Achieving Sustainability in Construction

Edited by

Ravindra K Dhir

Thomas D Dyer

Moray D Newlands

Achieving Sustainability in Construction

Proceedings of the International Conference
held at the University of Dundee, Scotland, UK
on 5-6 July 2005

Edited by

Ravindra K. Dhir
Director, Concrete Technology Unit
University of Dundee

Tom D. Dyer
Lecturer, Concrete Technology Unit
University of Dundee

and

Moray D. Newlands
CPD/Consultancy Manager, Concrete Technology Unit
University of Dundee

Thomas Telford

CONTENTS

Opening Paper

THEME 1 EFFICIENT USE OF ENERGY AND RAW MATERIALS

Keynote Paper

THEME 2 POLLUTION, WASTE AND RECYCLING

Keynote Paper

THEME 3 MINIMISING ENVIRONMENTAL IMPACT

Keynote Paper

THEME 4 ENVIRONMENTAL ENGINEERING WITH CEMENT AND CONCRETE
Keynote Paper

Closing Paper

Late Paper

Keynote Paper

ENVIRONMENTAL ASSESSMENT OF CEMENT BASED PRODUCTS: LIFE CYCLE ASSESSMENT AND THE ECOCONCRETE SOFTWARE TOOL

A Josa

R Gettu

A Aguado

Technical University of Catalonia

Spain

ABSTRACT. Life Cycle Assessment (LCA) is an essential tool for the quantitative evaluation of the impact of a product on the environment. Since this impact can occur in any stage of its life cycle (from the mining of raw materials to ultimate disposal), its whole life has to be considered. The basic features of LCA are an inventory (LCI) of environmental interventions (inputs and outputs of energy and materials used, emissions produced, etc.) and the assessment of their effect (LCIA) in terms of different potential environmental impacts (greenhouse effect, ozone layer, acidification or depletion of raw materials and energy, among others). LCA can be used for a number of purposes, including the environmental improvement of processes and materials, the comparison of products, or for eco-labelling. For conducting LCA studies, specific software must be used; a recently-developed program is the EcoConcrete software, compiled by the European concrete-related industries. In this paper, the main aspects of the application of LCA to concrete products are presented, including a brief description of the methodology used, some examples of application and the EcoConcrete software.

Keywords: Life cycle assessment, Cement, Concrete, Environmental impact, LCI, LCIA

Dr Alejandro Josa is a Civil Engineer and Professor of Geotechnical Engineering in the School of Civil Engineering, Technical University of Catalonia (UPC). His research interests include cement utilisation, environmental impact of construction products and modelling of concrete behaviour.

Dr Ravindra Gettu is a Senior Researcher in the Department of Construction Engineering of the UPC. His research interests include concrete technology, self-compacting and fibre-reinforced concretes, and nonlinear behaviour of concrete.

Dr Antonio Aguado is a Civil Engineer and Professor of Concrete Technology in the School of Civil Engineering, UPC. His research interests include technology transfer, concrete technology and dams.

INTRODUCTION

The limitation of available resources, the importance of protecting nature and the need to reach sustainable development makes the evaluation and minimisation of the environmental impact of any activity increasingly important [1, 2]. This is also the case in the design, manufacturing and use of construction products. The undeniable economic importance of the construction sector [3] occurs along with significant environmental impacts. Examples of such impact are the consumption of renewable or non-renewable resources, air and water pollution; energy consumption during product manufacture and maintenance, and waste generation as a consequence of the demolition of different types of installations [4].

Besides these negative impacts, it is important to underline the positive effects of the construction sector on the environment, in terms of the contribution to the improvement of the habitability conditions, control of the spreading of diseases and protection against aggressive climatological agents or natural phenomena, among other aspects [5, 6]. Along with bearing in mind the impact caused, it is necessary to evaluate it quantitatively. The most suitable tool currently available for such evaluation is Life Cycle Assessment (LCA), which is briefly described in the following section.

