556. Life cycle assessment as a tool for material selection and waste management within the building sector

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Abstract

Sustainable construction should consider the relationships between the choice of materials during the project phase, and the wastes generated during the construction and demolition phases. The objective of this work is to develop and apply several criterion for the building sector that help decision making at the design stages, thus reducing the environmental impact of the materials used, reducing the amount of wastes generated, and increasing the percentage of this wastes that is recycled. LCA methodology was applied in this work to evaluate the environmental impact of the construction phase of several building enclosure combinations, considering the type and amount of materials, their transport to the building site, the energy consumed by the machinery, and the disposal of material and packaging wastes. Three different scenarios of waste disposal were compared: landfilling, incineration and recycling. Eco-efficiency environmental indicators, such as resources, renewable and non-renewable energies and water consumptions were calculated, together with indicators from CML2001 methodology.

Keywords: LCA, building materials, construction and demolition wastes, eco-efficiency

1. Introduction

Sustainable construction should consider all steps within the whole building life cycle: the materials manufacturing, the execution of the building, its use during occupation, and its end of life and demolition, including the wastes generated during all the phases and the transport of the materials and the wastes.

The building sector uses a large amount of energy (for extracting, transporting, processing and assembling of materials) and thus emitting a large amount of carbon dioxide to the atmosphere.

The selection of the building materials to use depends on the future use of building and its design. The factors that usually influenced the choice of building materials were mainly cost, availability and appearance. However, these days environmental suitability of materials is another important factor that has to be considered [1].

In this frame, attention has to be paid to the relationships between the choice of materials during the project phase, and the wastes generated during the construction and demolition phases. Construction and demolition wastes mostly come from building demolition, construction materials rejected at new building and repairing sites, and materials packaging. Nowadays, most of these wastes are disposed to landfill, thus occupying a volume that clearly exceeds the volume of domestic wastes.

In many countries, the large volumes of construction and demolition wastes (C&DW) strain landfill capacities and leads to environmental concerns [2]. Within the European Union, C&DW represent more than 450 million tonnes per year, being the largest waste stream in quantitative terms, apart from mining and farm wastes. This constitutes a crucial problem in terms of the management of that stream [3]. C&DW have very high recovery potential, achieving recycling levels of more than 80%. However, the sad fact is that only a small proportion of this waste stream is actually recovered in the European Union as a whole. Actually, 75% of waste is being landfilled, though 80% recycling rates have been achieved in countries like Denmark, the Netherlands and Belgium. However, the south European countries (Italy, Spain, Portugal, Greece) recycle very little of their construction and demolition waste [3].

Life cycle assessment (LCA) is a tool for evaluating the environmental performance of goods as well as processes or services (collectively termed products). International standards [4, 5] define LCA as a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a system throughout its life cycle: from the production of raw materials to the disposal of the waste generated [6**Error! Reference source not found.**].

LCA Methodology has been widely used within the building sector, to evaluate building life cycle or specific materials [7].

When considering the whole building life cycle, the manufacturing of materials, the execution of the building work, the use of the building (including maintenance and restoring), its final demolition and the C&DW management are usually compared (figure 1). Among these phases, the use of the building usually presents the highest environmental impacts (between 70 and 90% of the total impact), followed by the manufacturing of the materials, while the impact of the execution and demolition phases is usually negligible [8].

LCA methodology was applied in this work to evaluate the environmental impact of the manufacturing phase of several building enclosure combinations, considering the type and amount of materials, their transport to the building site, the energy consumed by the machinery, and the disposal of material and packaging wastes. As the main focus of this work is the selection of materials and the minimization of wastes, the enclosure combinations were chosen in such a way that they all have similar energetic requirements during the use of the building. This means that the environmental impact of the use phase will be similar for all the scenarios compared.

For C&D wastes management, three different scenarios of waste disposal were compared: land filling, incineration and recycling.

Among the different environmental indicators used, CML2001 methodology is the most commonly applied. However, some indicators are not easy to understand for the common public. On the other hand, eco-efficiency indicators pretend to be more comprehensible and useful for non-environmental experts, especially for experts in the building sector.

Eco-efficiency environmental indicators, such as resources, renewable and non-renewable energies and water consumptions were calculated, together with indicators from CML2001 methodology.

