Life Cycle Assessment: Embedded and Maintenance Environmental Impacts of Social Interest Housing Construction Systems

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Abstract: Characterized by high consumption of natural resources and great generation of environmental impacts, civil construction becomes an important ally to the development of strategies for a more sustainable built environment. In this context, this article aims to evaluate construction systems of social interest housing and point out their participation in relation to total impacts, in addition to indicating the environmental impacts embedded in the construction materials present in these systems. To this end, a case study was selected to apply Life Cycle Assessment (LCA) methodology and assess impacts of the building materials used in a house of a social housing complex. LCA was applied to masonry, roof, coatings and floor systems. The scope adopted assesses impacts incorporated in construction materials, analyzing the stages of raw material extraction, materials production, transport to construction site, maintenance and materials replacement. Concerning life cycle inventory, Ecoinvent 3.6 database was used and environmental impacts were calculated using CML method with the aid of OpenLCA 1.9 software. In general, results showed that the maintenance phase has the greatest environmental impact participation related to analyzed systems. Furthermore, it was possible to conclude that coatings and masonry systems were the ones that most added to total environmental impacts.

Key words: LCA, environmental impacts, social interest housing, construction materials.

1. Introduction

Crucial for the development of environments capable of satisfying human needs, civil construction employs several techniques that comprise different production and transformation processes of its products. Construction sector is known for its prominent role to environmental impacts generated, stimulating discussions about sustainable development in construction.

Among the impacts generated, it is possible to highlight global emissions of greenhouse gases, energy consumption and waste generation. Regarding the consumption of natural resources, for the production and maintenance of built environments, materials industry uses more than half of the natural resources extracted on the planet [1]. The effects of civil construction on the environment are consequences of a vast productive chain comprising stages of raw materials extraction, materials production and transport, project design, execution, use, maintenance and end of life cycle [2].

Ref. [2] emphasizes that the production chain of construction materials inevitably influences impacts generated on buildings. They also point out that in Brazil, carbon dioxide (CO₂) emissions for materials production are more relevant compared to the use phase of buildings. Thus, design decisions and selection of constructive solutions directly affect the impacts generated, since intrinsically, these inputs have built-in impacts due to their production processes.

On the other hand, given the severe housing deficit in Brazil, civil construction sector stands out as an
important player in relation to public housing policies. Due to lack of housing, the importance of expanding social interest housing is evident, since a large portion of the population in Brazil has low incomes and needs public housing, or incentives of public programs for purchasing their dwellings [3]. Thus, with the incentive of the Programa Minha Casa Minha Vida (PMCMV) (My House My Life Program—our translation), until 2019, 4 million housing units were built in order to alleviate Brazil’s housing difficulties [4]. However, in the current context, social interest housing is associated with lower-cost construction, in which project designers often disregard factors related to sustainability when choosing their construction systems [5].

In this context, according to Ref. [6], this high housing demand makes civil construction one of the segments with the greatest generation of impacts on the environment. Therefore, it is of great importance analyzing products already available on the market and that are widely used in this sector, in order to contribute to project design and the selection of materials with lower levels of environmental impacts, collaborating with sustainable development. One way of measuring the environmental impacts of a given product or process is the Life Cycle Assessment (LCA).

LCA is a tool capable of helping to understand the impacts generated by a given process or product and to quantify them. LCA adopts a comprehensive and systemic approach to environmental assessment. Thus, it is possible to perceive an increase in interest in incorporating LCA for the evaluation of construction methods and in decision making to select environmentally preferable products, as well as for the evaluation and optimization of construction processes [7].

In this context, the present study aims to evaluate the construction systems of a house in a social interest housing complex and to point out the environmental impacts resulting from the productive processes and maintenance of the adopted building materials. To this end, a case study was conducted in a housing unit at Residencial Canaã located in the municipality of Passo Fundo (Brazil). In addition, the importance of analyzing its materials is highlighted, since the project comprises an evolutionary model, aiming at improvements and extensions over the years. Analyzing these materials provides the possibility to develop less impactful alternatives for the maintenance of these houses or for application in future projects.