LIFE CYCLE ASSESSMENT OF PROCESSES AND PRODUCTS

The life cycle assessment (LCA) methodology permits the evaluation of the environmental effects of a process or product, considering all the stages in its production from the extraction of resources to the processing of the wastes derived from it [7]. "This includes identifying and quantifying energy and materials used, and the wastes released to the environment, assessing their environmental impact and evaluating opportunities for improvement" [8, 9]. Obviously, there will always be certain limits in the phases considered, which must include the most relevant ones. This is not feasible with specific processes, such as the manufacturing of a specific element, or with intermediate products, such as cement or concrete, which have many subsequent applications. In these cases, the analysis ends in the considered process or in the manufacturing of the product ('gate to gate' or 'cradle to gate'). The ISO 207 Technical Committee is currently developing international standards for environmental management, and the committee LCA SC4 deals with LCA.

Figure 1 (adapted from [5] and enlarged) displays the generic life cycle of a concrete product. As seen in this figure, the life cycle begins in the acquiring of raw materials and ends when the product is dumped as waste or else when it is intended for other uses. In between, there are all the phases that the product goes through and where impacts on the environment can occur, including all the possible intermediate transportation phases.

The complete life cycle of a product includes phases that could be named "constructive" (i.e., manufacture, use, maintenance) and phases that could be named "deconstructive" (i.e., reuse, demolition, recycling). The concept of "deconstruction" is becoming increasingly important, since it facilitates the utilisation of previously-used materials and the reduction of the impact that their re-use, recycling or down-cycling may imply. In "pure" deconstruction, the process to follow would be the opposite of the process used in construction. Figure 2 shows the constructive and deconstructive phases of a product life, with a specific conception phase included both in construction and in deconstruction. Only by considering, from conception, that the products should minimise their global impact and be reintegrated in the environment, will it be possible to succeed in optimising these totally from this viewpoint.