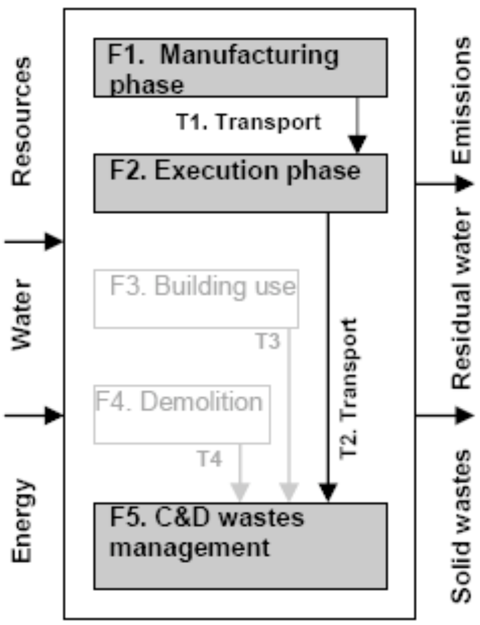

Fig 1.Building system life cycle. Grey processes are not considered within this study

2. Methodology

2.1 Determination of scenarios

The scenarios under study have been divided into two main groups: Vertical interior enclosures (VIE, such as partition walls) and Vertical exterior enclosures (VEE, such as facades). Reference scenarios are based on a real construction located in Barcelona, Spain. Variations on materials combinations were selected considering climate zone specifications [9], similar energetic requirements during the building use phase (similar thermal transmittance), material and energy saving during the execution phase, and C&DW reduction. Tables 1 and 2 present the detail for every scenario.

Table 1: VIE details on materials combination

VIE	Element	Materials
A1 ref	Single hollow brick, rendering	Water, sand, cement, ceramic brick, plaster
A2	Rolled plaster board, galvanised steel structure, glass wool insulation	Galvanised steel, bitumen, glass wool, acrylic filler, nylon, paper, polyethylene, plaster board
B1 ref	Double hollow brick, rendering, mortar coating layer, tiled with mortar	Water, sand, additive, cement, ceramic brick, ceramic tile, plaster
B2	Tiled with glue, rolled plaster board, galvanised steel structure, glass wool insulation	Sand, additive, cement, galvanised steel, bitumen, ceramic tile, glass wool, acrylic filler, nylon, paper, polyethylene, plaster board, polyester resin
C1 ref	Drilled brick, rendering (2 units)	Water, sand, additive, cement, ceramic brick, plaster
C2	Rolled plaster board (5 units), galvanised steel structure (2 units), glass wool insulation (2 units)	Galvanised steel, bitumen, glass wool, acrylic filler, nylon, paper, polyethylene, plaster board
C3	Rolled plaster board (4 units), galvanised steel structure (2 units), corrugated steel sheet, glass wool insulation (2 units)	Galvanised steel, bitumen, glass wool, acrylic filler, nylon, paper, polyethylene, plaster board

The construction database PR/PCT 08 [10] was used to determine the amount of C&DW generated at the building site, the packaging wastes, the energy consumed by the building machinery and the CO_2 emitted by this machinery.

The TCQ GMA – Environmental management software [11] was used to analyse the environmental impact of the constructive elements obtained from PR/PCT database. This software relates the environmental impact of the construction materials with their technical and economic aspects.

2.2 LCA methodology

LCA methodology was applied in this work according to International Normative [4, 5].

2.2.1 Goal and scope definition

The objectives of the study are the following:

To get the environmental profile of different materials combinations for building enclosures

To identify the materials with the lowest environmental impacts, allowing their selection during the project phase.

To select the best environmental alternatives for the C&D wastes management.

