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Life Cycle Assessment of building systems of a social interest housing unit

Marianne Di Domênico[1] Thaísa Leal da Silva[2] Lauro André Ribeiro[3]

[1] Mestre em Arquitetura e Urbanismo pela Programa de Pós-graduação em Arquitetura e Urbanismo, Escola Politécnica – IMED. Passo Fundo, RS – Brasil. mariannedidomenico@gmai.com

[2] Doutora em Engenharia Eletrotécnica e de Computadores pela Universidade de Coimbra – Portugal. Programa de Pós-graduação em Arquitetura e Urbanismo, Escola Politécnica – IMED. Passo Fundo, RS – Brasil. thaisa.silva@imed.edu.br

[3] Doutor em Sistemas Sustentáveis de Energia pela Universidade de Coimbra – Portugal. Programa de Pós-graduação em Arquitetura e Urbanismo, Escola Politécnica – IMED. Passo Fundo, RS – Brasil. lauro.ribeiro@imed.edu.br

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Abstract

Objective: The article aims to evaluate the constructive systems of a social interest housing unit and identify environmental impacts resulting from the production and maintenance processes of the adopted construction materials.
Methodology: To achieve the desired results, we followed the guidelines of NBR 14040 (ABNT 2009a) and NBR 14044 (ABNT 2009b), adopting a case study for the identification and quantification of materials. The scope covers the impacts incorporated in construction materials, analyzing the stages of raw material extraction, production, and transport to the construction site, maintenance, and material replacement.
Relevance: Growing awareness of environmental impacts resulting from human activities leads to the importance of studies to assess the participation of the civil construction sector concerning this issue. In this context, it is essential to adopt new tools to analyze the materials used in buildings, aiming to support the search for mitigation strategies for future impacts.
Results: The results showed that the maintenance stage has the greatest impact on contributions referring to the analyzed systems. In relation to construction systems, the wall system was the element with the highest concentration of impacts compared to the other systems analyzed.
Social contributions / for management: As it is an environmental management tool, the Life Cycle Assessment allows professionals to obtain relevant information about the impacts of materials and construction systems to develop and manage buildings that are less environmentally impactful.

Keywords: Environmental impacts. Housing of social interest. Building systems. Construction Materials. Life Cycle Assessment.

Avaliação de Ciclo de Vida dos sistemas construtivos de uma unidade habitacional de interesse social

Resumo

Objetivo: O artigo tem como objetivo avaliar os sistemas construtivos de uma habitação de interesse social e apontar os impactos ambientais resultantes dos processos produtivos e de manutenção dos materiais de construção adotados.
Metodologia: A metodologia utilizada para atingir os resultados desejados, foi realizada seguindo as diretrizes da NBR 14040 (ABNT 2009a) e NBR 14044 (ABNT 2009b), adotando-se um estudo de caso para identificação e quantificação dos materiais. O escopo abrange os impactos incorporados nos materiais de construção, analisando as etapas de extração da matéria-prima, produção, transporte até a obra, manutenção e substituição de materiais.
Relevância: Devido à crescente conscientização acerca dos impactos ambientais resultantes das atividades humanas, torna-se evidente a importância de estudos para a avaliação da participação do setor da construção civil em relação a essa problemática. Neste contexto, é importante a adoção de

novas ferramentas para analisar os materiais empregados em edificações, visando subsidiar a busca por estratégias de mitigação de impactos futuros.
Resultados: Os resultados demonstraram que a etapa de manutenção detém as maiores contribuições de impactos referentes aos sistemas analisados. Em relação aos sistemas construtivos, o sistema de paredes foi o elemento com a maior concentração dos impactos em comparação aos demais sistemas analisados.
Contribuições sociais / para a gestão: Por se tratar de uma ferramenta de gestão ambiental, a Avaliação de Ciclo de Vida permite que profissionais possam obter informações pertinentes acerca dos impactos de materiais e sistemas construtivos para desenvolver e gerenciar edificações menos impactantes ambientalmente.

Palavras-chave: Impactos ambientais. Habitação de interesse social. Sistemas construtivos. Materiais de construção. Avaliação do Ciclo de Vida.

Evaluación del Ciclo de Vida de los impactos incorporados de una unidad habitacional de interés social