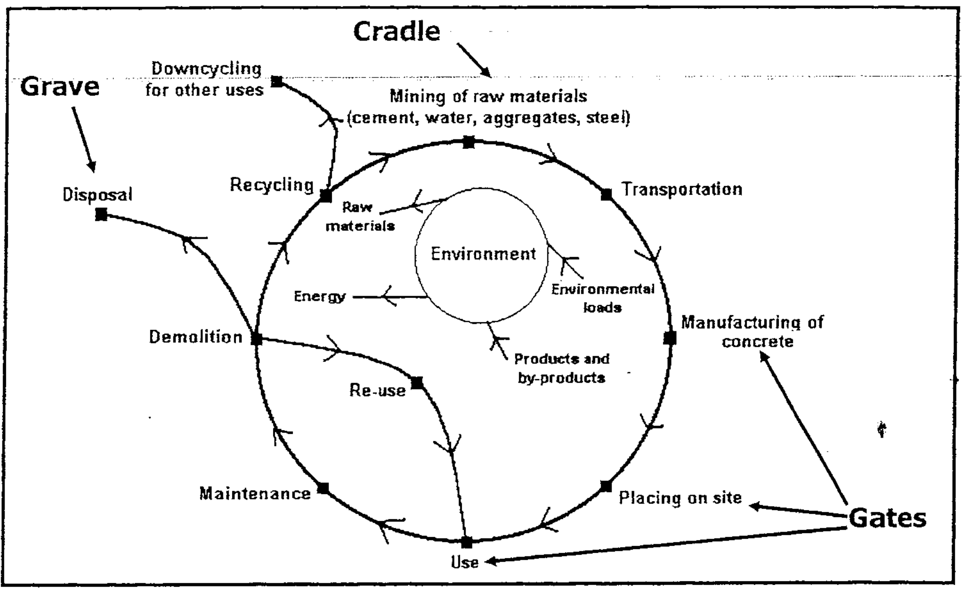

Figure 1 Generic life cycle of a concrete product

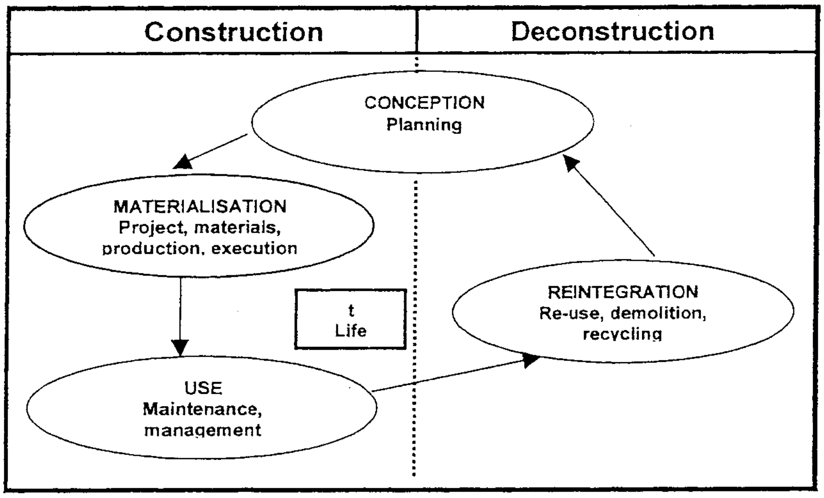

Figure 2 Phases in the generic life cycle of a product

The absence of a single environmental unit for different environmental loads (i.e., consumption of raw materials, emission of CO_2, water and air pollution, etc.) implies that the result of a LCA is made up by a series of values corresponding to each impact considered. Nevertheless, in some cases, using criteria in which social or political preferences must be assessed, such values may be reduced to just one. Generally speaking, this implies that, whenever alternatives are compared, the result cannot be definite if one or more alternatives have some, not all, higher impacts than the others.