Table 2: VEE details on materials combination

VEE	Elements	Materials
Ref	Mortar layer, drilled brick, internal hollow brick, rendering, polyurethane insulation	Sand, cement, additive, water, lime, ceramic brick, plaster, polyurethane foam
3A-1	Mortar layer, drilled brick, internal hollow brick, rendering, extruded polystyrene (XPS) insulation	Sand, cement, additive, water, lime, ceramic brick, plaster, XPS, nylon
3A-2	Mortar layer, external hollow brick, internal hollow brick, rendering, XPS insulation	Sand, cement, additive, water, ceramic brick, plaster, XPS, nylon
3B-1	Mortar layer, light clay block, steam barrier, plaster board partition, rock wool insulation	Sand, cement, additive, water, light clay brick, polyethylene, galvanised steel, acrylic filling, paper, nylon, plaster board, rock wool, nylon
3B-2	Mortar layer, expanded clay block, steam barrier, plaster board partition, rock wool insulation	Sand, cement, additive, water, expanded clay brick, polyethylene, galvanised steel, acrylic filling, paper, nylon, plaster board, rock wool
3C-1	Mortar coating layer, drilled brick, internal hollow brick, rendering, XPS insulation	Sand, water, cement, additive, lime, ceramic brick, plaster, XPS, nylon
3C-2	Mortar coating layer, drilled brick, plaster board partition, XPS insulation	Sand, water, cement, additive, lime, ceramic brick, galvanised steel, acrylic filling, paper, nylon, plaster board, XPS, nylon
3D-1	Expended clay block at sight, mortar coating layer, steam barrier, plaster board partition, rock wool insulation	Water, sand, cement, expanded clay brick, additive, polyethylene, galvanised steel, acrylic filling, paper, nylon, plaster board, rock wool

2.2.2 System boundaries

The system limits determine the processes that are included in the study. Figure 1 presents the scheme of the life cycle of a building system, detailing the phases considered within this work.
For the enclosures under study, the analysis was divided into the following phases:
F1. Manufacturing phase: evaluates the material and energy consumption associated with the extraction of raw matters, their transport to the factory, their manufacturing process and the internal wastes management.
T1. Transport of the raw matter materials from the factory to the building site.
F2. Execution phase: evaluates the energy used by the building machinery, considering the system limitations.
T2. Transport of the wastes generated at the building site (rests of materials and packaging) to their final destination (landfill, incineration or recycling plant).
F3. Building use: evaluates the materials and energy consumptions associated to the use of a building, its maintenance and restoring. As the scenarios compared were chosen to behave the same during the use of the building, this phase was not considered within this study.
T3. Transport of the wastes generated during the use phase, not considered within this study.
F4. Demolition phase: evaluates the energy consumed by the machinery used during demolition, not considered within this study.
T4. Transport of the wastes generated during the demolition phase, not considered within this study.
F5. C&DW management: evaluates the final destination of the wastes generated during all the building phases. In this study only wastes from F1 and F2 were considered, comparing three treatment scenarios (landfilling, incineration or recycling).

2.2.3 Hypothesis

Transport T1 considers an average distance of 50 km.
Transport T2 considers the distance (in km) to the waste management plants closer to the building site.
Landfill scenario: considers the emissions to the soil, air and groundwater related to the disposal of wastes to sanitary landfills, inert materials landfills and hazardous wastes landfills.
Incineration scenario: considers the incineration process, the electrical energy produced (calculated form calorific capacity data) and the amount of residual ashes (which are disposed to landfill).
Recycling scenario: considers the sorting and recycling processes and the material saving due to recycling.
The Swiss energetic mix of the processes (ecoinvent database) was adapted to the Spanish electrical mix.
The transport process was adapted from the Swiss transport system (ecoinvent database) to the European transport system.

2.2.4 Functional unit

The functional unit has been defined as 1 m^2 of vertical constructed unit or scenario that accomplishes the specifications, with an end of life of 50 years.

2.2.5 Inventory

The ecoinvent V2.01 (2007) database [12] was used to obtain the inventory data of the processes involved in the study.
The quality requirements related to the data used are defined by the following parameters:
- Geographic field: European data
- Temporal field: data from 1995 to 2005
- Technological field: mixed technology

2.2.6 Impact assessment

For the evaluation of the environmental profile, the CML 2 baseline 2000 methodology [13] was used (developed by the *Centre of Environmental Science*, Leiden), considering three main indicators:
AP - Acidification Potential (kg SO_2 eq)
GWP – Global Warming Potential, or climate change (kg CO_2 eq)
IR - Ionising Radiation (DALYs)

The software LCAManager [14], (environmental management tool developed by SIMPPLE S.L., spin-off from the URV), was used to create and modify the scenarios under study, to make the material balances and the inventory. By the selection of environmental indicators, the environmental profile was obtained.

