with the largest environmental impact. This result is not unexpected taking into account the relatively large value (100 km) selected for the distances A and B. It is surprising, however, to note that reduced distances do not lead to significant reductions of toxic substance emissions. On the other end, the energy usage decreases with decreasing distances, however, the predictions correctly indicate that there is no direct proportionality between the two variables, as the energy usage per km traveled decreases with the increased distance. The sensitivity analysis also serves to demonstrate the ability of selecting the construction material, in this particular case cement mix, based on the LCA methodology. The two mixes, CEM I and CEM II, although with different compositions, yield similar results with an advantage of 14% in terms of energy usage for CEM II, but yielding a 13.8% increase in acidification. Obviously, with the guidance of the LCA methodology, different mixes with similar strength can be designed to yield reduced environmental impact.

The proposed procedure and the case study used for its illustration clearly indicate the potential of LCA as a decision tool in what concerns buildings, and, in particular, building components. The designer can make an educated choice when selecting the best-suited construction material, while the planner can use as a component of the decision process the environmental impact due to the relative distances of the suppliers.

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