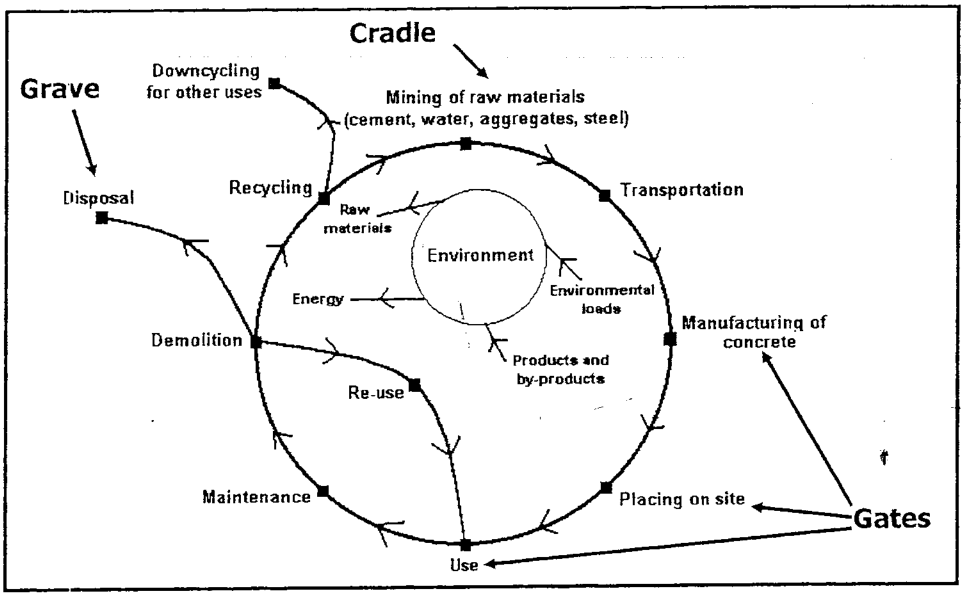

Figure 1 Generic life cycle of a concrete product

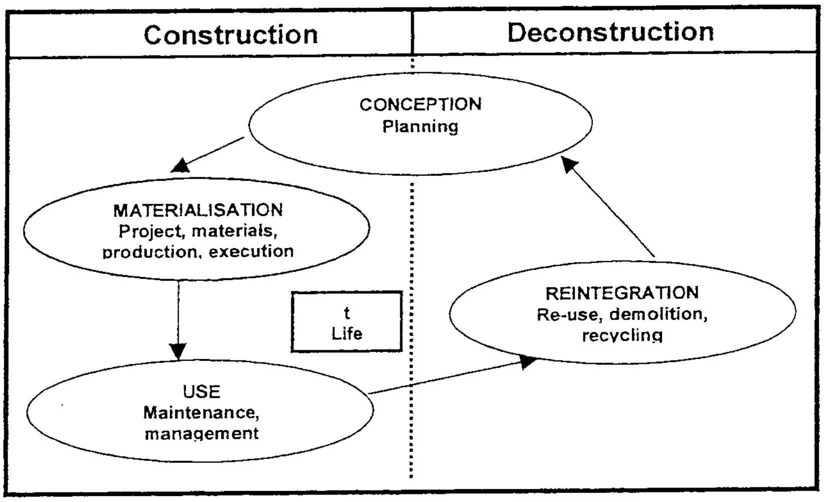

Figure 2 Phases in the generic life cycle of a product

The absence of a single environmental unit for different environmental loads (i.e., consumption of raw materials, emission of CO_2, water and air pollution, etc.) implies that the result of a LCA is made up by a series of values corresponding to each impact considered. Nevertheless, in some cases, using criteria in which social or political preferences must be assessed, such values may be reduced to just one. Generally speaking, this implies that, whenever alternatives are compared, the result cannot be definite if one or more alternatives have some, not all, higher impacts than the others.

LCA may be used, mainly, as an environmental analysis tool in order to improve industrial processes or to compare alternative processes or products, or else as a tool for environmental management to guide the development and research of new products and processes (i.e., granting of eco-labels, setting-up of environmental basis for comparison, etc.). On the other hand, LCA provides a common framework of reference to systematise the terminology and the methodology used, and to compare environmental surveys of different origins.

The fact that, at the moment, LCA is not totally standardised is a distinctive disadvantage since different methodologies [10-14] may lead to contradictory results if different hypotheses (i.e., system boundaries, time and location, etc.) are adopted [15]. In spite of these inconveniences, LCA has a great advantage: it is generally accepted by the different parties involved (i.e., administrations, NGOs and ecological organisations, the industry, etc.).

Usually, a LCA is composed of the following basic phases:

a) Definition of the objective and the scope of the survey [7] including system boundaries (i.e., phases included), and the origin and accuracy of data, among other aspects.

b) Inventory (LCI): In this phase, all the environmental interventions of the system (i.e., consumption of materials and energy, emissions, waste, etc.) are compiled [7], resulting, in general, in a very long list of figures (Figure 3 shows a relatively short example).

c) Impact assessment: The environmental interventions of the inventory are classified, characterised and normalised during this phase [17], and the results are duly added in different impact categories (i.e., consumption of resources, greenhouse effect, acidification, toxicity, etc.) after having applied the corresponding coefficients based on scientific evidence (i.e., comparison of the effects of different environmental interventions). In some cases, a single final value is obtained [18, 19] using assumptions based on social or political criteria.

d) Analysis of results and conclusions.

EXAMPLES OF APPLICATION OF LCA ON CONCRETE PRODUCTS

The Zaltbommel Road Bridge

This case, presented in [5] and [20], compares the environmental impact of two alternative bridges through the CML methodology [10]. The study was commissioned by the Dutch national highways authority and conducted by the University of Amsterdam. The proposed road bridge was planned across the River Waal, about 20 km north of Hertogenbosch, in The Netherlands. This bridge had to meet growing road traffic in the motorway and was intended to replace the existing steel bridge built in 1933.

Figure 4 shows a summary of the results obtained. In this figure the value of 100% has been given, for each impact category, to the worst alternative (concrete or steel), and the corresponding relative value (<100%) has been given to the other one. This way of representing LCA results does not allow the comparison of the relative importance of each impact category but provides the quickest way to see the results. It can be seen in this figure the good results of the concrete solution except in the depletion of natural resources. The latter result is due to the scarcity of some resources in The Netherlands. Taking into account these results, the Dutch authorities finally selected and constructed the concrete bridge.

Railway sleepers

This case is presented in [5] and [21], and compares the environmental impact of two alternative solutions for railway sleepers through the CML methodology [10]. The study was commissioned by the environmental office of the Dutch Railways and conducted by external consultants. Since 1950s, The Netherlands have used both prestressed concrete (about 35% of all sleepers) and treated timber sleepers. Since the Dutch Railways replaced sleepers on about 200 km of track every year, in addition to the construction of new tracks, the authorities were interested in using the best solution from the environmental viewpoint.

LCI	
Use of natural resources and materials	
Limestone	Slags
Clay	Explosives
Gypsum	Water
Iron oxides	Etc.
Natural gas	Diesel
Heavy fuel oil	Crude Oil
Coal	Biomass
Petcoke	Etc.
Emissions	
Particules	Hg
CO_2	Cd
CO	Tl
NO_x	Sb
SO_2	As
N_2O	Pb
HC	Cr
NH_3	Co
HCl	Cu
HF	Mn
CH_3	Ni
VOC	V
COD	Sn
Wastes	Etc.
Other	
Energy	Noise
Area	Etc.