2. Life Cycle Assessment in Civil Construction

In civil construction, LCA can be applied in different ways, both in relation to construction materials, impacts related to building maintenance, energy consumption, post-occupational impacts up to the complete building evaluation. Regarding LCA applied to construction materials, Bribián et al. [8] in a study in Spain, compared the most widely used construction materials in civil construction and environmentally friendly materials. The authors conclude that the use of innovative eco techniques can reduce environmental impacts generated throughout the life cycle of a building, thus guiding materials’ replacement that uses too much non-renewable raw material.

Also, in relation to construction materials, LCA can be used to compare different materials used during the life cycle of a building and to identify where the greatest impacts are originated. Regarding this methodology, Petrovic et al. [9] analyzed and compared impacts of construction systems of a residence in Sweden. Their results found that the concrete slab is the element that most contributed to the total impacts of the building, whereas wood-based systems have shown to have a low environmental impact.

Some studies evaluate the environmental impacts using LCA methodology in social housing [3, 7, 10]. Caldas et al. [10] applied LCA methodology for analyzing facades of four building systems. They were
able to verify that the concrete wall system had the least impacts during its processes. Furthermore, they studied CO₂ emissions in the life cycle of two social housing units. Ref. [7] evaluated impacts from a case study, covering the entire building, identifying the greatest impacts in each analyzed construction system. Ref. [3] compared different wall systems, concluding that cast-in-place reinforced concrete system is more advantageous than conventional wall system in ceramic blocks.

Regarding the stages of buildings’ life cycle, according to Refs. [11, 12] operational stage is where the greatest impacts occur. However, Ref. [2] highlights that the production chain and construction components, even when analyzed in isolation, present significant impacts that must be mitigated, since the materials used influence all stages of a building life cycle.

Two LCA studies were carried out for the Brazilian National Association of the Ceramic Industry (ANICER). Maia de Souza et al. [13, 14] developed a comparative LCA of ceramic versus concrete roof tiles in the Brazilian context and compared ceramic brick, concrete brick and cast-in-place reinforced concrete exterior walls. Data for both studies were provided by ANICER and complemented with the inventory available in Ecoinvent 2.2. In general, both studies demonstrated that ceramic materials resulted in minor impacts in relation to the studied concrete elements.

In Brazil, LCA studies in the civil construction sector show that they are still in the initial stages; it was only after the 2000s that there was an increase in publications of LCA studies in the country. The authors also cite the advanced stage of other countries regarding regulations related to the LCA of construction products [15].

As it is a tool under development in Brazil, difficulties are often found when using LCA methodology. These obstacles are mainly related to available databases, which often do not have all the necessary information for a complete assessment. In their analysis, they concluded that, despite the considerable amount of available databases, few have a complete and reliable inventory for construction materials [16].

3. Method and Materials

In order to achieve the desired results, Life Cycle Impact Assessment was carried out following the guidelines of NBR 14040 [17] and NBR 14044 [18], adopting a case study to identify and quantify materials. In this way, LCA of the building systems of a residential unit at a housing complex (Residencial Canaã) located in Passo Fundo/RS (Brazil) was carried out. Housing units cover an area of 45.19 m² each. The housing complex has 210 housing units and they all follow a same standard design and area. The case study will be applied to a housing unit. Blueprint Design Plan can be found in Ref. [19].

3.1 Scope and Objective

This study presents the identification and evaluation of environmental impacts generated in the design of the housing units at Residencial Canaã. In this way, construction materials embedded and maintenance impacts were analyzed. The product system adopted in this study is the life cycle of materials in a housing unit (Fig. 1).

The scope takes into account the pre-operational stage of a building, analyzing the impacts embedded in the construction materials, analyzing the stages of raw material extraction, materials production, transport to the building site and materials maintenance for a 50-year lifespan.

The functional unit, according to Ref. [20], aims to provide references for the study of LCA, so, to ensure compatibility, functional units used in the construction industry are adopted. In this sector, this author indicates that the unit generally used is built area per square meter (m²). Thus, the functional unit adopted in this study is the built area per square meter (m²).
For this study, as a form of delimitation and due to the difficulty of finding compatible data, structural systems were not analyzed.