2.3 Eco-efficiency indicators

Apart from the commonly known indicators, we have developed some eco-efficiency indicators. Eco-efficiency indicators were proposed considering a general use, but also a specific understanding among the building sector, reflecting the results in a clear and easy way, for non-environmental expert users. These indicators were obtained from the TCQ GMA and the LCAManager softwares, working with data from PRPCT and ecoinvent database, respectively. Eco-efficiency indicators proposed include the following:

RC - Resources consumption (kg): Consumption of resources, except for water, fuels and other energy sources, along the whole scenario life cycle (source: ecoinvent database).

MC - Materials consumption at the building site (kg): Consumption of materials in F1 (source: PR/PCT 08).

ERU - Resources use efficiency (%): Relation between RC and MC (obtained by manual calculation).

TE - Total energy (MJ): Energy consumption along the whole scenario life cycle. Sum of the renewable and non-renewable energy MJ (manual calculation).

RE - Renewable energy (MJ): MJ due to solar, eolic, hydraulic and biomass energy, consumed along the whole life cycle (source: ecoinvent database).

NRE - Non renewable energy (MJ): MJ due to geothermic, nuclear, petroleum, coal and natural gas energy, consumed along the whole life cycle (source: ecoinvent database).

GWC - Global water consumption (m^3): Water consumption from different sources, along the whole life cycle (source: ecoinvent database).

BWC - Water consumption at the building site (m^3): Water consumption in F2 (source: PR/PCT 08).

CDW - Total solid wastes (kg): Total amount of wastes generated in F2 (source: PR/PCT 08).

RW - Recyclable wastes (%): of recyclable wastes in F2 (manual calculation).

IW - Inert wastes (%): inert wastes in F2 (source: PR/PCT 08).

SW - Special wastes (%): special wastes in F2 (source: PR/PCT 08).

NSW - Non-special wastes (%): non-special wastes in F2 (source: PR/PCT 08).

3. Results and discussion

3.2 LCA of building enclosures

Figure 2 shows the comparison of the different phases under study, for the global warming indicator category and the reference scenario for interior enclosures. The manufacturing phase (F1) is the mayor contributor to the environmental impact of the scenario.

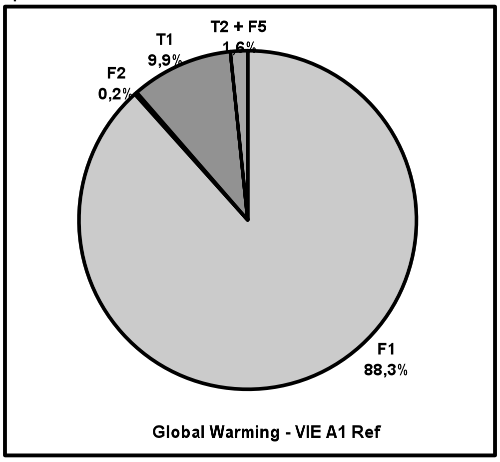

Fig 2. Comparison of the different phases for the global warming category and VIE reference scenario

The environmental profiles for all the scenarios studied are presented in tables 3 and 4, for VIE and VEE respectively.

According to the materials selection, the highest environmental impact is due to the use of galvanised steel (scenarios that contain plaster board and metallic shells for VEE and VIE scenarios respectively). This is true for most of the environmental categories studied.

Table 3: Environmental profiles for VIE scenarios.

	A1ref	A2	B1ref	B2	C1ref	C2	C3
AP	0,04	0,14	0,13	0,22	0,1	0,29	0,27
GWP	15	23	43	45	40	51	47
IR	3E-08	1E-07	1E-07	2E-07	6E-08	2E-07	2E-07
RC	110	42	238	81	264	99	84
MC	99	31	197	56	214	76	63
ERU	90	74	83	69	81	77	74
TE	183	444	572	844	449	974	896
RE	18	26	40	44	42	57	52
NRE	166	418	532	800	408	917	844
GWC	0,16	0,58	0,61	1,11	0,35	1,24	1,17
BWC	0,016	0,000	0,016	0,000	0,019	0,000	0,000
CDW	5,7	1,8	11,1	4,2	11,2	4,4	3,7
RW	94	97	96	89	96	97	97
IW	30,9	0,0	77,5	44,1	64,1	0,0	0,0
SW	0,0	0,3	0,0	6,8	0,0	0,3	0,3
NSW	69,2	100,0	22,6	48,8	36,0	99,5	99,6

When classifying the type of wastes, we can observe that VIE scenarios generate between 89 and 97% of recyclable wastes, while VEE scenarios generate between 72 and 94%. Most of the wastes generated in both cases are inert or non-special.