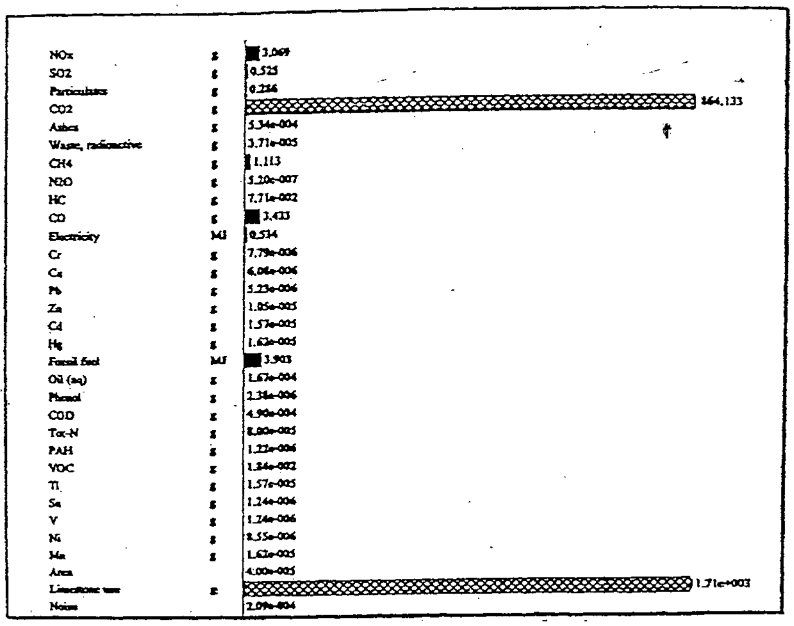

Figure 3 Environmental interventions for cement (left, [16]) and LCI for 1 t of cement (right)

Table 1. Example of impact categories [14]

IMPACT CATEGORIES			
Global warming	Photochemical smog	Human toxicity air	Hazardous waste
Ozone depletion	Ecotoxicity water chronic	Human toxicity water	Radioactive waste
Acidification	Ecotoxicity water acute	Human toxicity soil	Slags/ashes
Eutrophication	Ecotoxicity soil chronic	Bulk waste	Resources (all)

Figure 5 shows a summary of the results obtained, with the same format as in Figure 4. It can be seen that the concrete solution also has good results except in the depletion of natural resources, for the same reason as in the previous case, and in non-chemical waste. The negative effects of the timber sleepers are largely due to the creosote treatment.

External Sewer

This case is presented in [22]. It analyses the environmental behaviour of an external concrete sewer and compares the results with those of several alternative solutions (i.e., three types of PVC and vitrified clay). The study was commissioned by the industrial sector and was conducted by Intron. In general, all results were favourable to the concrete solution. Figure 6 shows a summary of these results in the same format as in the previous cases.

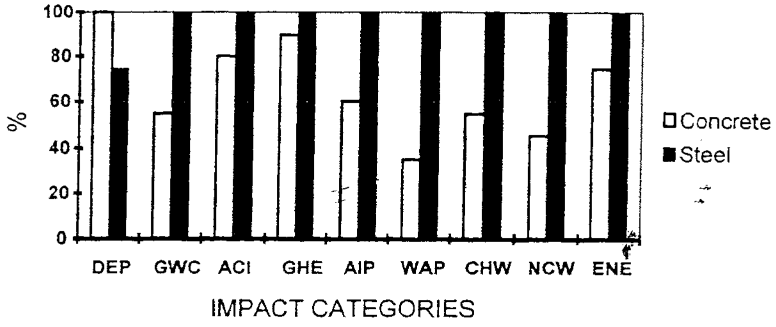

Figure 4 Results for the Zaltbommel road bridge [5, 20]
(DEP: depletion of non-renewable natural resources; GWC: groundwater consumption; ACI: acidification; GHE: greenhouse effect; AIP: emissions to air; WAP: emissions to water; CHW: chemical wastes; NCW: non-chemical wastes; ENE: energy consumption)