### 3.2 Inventory Analysis

In order to obtain the quantitative data of the analyzed system, data from the work’s descriptive memorial were used. Missing data were calculated from Ref. [21] and data of material yield per m² were found from manufacturers. The quantitative inventory for the materials used is shown in Table 1. The house’s walls system under study consists of masonry with ceramic blocks laid with cement mortar, lime and sand in the 1:0.5:8 mix ratio and aluminum frames. Built walls are covered with roughcast composed of cement mortar and medium sand in the 1:3 mix ratio with 5 mm thickness and one coat plaster with 1 cm thickness. For the roofing system, natural colonial type ceramic tiles with an inclination of 35% were analyzed.

Hydraulic walls of the kitchen and bathroom were covered with tiles laid with adhesive mortar type 1 (ACI) for indoor use. Final external painting was made with acrylic paint and internal with two coats of Polyvinyl Acetate (PVA) paint. Floor system is formed by ceramic floor tiles with 30 × 30 cm dimensions laid with adhesive mortar ACI. For calculating the amount of construction materials, an addition of 10% was made in order to include possible material losses [21][21].

Within the systems analyzed, components that had little participation regarding to total mass and that would not compromise the development of the study were not considered. Thus, elements such as electrical and hydraulic installations, ceiling system and baseboards were not considered in this study.

Regarding information availability on the construction systems, as in the selected database no similar or equivalent data for the frames used in the social housing were found, these were not considered in the present study. Still related to selected data, there were no inventories related to the exact paints used in the case study, being necessary to use similar material. Thus, alkyd paint was selected. Despite this paint is not used frequently in social buildings, it was also used, for the same purpose, in Ref. [7]. According to the author, alkyd paint is described in NBR 15494 [23] as an alternative for internal or external building painting of buildings.

Inventory survey was carried out using secondary data available in the database Ecoinvent version 3.6 and the cut-off system model with market processes (Market). Market data represent data related to product transformation activities plus transportation. To assist in the organization of inventory data, OpenLCA [24] software was used.
Table 1 Description of analyzed construction systems.

| System          | Description of materials                        | Area (m²) | kg/m² | kg total |
|-----------------|-------------------------------------------------|-----------|-------|---------|
| Masonry (wall)  | Ceramic blocks 8 holes in dimensions 11.5 × 19 × 19 cm<sup>1</sup> | 91        | 82.5  | 7,507.5 |
|                 | Mortar, cement, lime and sand in mix ratio 1:0.5:8 | 91        | 15    | 1,365   |
|                 | Internal and external roughcast: cement mortar and medium sand in the trace 1:3 | 182 | 17    | 1,550   |
|                 | Internal and external plaster: prefabricated mortar | 182 | 17    | 6,188   |
| Roof            | Ceramic roof tiles<sup>1</sup>                  | 72        | 38.4  | 2,764.8 |
| Coatings        | Wall tile 30 × 30                                | 12.65     | 13    | 179     |
|                 | Adhesive mortar ACI                              | 13        | 5     | 69      |
|                 | External painting                                | 71.90     | 0.26  | 37.4    |
|                 | Internal painting<sup>2</sup>                   | 100       | 0.26  | 52      |
| Floor           | Ceramic tile 30 × 30 PEI 4                       | 38.80     | 13    | 504.40  |
|                 | Adhesive mortar ACI                              | 38.80     | 5     | 194     |

Regarding Ecoinvent geographic location, global (GLO) geography data were prioritized for this study, in order to obtain results for global estimates and trends. However, some materials studied here are not available in this geography and it was necessary to combine different geographies. Thus, for data relating to mortar and paint, Rest of the World (ROW) data were used.

Despite uncertainties generated by the difficulty of finding local bases, results help to understand impacts generated by the components and which of those have the greatest participation of general environmental impacts of the system, in a generic way. These results can also be compared in the future with new studies to be carried out when local inventories or adapted data are available.<sup>1</sup>

3.3 Materials Maintenance and Replacements

To define the maintenance and replacements scenario for the analyzed construction materials over the 50-year useful life of the building, guidelines established in NBR 15575-1 [25] and the minimum project useful life (VUP) defined in the standard. Table 2 describes materials, useful life and replacements defined from the standard.