When comparing the amount of wastes generated (CDW) to the materials consumption at the building site (MC), we observe that VIE scenarios generate an average of 5,7% wastes, except for B2 scenario that generates 7,5%. This result is due to the use of ceramic tiles. In the case of VEE scenarios, the average percentage of wastes generated is 4,5%, except for Ref scenario with 5,6% wastes (due to the use of polyurethane insulation), and 3B2 scenario with 3,7% wastes (due to the combination of mortar layer to expanded clay blocks).

Table 4: Environmental profiles for VEE scenarios.

	Ref	3A1	3A2	3B1	3B2	3C1	3C2	3D1
AP	0,18	0,16	0,12	0,22	0,7	0,16	0,24	0,71
GWP	68	71	53	68	117	70	74	117
IR	9E-08	9E-08	7E-08	1E-07	2E-07	9E-08	1E-07	2E-07
RC	375	372	306	375	340	370	302	341
MC	287	287	248	297	281	288	223	284
ERU	77	77	81	79	83	78	74	83
TE	788	738	559	1735	1471	733	890	1475
RE	61	57	45	686	58	57	60	58
NRE	727	681	514	1048	1413	676	830	1417
GWC	6,2	5,8	0,6	0,8	1,2	5,8	6,2	1,2
BWC	0,013	0,013	0,019	0,002	0,004	0,015	0,006	0,006
CDW	16,2	13,9	10,6	12,8	10,3	13,5	10,5	11,8
RW	78	92	88	84	82	93	94	85
IW	65,0	75,8	65,2	72,3	66,9	77,8	83,5	74,1
SW	15,2	0,0	0,0	0,0	0,0	1,3	1,7	1,5
NSW	19,8	24,2	34,8	27,7	33,1	20,9	14,8	24,3

With respect to the water consumption, the use of lime (single and mortar layers) increases the water global consumption (GWC), independently to the water used at the building site (BWC).
The energy consumption is higher for the scenarios that contain galvanised steel, however the relation between renewable and non-renewable energy use is similar for all the scenarios. The materials use efficiency of all the studied scenarios was found within the range 70-90%.

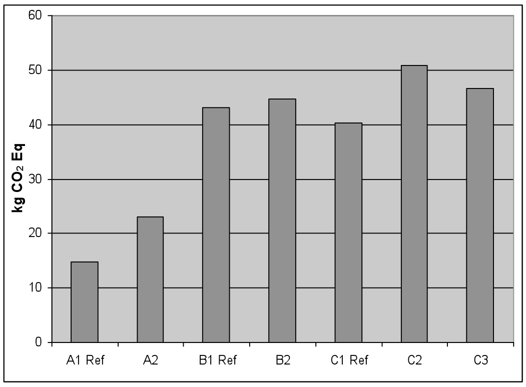

Fig 3. Global warming impact for the F1 of VIE scenarios

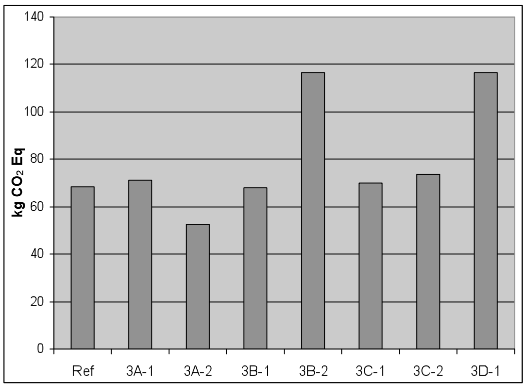

Fig 4. Global warming impact for the F1 of VEE scenarios

According to the global warming indicator, we can observe that the scenarios that contain steel (specially galvanised steel) among their materials have the highest impacts, followed by those that contain high amounts of expanded clay blocks (pre-manufactured materials).