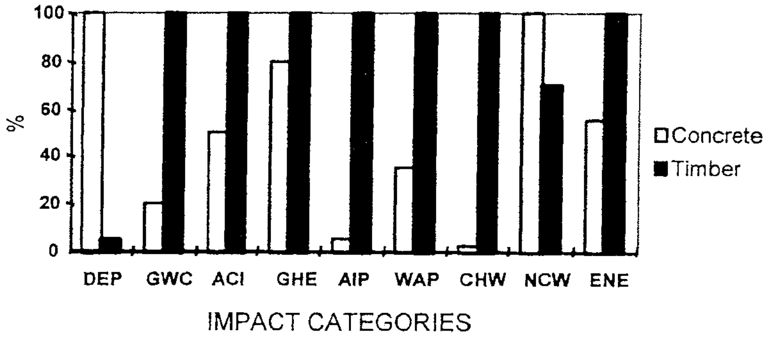

Figure 5 Results for the railway sleepers [5, 21]
(DEP: depletion of non-renewable natural resources; GWC: groundwater consumption; ACI: acidification; GHE: greenhouse effect; AIP: emissions to air; WAP: emissions to water; CHW: chemical wastes; NCW: non-chemical wastes; ENE: energy consumption)

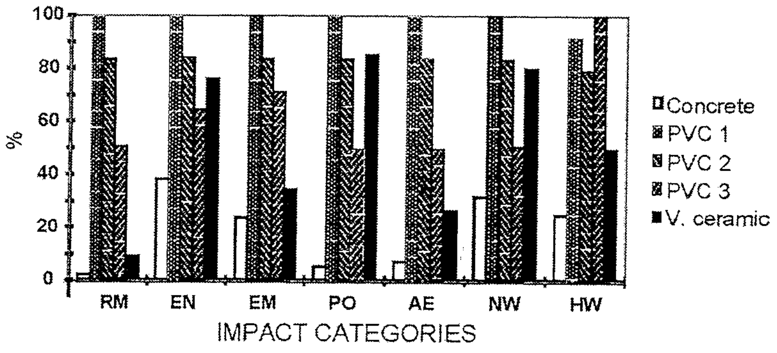

Figure 6 Results for the external sewer [22]
(RM: raw materials; EN: energy; EM: emissions; PO: photochemical oxidant formation; AE: aquatic eco-toxicity; NW: normal wastes; HW: hazardous wastes)

Pavements

This case is presented in [23], and compares the environmental impact of concrete and asphalt pavements for a specific application in a Nordic motorway. The study was commissioned by several industrial sectors, including those involved in concrete and asphalt, and was conducted by Technical Research Centre of Finland (VTT).

Table 2 shows a summary of the results. It can be seen that, in this case, each alternative scores better than the other in 5 out of 10 parameters, which means that no clear conclusions can be drawn. Other cases of pavement comparisons can be found in [24].

Table 2 Results for the pavements [23]

	CONCRETE PAVEMENT	ASPHALT PAVEMENT (Finnish maintenance)	ASPHALT PAVEMENT (Swedish maintenance)
CO_2, kg/km	940000	590000	670000
SO_2, kg/km	1700	2500	2800
NO_x, kg/km	4700	3000	3600
CO, kg/km	2000	610	670
VOC, kg/km	1000	1900	2100
Particulates, kg/km	650000	1200000	1200000
Hg, kg/km	0.0076	0.000042	0.000064
Non-renewable energy, GJ/km	11000	21000	25000
Noise (affected land) , ha/km	70	52	52

Comments on the Cases Presented

The cases presented in the previous paragraphs are a selection of those published in different references. Concrete solutions have frequently good results in relation to alternatives due to a number of reasons. On the one hand, the resources required (i.e., limestone, clay) are very abundant in nature and are easily mined. On the other hand, concrete products are chemically inert and very durable, require low maintenance and can be completely recycled. Finally, the emissions and wastes produced are non-toxic. On the negative side it should be said that cement manufacture requires important amounts of energy and produces high quantities of some gases, in particular CO_2. It is important to emphasize, again, that for analysing the results of an LCA it is always essential to take into account the assumptions adopted.

