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Life Cycle Impact Assessment of masonry system as inner walls: A case study in Brazil

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HIGHLIGHTS

- Life cycle impacts of masonry inner walls are assessed.
- A method to estimate building materials demand and waste generation is established.
- The life cycle phase of use present higher impacts than construction and demolition.
- Lime is the highest contributor to radiation, greenhouse and smog.
- Impacts of waste are larger than impact of materials during wall lifespan.

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ABSTRACT

The Life Cycle Assessment enables us to determine environmental loads associated to products, processes or activities. This paper uses this methodology to evaluate the impact of inner walls, considering as case study a traditional house in Brazil, made by: ceramic bricks masonry and sand and cement mortar. The impacts are assessed with the CML2001 method for a lifespan of the building of 50 years. Results show which phase has the greatest influence over life cycle impacts, the most impactful material-component, the waste behavior and other peculiarities of life cycle impacts derived from masonry walls. In addition, we created a method for estimating the demand for materials, waste generation and distance traveled in the transportation of materials and waste. This method can assist not only, in environmental assessment, but also in construction and waste management, and policy development.

1. Introduction

Buildings generate high environmental impacts during all their life cycle [1,2]. The lifespan of the buildings is long and concerns different sectors, activities and stakeholders, which makes their analysis complex [3].

The manufacturing phase embeds the extraction of raw materials, the manufacture of by-products and the transportation to consumers. The extraction of natural resources represents a large impact on scarcity of non-renewable resources [4] while at the same time consumes other resources such as water, electricity or fuel, and also includes dumping waste in the water, air and soil.

As material consumption in construction is large, wrong choices in material specifications, suppliers and constructive technologies, as well as management failures result in a waste of material and handmade and accordingly, in environmental damages and financial losses.

During the use of buildings, natural resources are consumed for building materials substitution in maintenance, remodeling, and extension reforms. Water and energy [5,6] are required for users and equipment's such as Heat-Ventilation-Air Conditioning (HVAC) [7,8]. Solid waste is generated by the partial demolitions, the periodic replacement of building elements like doors, windows, ceramics, metal, and the building materials waste during replacements and extensions [9,10].

During the demolition phase, large amounts of Construction and Demolition Waste (C&DW) are generated, especially if reuse or recycling is not considered [10]. C&DW dumped in landfills becomes useless and obsolete material, while the same natural

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resources are again extracted from the environment in order to meet the demand of materials.

The transport between extraction, manufacturing, trade, construction and landfill, requires consumption of fossil fuels, thereby depleting non-renewable raw materials and emitting greenhouse gases to the atmosphere [11,12].

The environmental load of buildings concerns impacts linked to activities for building material supply chain, construction, maintenance, waste and transport, yet their impacts are all embedded in the life cycle impacts of the building.

The Life Cycle Assessment (LCA) methodology has been applied to assess potential environmental impacts of products and services throughout their life cycle and has already been reported in studies concerning the building sector. Monteiro and Freire LCA to compare three construction systems of external walls for an English single-family house, evaluating abiotic depletion (CML2001) and resource consumption categories (Ecoindicator99 – EI99), and comparing results of climate change/Global Warming Potential (GWP), acidification and eutrophication [13]. Ortiz et al. evaluated life cycle impacts of building materials and compared three different scenarios for solid waste management: landfilling, incineration and recycling. Eco-efficiency was calculated using the CML2001 method focusing on the aspects of renewable and non-renewable resources, as well as energy and water consumptions [14]. Cuéllar-Franca and Azapagic used LCA to assess the carbon footprint throughout the life-span (50 years) of three typical types of houses in the United Kingdom. The buildings have different areas: individual (130 m^2), semi-detached (90 m^2) and terraced (60 m^2), and were built with bricks and concrete blocks. They applied CML2001 method through the software GaBi to assess the environmental performance, of the buildings, computing the impacts in global warming for the constructed area of the buildings. The results highlighted the gains in household recycling materials and the importance that decisions taken in the design and construction phases have in the impacts of use and end of life phases [15].

There are many aspects that affect the life cycle impacts of buildings. These aspects must be considered in the planning for the building construction, in use and maintenance and waste management of the building. However, a study that assesses the strengths and weaknesses of each building system would be unprecedented and useful to decision makers involved in the construction sector.