Resumen
Objetivo: El artículo tiene como objetivo evaluar los sistemas constructivos de una vivienda de interés social y señalar los impactos ambientales derivados de los procesos de producción y mantenimiento de los materiales de construcción adoptados.
Metodología: La metodología utilizada para lograr los resultados deseados se llevó a cabo siguiendo los lineamientos de NBR 14040 (ABNT 2009a) y NBR 14044 (ABNT 2009b), adoptando un caso de estudio para la identificación y cuantificación de materiales. El alcance cubre los impactos incorporados en los materiales de construcción, analizando los pasos de extracción de materia prima, producción, transporte a la obra, mantenimiento y reposición de material.
Relevancia: Debido a la creciente conciencia de los impactos ambientales derivados de las actividades humanas, se hace evidente la importancia de los estudios para evaluar la participación del sector de la construcción civil en este tema. En este contexto, es importante adoptar nuevas herramientas para analizar los materiales utilizados en las edificaciones, con el objetivo de apoyar la búsqueda de estrategias de mitigación de impactos futuros.
Resultados: Los resultados mostraron que la etapa de mantenimiento tiene las mayores contribuciones de impacto referidas a los sistemas analizados. En relación a los sistemas constructivos, el sistema de muros fue el elemento con mayor concentración de impactos en comparación con el resto de sistemas analizados.
Contribuciones sociales / para la gestión: Al ser una herramienta de gestión ambiental, el Análisis de Ciclo de Vida permite a los profesionales obtener información relevante sobre los impactos de los materiales y sistemas constructivos para desarrollar y gestionar edificaciones de menor impacto ambiental.

Palabras clave: Impactos ambientales. Vivienda de interés social. Sistemas constructivos. Materiales de construcción. Evaluación del Ciclo de Vida.

Introduction

Civil construction requires using different techniques and different production and transformation processes for its products and is indispensable for the development of environments capable of satisfying human needs. The sector is known for its significant contribution to the environmental impacts generated, stimulating discussions on sustainable development in construction.

Among the impacts generated, it is possible to highlight global emissions of greenhouse gases, generation of waste, and consumption of energy and non-renewable goods. For the production and maintenance of environments, the materials industry uses more than half of the natural resources extracted on the planet (CNI, 2017). According to Agopyan and John (2011), the effects of civil construction on the environment depend on a vast production chain comprising the stages of extraction of raw materials, production and transport of materials, project preparation, execution, use, maintenance, and end of life.

The authors emphasize that the production chain of construction materials in isolation inevitably influences the impacts generated in buildings. However, since the housing deficit is still a problem facing the country, it is important that the civil construction sector, together with housing programs, continue to develop. Surveys performed by the Brazilian Association of Real Estate Developers (ABRAINC) in partnership with the Getúlio Vargas Foundation (FGV), which compose the report on the Analysis of Housing Needs and Trends for the Next Ten Years, show that the housing deficit grew by 7% in ten years. To solve this problem, it would be necessary to build one million properties per year (ABRAINC, 2018).

Faced with the encountered problems, with the incentive of the *Minha Casa Minha Vida* Program (PMCMV), by 2019, 4 million housing units were built to alleviate housing difficulties in Brazil (CNM, 2019). According to Tavares (2006), the large housing demand makes civil construction one of the segments with the greatest impact on the environment, because of these impacts, the housing construction practice has been subject to changes related to its environmental responsibility.

To promote sustainable development in the low-income and social interest housing construction sector, the fund created the Casa Azul Seal. The Casa Azul Seal is the first certification system created factoring in the Brazilian housing reality. The system consists of a socio-environmental classification of housing projects built through *Federal Savings Bank* programs. It can promote sustainable development, encouraging the rational use of natural resources, in addition to reducing costs of using and maintaining buildings (GRÜNBERG et al., 2014). To qualify for the Casa Azul Seal, fifty-three criteria are analyzed and divided into six categories, namely: urban quality, design and comfort, energy efficiency, conservation of natural resources, water management, and social practices (CEF, 2010).

To contribute to the design of materials with lower levels of environmental impacts and collaborate with sustainable development, the emphasizes the importance of analyzing the products available on the market and widely used in this sector. One method to measure the environmental impacts of a given product or process is the Life Cycle Assessment (LCA). Life Cycle Assessment is a tool capable of helping to understand the impacts generated and their quantification in different products. LCA adopts a comprehensive and systemic approach to environmental assessment, which enables the analysis of each stage of a product's life cycle. Thus, it is possible to see an increase in interest in incorporating LCA for evaluation of construction methods and decision-making in the selection of environmentally preferable products, as well as for the evaluation and optimization of construction processes (MORALES et al., 2019).

This article aims to evaluate the constructive systems of housing of social interest and reveal the environmental impacts resulting from the production and maintenance processes of the adopted construction materials. Therefore, a case study was performed in a housing unit at *Canaan House* (*Residencial Canaã*), located in the municipality of Passo Fundo. The housing unit is part of a housing complex with 210 homes. Furthermore, the importance of analyzing its materials since the project comprises an evolutionary model, aiming at improvements and expansions over the years. Analyzing these materials provides the possibility of developing alternatives that are less impactful for the maintenance of these homes or applications in future projects.

Life Cycle Assessment

The Life Cycle Assessment (LCA) is a method that analyzes the entire life cycle of a product or service. The tool helps to quantify and assess the impacts caused on the environment. The first studies conceptualized as LCAs developed in the early 1970s (KLÖPFFER, 2012). From 1990 onwards, the growth of the tool and scientific activities related to the theme is evident, with guides and manuals relating to LCA being subsequently produced, guiding the processes for its realization (BENTO, 2016).