THE ECOCONCRETE SOFTWARE TOOL

The EcoConcrete software tool is a tailor-made software providing fully-fledged, peer reviewed results of LCA of 10 selected concrete applications, according to three different methodologies (CML [10, 14], EDIP [12], Eco-Indicator [13]) and ISO standards. The tool is based in a user-friendly development of Microsoft Excel and is co-owned by BIBM, the International Bureau for Precast Concrete, CEMBUREAU, the European Cement Association, EFCA, the European Federation of Concrete Admixtures Associations, ERMCO, the European Ready Mixed Concrete Organization, and EUROFER, the European Confederation of Iron and Steel Industries.

The ten functional units correspond to the following concrete applications: a flat slab, a continuous beam, a foundation pile, a motorway pavement, a bridge pylon, a separation floor, a load bearing wall, the elements of a solid wall, a column and pavement blocks. The first five correspond to ready-mixed concrete applications and the last five correspond to precast concrete applications.

These ten functional units are analysed from cradle to grave using inventory data provided by the software co-owners, and taking into account the use and maintenance phases and the end-of-life scenario of the different applications considered. An example of graphical results corresponding to the analysis of precast pavement blocks is shown in Figure 7. These results are also given numerically and can be processed further. All the results are split into the different stages of the life cycle allowing the analysis of the relative importance of each of them in the final impact.

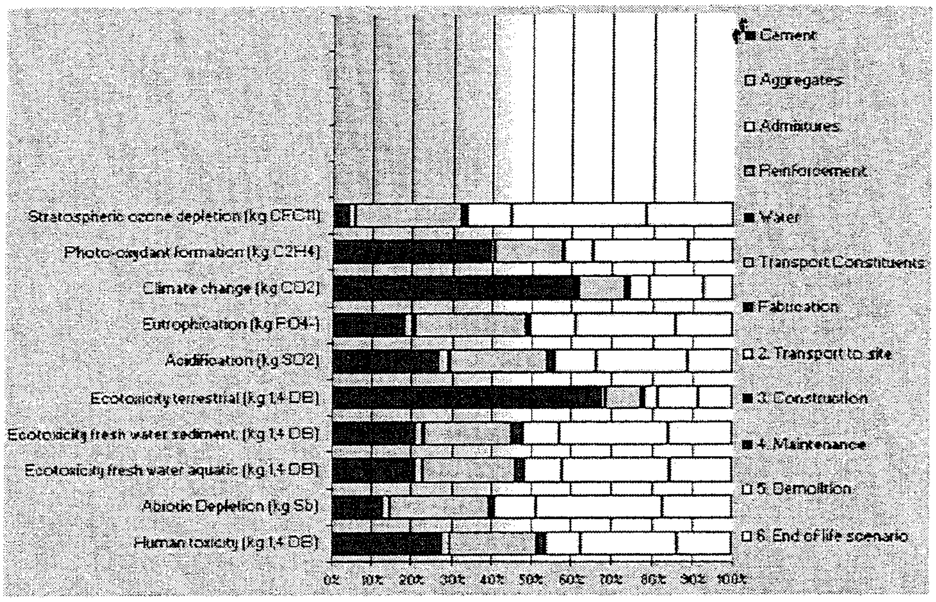

Figure 7. Example of graphical results of the EcoConcrete software tool

FINAL REMARKS

LCA methodology is widely accepted for assessing the effect that all kinds of products, and in particular those corresponding to the construction sector, cause on the environment. Since relevant effects can take place in any stage of the life cycle of the product, a cradle to grave approach must be considered. It is important to have this approach from the very beginning of the design in order to minimise the global effect on the environment including the end-of-life scenario.

Applying LCA to the field of concrete products enables the identification of the life cycle phases where it might be necessary to introduce environmental improvements, as well as comparing alternative solutions (i.e., processes, products) from the perspective of their impact on the environment.

Concrete based solutions frequently have a good environmental behaviour in comparison with alternatives due to a number of reasons. However, the results are highly dependent on the assumptions of the analysis conducted, which means that in many cases it is difficult to reach definitive conclusions.

EcoConcrete is a new tailor-made software tool for the use of the LCA methodology to 10 specific concrete applications. It provides fully-fledged and peer reviewed results applying three different methodologies following ISO standards.

ACKNOWLEDGEMENTS

The financial assistance for the work presented has been partially provided by the Spanish MCYT grants MAT02-04310 and MAT 2003-5530, and by several research projects funded by the Spanish Institute of Cement and its Applications (IECA).