When comparing the use of resources and the materials consumption at the building site, it is observed that the efficiency is similar for all the scenarios and that the use of resources is proportional to the materials consumed at the building site.
Figures 3 and 4 present as an example, the comparison of the global warming impact for VIE and VEE scenarios respectively.

3.3 LCA of waste management

The impact of the C&DW management (T2+F5) was evaluated in separate figures in order to compare the different management options. Results for these phases are presented in figures 5 and 6.
The global warming indicator shows that the disposal to landfill is the worst C&DW management option for all the scenarios analysed, while incineration and recycling show environmental benefits due to the energy production and material saving respectively. It is also observed that for those scenarios that contain glass wool as insulating material, and plastic packaging wastes, the best option is recycling.

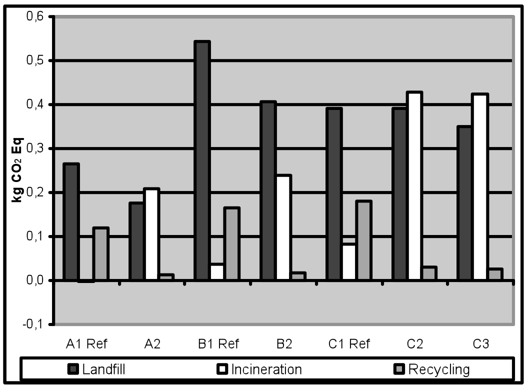

Fig 5. Global warming due to C&DW management, impact for the VIE scenarios

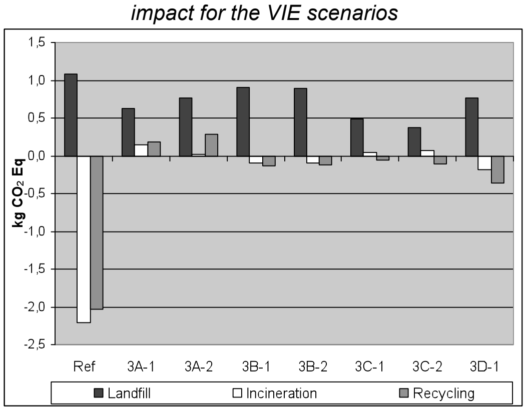

Fig 6. Global warming due to C&DW management, impact for the VEE scenarios

According to the C&DW management, we can observe that the environmental impacts are reduced by the credits obtained by the energy production and raw-matter saving in the incineration and recycling scenarios.
Incineration is the recommended final destination of hazardous wastes (due to their high energy content), while recycling is recommended for inert

and non-special wastes, specially for plastic packaging.

4. Conclusion

This study allows us to conclude that LCA methodology is a powerful analysis tool that permits the evaluation of the materials contribution and the construction phase within the environmental profile of different building scenarios.

LCA allows the identification of the environmental impacts due to the materials manufacture and the C&DW management, compared to the construction process. As an example, we observe that:

- CO_2 emissions are higher for the pre-manufactured elements in comparison to similar components built *in situ;*
- the use of galvanised steel greatly affects the environmental profile of the studied scenarios;
- the use of lime increases the global water consumption;
- the use of polyurethane foam as insulation material increases the amount of wastes generated;
- most C&DW are recyclable and non-special.

The combination of materials analysis and C&DW management reflects the importance of recycling materials that generate a high environmental impact during their manufacturing.

The C&DW management phase represents less than 2% of the environmental impact of the total scenarios. However, the amount of wastes generated at the building site is elevated in comparison to other urban wastes.

When analysing the use of resources, it can be concluded that the recycling of C&DW is the best environmental option for all the building scenarios, due to the material recovered, while incineration and landfilling present similar results. These results can be extrapolated to the wastes originated in the use and demolition phases, not considered within this study.

Finally, the selection of material combinations during the project phase, based on LCA results, helps to select those combinations that have the lowest environmental impact, or uses the lowest amount of material at the building site, thus generating lower amounts of wastes in case of demolition, and reducing the impact of the transport of the materials.

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