For life cycle impact assessment stage, OpenLCA 1.9 software was used to calculate the impact assessment. Impact categories were evaluated and are present in the CML impact method. Categories selected for the study are: abiotic depletion potential (ADP), abiotic depletion potential—fossil fuels (ADPF), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), human toxicity potential (HTP), ozone layer depletion potential (ODP) and photochemical oxidation potential (OP).

4. Results and Discussions

For better understanding, results were divided into two parts. Initially, total environmental impacts of the systems were generated and the participation of each system was presented. Subsequently, systems were analyzed separately, in which embedded impacts and maintenance impacts of the systems were compared and presented.

4.1 Building Systems Impacts

Initial analysis sought to identify total participation of each system for each of the eight categories of impacts selected for the study. Fig. 2 shows these results. Regarding abiotic depletion potential (ADP), floor system presented the largest impacts' contribution, showing 47% of total impacts. In contrast, roof system presented the lowest participation in relation to the
Table 2  Materials, useful life and replacements from NBR.

| Materials               | VUP | Replacements |
|-------------------------|-----|--------------|
| Coating mortar (plaster)| 13  | 3            |
| External painting       | 3   | 17           |
| Internal painting       | 8   | 5            |
| Ceramic tiles           | 13  | 3            |
| Wall tiles              | 13  | 3            |
| Roof tiles              | 13  | 3            |

Source: data from Ref. [25] adapted by authors.

Fig. 2  Total environmental impacts of each system in each category.

total impacts, representing 4% of the total impacts. In the category of abiotic depletion potential of fossil resources (ADPF), the greatest impacts are presented in the coating system that represents 34% of the impacts. However, masonry also contributes significantly in the category, representing 30% of the total impacts. Roof and floor systems showed 20% and 15%, respectively. Abiotic depletion potential is responsible for damage to natural resources and ecosystem imbalance. In general, it is related to the consumption of non-biological resources and available fossil resources [26].

Acidification potential (AP) is linked to damage to the quality of ecosystems and a decrease in biodiversity. Eutrophication potential (EP) is the impact related to excessive increase of algae in the water and reducing the available oxygen for other living beings [27]. In these two categories, coating system showed the highest participation with 42% and 46% in AP and EP category, respectively. The lowest impacts came from the roof system.

Global warming potential is considered one of the main environmental impacts in civil construction. Ref. [20] estimates that 30% of CO₂ global emissions are generated in activities carried out in the civil construction sector. In the impacts related to GWP, the largest participation is made by masonry system (40%), followed by coatings (32%) and roof (18%). Floor system presented the lowest participation with 10% of the total impacts.

As in GWP category, for impacts related to ODP, most of the impacts originated from the masonry system (33%) and the lowest participation is from the floor system (14%). In HTP category, the greatest impact was found in the coating system, which resulted in 37% of total impacts. Other systems presented similar impacts, with results around 20% in each system.

With consequences for ecosystems quality, photochemical oxidation potential (OP) is related to
secondary air pollution, also known as summer smog [26]. In this category, results show that 56% of total impacts are concentrated in the coating system. Masonry and floor systems contributed with 19% and 14% of total impacts, respectively. The lowest impacts were obtained in the coverage system (11%).

4.2 Embedded and Maintenance Impacts

In the second stage of the study, embedded and maintenance impacts on each system were analyzed—masonry, roof, coatings and floor—still using the same functional unit. In general, impacts were greater in the maintenance phase of the systems analyzed (Fig. 3).

As shown in Fig. 3, impacts related to coatings maintenance system were responsible for greater participation in almost all categories. This system showed less impact only in ADP category, in which floor maintenance system obtained the greatest participation. It is also possible to notice the difference between results for embedded and maintenance impacts, where maintenance results show greater impacts. The greatest discrepancy occurs in the coating system where embedded impacts presented values between 3% and 5%, and maintenance of this system reached results of up to 51% (OP) in relation to total impacts of the system.

This difference occurs due to the number of replacements during the life cycle of the building, mainly in relation to painting, where in 50 years, according to NBR 15.575-1 [25], five paintings are established for the internal environment and seventeen in the external part of the building, since it is exposed to different weather, wearing off more quickly.