REFERENCES

1. JOSA, A., GETTU, R. AND AGUADO, A. Evaluación medioambiental de productos de la construcción derivados del cemento (I and II). CIC Información (Barcelona), 1997, No. 299, pp. 30-35, No. 300, pp. 49-55.
2. JOSA, A., AGUADO, A. AND GETTU, R. Life cycle assessment of concrete products. 5 Ulusal Beton Kongresi – Beton Dayanikliligi (Dürabilite), Istanbul, 2003, pp. 279-293.
3. SEOPAN. Informe trimestral sobre el sector de la construcción. Asociación de Constructoras de Obras de ámbito Nacional, Spain, 2004, 12 pp.
4. STANNERS, D. AND BOURDEAU, P. (Ed.). Europe's Environment - The Dobris Assessment. European Environment Agency, 1995.
5. CEMBUREAU. Concrete: the benefit to the environment. 1995, 104 p.
6. JOSA, A. AND ALEIXANDRE, J.L.. El hormigón y el medio ambiente. IECA Levante, Spain, 1998, 77 p.
7. ISO 14040: Environmental management - Life cycle assessment - Principles and framework. International Organisation for Standardisation, Geneva, 1997.
8. CEMENT AND CONCRETE ASSOCIATION OF AUSTRALIA. The Sydney House - Life Cycle Assessment – Report, 2001.
9. SETAC. A Conceptual Framework for Life-Cycle Impact Assessment - Guidelines for Life-Cycle Assessment: a 'Code of Practice'. SETAC, Brussels, 1993.
10. CML. Environmental Life-Cycle Assessment of Products - Guide - Backgrounds. CML-TNO-B&G, NOH-9253/54, Leiden, 1992, 224 pp.
11. NORDIC. Nordic Guidelines on Life-Cycle Assessment. Nord, Stockholm, 1995.

12. WENZEL, H., HAUSCHILD, M., AND ALTING L. Environmental Assessment of Products. Chapman and Hall, 1996.

13. GOEDKOOP, M., AND SPRIENSMA R. The Eco-indicator 99, A damage oriented method for Life Cycle Impact Assessment. Pré Consultants, Amersfoort, Netherlands, 1999.

14. GUINEE J., GORREE M., HEIJUNGS R., HUPPES G. ET AL. Life Cycle Assessment, an operational Guide to ISO Standards, volume 1,2,3. Centre of Environmental Science, Leiden University (CML), Leiden, Netherlands, 2000.

15. JOSA, A., AGUADO, A., HEINO, A., BYARS, E. AND CARDIM, A. Comparative analysis of available life cycle inventories of cement in the EU. Cem. Concr. Res., Vol. 34, Issue 8, pp. 1313-1320, 2004.

16. CEMBUREAU. Cembureau LCI Format for Cement. Cembureau, Brussels, 1999.

17. ISO 14041: Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis. International Organisation for Standardisation, Geneva, 1998.

18. AHBE, S., BRAUNSCHWEIG, A. AND MÜLLER-WENK, R. Methodik für Oekobilanzen auf der Basis ökologischer Optimierung. 133, BUWAL, Berne, 1990.

19. KORTMAN, J.G.M., KINDEIJER, E.W., SAS, H. AND SPRENGERS, M. Towards a single indicator for emissions - An exercise in aggregating environmental effects. IDES, CE, Infoplan, Amsterdam, 1995.

20. KORTMAN, J.G.M. AND LIM, R.G. Milieu-Vergelijking van twee Aanbruggen. University of Amsterdam, 1992.

21. HOEFNAGELS, F. AND DE LANGE, V. De millieubelasting van houten en betonnen dwarsliggers. CREM, Amsterdam, 1993.

22. INTRON. LCA study – Environmental profile and environmental measures of a concrete external sewer. Sewer Technology, 6th year, 1995.

23. HÄKKINEN, T. AND MÄKELÄ, K. Environmental adaption of concrete. Environmental impact of concrete and asphalt pavements. VTT, Tech. Res. Centre of Finland, Espoo, 1996.

24. JOSA, A., AGUADO, A., CARDIM, A. AND GETTU, R. Construcción y medio ambiente - Evaluación ambiental de productos derivados del cemento - Aplicación a pavimentos de hormigón. II Congreso Interamericano de Pavimentos de Concreto, Cartagena de Indias (Colombia), 2000, pp. 27-29.