The aim of this study is to analyze internal walls of masonry in order to visualize an overall picture of this construct system. We evaluate the behavior of materials-components and waste of masonry as potential polluter and appraise impacts linked to each phase of the building life cycle. Thereby, we intend to offer data to decision makers so that they can conduct an improvement in new ventures planning.

2. Methodology

The methodology in this study is linked to LCA standards – ISO 14040 series [16,17] and to procedures of CML2001 method [18]. However, some regional differences were considered in selecting data from the LCA database, and in elaborating datasets for calculation. These particularities are explained in detail in the description of model limitations and procedures.

2.1. Life Cycle Assessment

The LCA methodology is guided by the ISO 14040 series, which suggests that the application of LCA is composed of four phases [16,17]:

- *Schedule definition and scope* – definition of functional units, boundaries of the study, indicators to be used and desired goals;
- *Life Cycle Inventory (LCI)* – detailed research of the processes, their inputs and outputs;
- *Life Cycle Impacts Assessment (LCIA)* – application of Impact Assessment Method and calculation of environmental impacts; and
- Analysis and interpretation of results.

2.2. CML2001

CML2001 is an Impact Assessment Method, which has a problem-oriented approach (also called midpoint or impact-oriented) that evaluates impacts for CML2001 characterization factors. Table 1 presents the types of CML2001 characterization adopted in this study and their corresponding scientific unit.

2.2.1. Characterization factors CML2001

The characterization factors CML2001 represents impact indicators at “midpoint level” which represent, in simplified form, the type of impact which affect the environment [18]. Table 2 shows the characterization factors CML2001 and the acronyms adopted for them.

2.3. Model limitation and implications

For the elaboration of our model, the data of material and waste impacts are retrieved from the EcoInvent database [19]. This data is not specific for the inventories held in our case study and they may not be representative. In order to minimize errors in the final results, we created a dataset for LCA impacts using similar manufacturing, similar destinations to waste and similar vehicles for transport instead of using the market datasets, which are calculated by averaging many countries around the world.

2.4. Procedure

Estimation of material required in the different phases of the life cycle of the building and the distances between the manufacturing-trade-sites and the landfills are calculated. The LCIA is then performed, according to the following steps:

- The building material consumption and C&DW generation are estimated based on technical and academic literature corresponding to Brazil [20–22].

Table 1
Characterization factor CML2001, adapted from [36–38].

Characterization factor CML2001	Type	Unit
Acidification potential	Generic	kg SO_2-Eq
Climate change	GWP 100a	kg CO_2-Eq
Eutrophication potential	Generic	kg PO_4-Eq
Freshwater aquatic Eco toxicity	FAETP 100a	kg 1,4-DCB-Eq
Freshwater sediment Eco toxicity	FSETP 100a	kg 1,4-DCB-Eq
Human toxity	HTP 100a	kg 1,4-DCB-Eq
Ionizing radiation	Ionizing radiation	DALYs
Land use	Competition	m^2a
Malodours air	–	m^3 air
Marine aquatic Eco toxicity	MAETP 100a	kg 1,4-DCB-Eq
Marine sediment Eco toxicity	MSETP 100a	kg 1,4-DCB-Eq
Photochemical oxidation (summer smog)	Low NOx POCP	kg ethylene-Eq
Resources – depletion of abiotic resources	Depletion of abiotic resources	kg antimony-Eq
Stratospheric ozone depletion	ODP 40a	kg CFC-11-Eq
Terrestrial Eco toxicity	TAETP 100a	kg 1,4-DCB-Eq

Table 2
Characterization factor CML2001.

Characterization factor CML2001	Acronym
Acidification potential	AP
Climate change	CC
Eutrophication potential	EP
Freshwater aquatic Eco toxicity	FAE
Freshwater sediment Eco toxicity	FSE
Human Toxity	HT
Ionizing radiation	IR
Land use	LU
Malodours air	MA
Marine aquatic Eco toxicity	MAE
Marine sediment Eco toxicity	MSE
Photochemical oxidation	PO
Resources – depletion of abiotic resources	RE
Stratospheric ozone depletion	SOD
Terrestrial Eco toxicity	TE