Masonry embedded and maintenance impacts included analysis of ceramic blocks, cement and coating mortar. In this system, for maintenance, plaster replacements were taken into account for 50 years of the building’s life cycle. There were no great differences between the embedded impacts and those related to maintenance (Fig. 3).

Regarding the roof system, the analyzed material corresponds to the ceramic roof tiles and maintenance corresponding to this material. Fig. 3 demonstrates that in the ADP category, this system obtained the lowest participation, both in relation to embedded impacts (1%) and maintenance (3%). In this system it is also possible to observe that maintenance impacts are greater in relation to total impacts where at least 3 replacements are necessary.

Concerning the floor system, which is comprised by ceramic floor tiles and adhesive mortar, impacts were also greater in the maintenance phase. In the ADP category was where the greatest participation was observed, both in embedded impacts (12%) and maintenance (35%). In the other categories, this
system showed the lowest results in most cases.

It is observed that the lower the VUP of the component, the greater the number of replacements needed throughout the buildings’ life cycle. In this way, maintenance impacts participate significantly in total impacts analyzed, even when the initial impacts of this element show lower results. Therefore, it is possible to conclude that, in all impact categories, results were greater in the maintenance phase of the systems.

When analyzing embedded impacts in building materials, Fig. 4 presents percentages of each element used in the coating system. It is possible to identify that painting is the major contributor to environmental impacts in this system. The only exception is seen on abiotic depletion potential (ADP) where ceramic tiles used for wall covering hold 70% of the total embedded impacts. Regarding overall impacts in coatings system, painting represented the greatest impacts, confirming results obtained by Ref. [7].

As shown in Fig. 5, when referring to embedded impacts for each material of the masonry system, there is a predominance of impacts related to ceramic bricks production. Among the analyzed categories, ceramic bricks did not obtain the greatest participation only in ADP category. In all other categories, ceramic bricks alone obtained more than 50% of the share of impacts. It is important to highlight its impacts regarding HTP category in which this material obtained almost 70% of participation.

Regarding mortar, a large part of CO₂ emissions is related to cement production, due to clinker processes.
As for ceramic bricks, a large part of the emissions is concentrated in the bricks’ burning process, since according to Crivelaro and Pinheiro [28], the main source of energy used in this process in Brazil is firewood.

In this study, the same material was taken into account for the evaluation between coating mortar and cement mortar. Therefore, differences in participation between these materials occur only by used volume in construction.

As presented in Fig. 6, in relation to embedded impacts of the floor system, ceramic tiles were the predominant element in the impacts generated. It did not obtain higher results only in the photochemical oxidation potential (OP) category, in which impacts were a slightly higher for the adhesive mortar. It is important to highlight ceramic tiles impacts regarding abiotic depletion potential (ADP) category in which this material obtained almost 90% of participation.

Among impacts embedded in studied materials, it was found that the total mass of the components in relation to the system influences overall impact participation within systems. Regarding maintenance, the number of replacements over the buildings’ life cycle directly influences the results.

5. Conclusions

In view of constant discussions related to sustainable development in civil construction and the related environmental impacts of construction materials manufacturing processes, this study aimed to quantify and compare, through LCA, embedded and maintenance impacts of building systems (masonry, roof, coatings and floor) of a residential unit of a social interest housing complex.

Results showed how LCA methodology is an alternative for assessing the impacts of a building. It can be concluded that, among the phases considered in this study, pre-operational and maintenance phases, impacts were predominant in the maintenance phase of the construction systems analyzed. Mainly due to the quantity of replacements that the different systems needed throughout their lifecycle, estimated for 50 years.

It is possible to conclude that coatings and masonry systems were the ones that most added to total environmental impacts. Therefore, it is essential to highlight the importance of defining and choosing project design and materials in relation to overall environmental impacts, since these elements can contribute to reducing or increasing impacts. Results obtained in LCA studies allow designers, architects and engineers to conceive future buildings with fewer impacts since they can gather information about impacts of each element of the building.

In the inventory survey phase, some limitations
were found in relation to data availability, as some materials data were not compatible with the materials used in the housing unit. Selected data were considered for the global context, which may generate some uncertainties for the study. However, as it follows global standards, the study’s contribution to environmental analysis is not ruled out. In future studies, results can be compared with different databases and, when available, with an inventory based on regionalized data.

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