In Brazil, the first initiatives to use the Life Cycle Assessment methodology began in 1994 with the implementation of the subcommittee of the Support Group for Environmental Standardization, developed analysis in accordance with the Brazilian Institute of Information in Science and Technology (IBICT, 2014) of ISO 14000 standards on environmental management (SEO and KULAY, 2006).

The Life Cycle Assessment allows for the analysis of products and inputs to better understand their cycles and thus contribute to proposing solutions that reduce their negative impacts on the environment. Silva et al. (2015, p.11) define life cycle assessment as "Assessment used to quantify an environmental load of a product from the removal of elementary raw materials from nature that enter the production system (cradle) to the disposal of the final product (tomb)".

According to Saade et al. (2014), the objective of an LCA is to analyze the flows originating from nature and that is directed to it, to mitigate the consumption of natural resources and the emissions derived from activities enacted during the process of production, use, and disposal of products. Since it is an analysis with a holistic approach, according to Tavares (2006), the applications of an LCA are comprehensive and allow for several possibilities for studies.

Guided by NBR 14,040 (2009) Environmental management - Life Cycle Assessment - Principles and structure, and by NBR 14,044 (2009) Environmental management - Life Cycle

Assessment - Requirements and guidelines, the LCA is performed by: compilation of an inventory, inputs and outputs associated with the product, and the assessment and interpretation of environmental impacts related to these inputs and outputs (NBR ISO 14040, 2009).

NBR 14,040 describes minimum requirements, principles, and structure to guide LCA studies. NBR 14,044 covers two types of research: the life cycle assessment study and life cycle inventory studies. This standard provides several guidelines and recommendations to ensure the transparency of these studies. According to the recommendations described in NBR ISO 14,040, an LCA must be structured into four stages, namely: Definition of the objective and scope; Inventory analysis; Impact assessment, and interpretation of results.

The objective and scope steps are considered the main phases of the study since this is when the study is defined. The purpose of the LCA must describe the intended application as well as the reasons for conducting the study (ABNT, 2009). The LCA Scope must define the analyzed product system, the functional unit, the impact assessment methodology, the types of environmental impacts considered in the study, the data quality, and the limitations of the research (SILVA et al., 2015).

The inventory analysis comprises the second phase of an LCA, and Silva et al. (2015, p.10) define this stage as: “LCA phase that involves the compilation and quantification of inputs and outputs of matter and energy throughout the life cycle of a product”. According to Chehebe (1997), the second stage of the LCA corresponds to the phase of collection and quantification of the variables involved in the life cycle of the analyzed product.

The impact assessment aims to provide an understanding of the significance of the environmental impacts addressed in the study throughout the product's life cycle. Finally, the interpretation of results step encompasses the identification of significant results found in the Inventory Analysis and Impact Assessment phases. The findings of this stage must be related to the objective and scope defined in the initial stages of the LCA structure (ABNT, 2009).

According to Passuelo et al. (2014), when adopted for studies related to the Brazilian civil construction industry, ACV allows greater access to the internal and external market, due to its internationally known methodology. Its application also tends to satisfy the expectations of consumers who are currently gradually characterized by concern with the environmental profile of materials and construction systems used.

Life cycle assessment in construction

In the civil construction sector, the life cycle of a building is usually divided into stages to enable the necessary survey to apply the LCA. Tavares (2006) defines this subdivision into three phases: pre-operational, operational, and post-operational stages. As described by

Sposto and Paulsen (2014), the pre-operational phase of a building comprises the impacts generated until the execution phase of the building, including the steps of raw material extraction, manufacturing of materials and components, transportation of materials, and inputs to the construction site, including the generation of waste and waste during the execution phase.

The operational phase comprises the steps of replacement of materials, maintenance, and impacts resulting from the use of the building. The post-operational phase, which is the end of a building's life cycle, considers the environmental impacts produced in the stages of demolition and transport of waste generated in this process (TAVARES, 2006).

In civil construction, LCA can be applied in different spheres, which can be related to construction materials, impacts related to the maintenance of buildings, energy consumption, and post-occupational impacts until the evaluation of the building is complete. Regarding LCA applied to construction materials, in a study in Spain, Bribián et al. (2011) compare the most used building materials in civil construction and ecologically correct materials. The authors conclude that the use of eco-innovative techniques can reduce the environmental impacts generated throughout the life cycle of a building, thus guiding the replacement of materials that use too much non-renewable raw material.

LCA can be used to compare different materials utilized during the life cycle of a building and identify where the greatest contributions to such impacts originate. In this follow-up, based on a case study, Petrovic et al. (2019) analyzed and compared the impacts of the constructive systems of a residence in Sweden. The results of the analysis show that the concrete slab is the element that contributes the most to the total impacts of the building, whereas wood-based systems have a low environmental impact.

Some researchers assess the environmental impacts on social interest housing, as is the case of the study by Caldas et al. (2016) where they applied the tool in four construction systems for facades. Through the tool, they were able to verify that the concrete wall system had the smallest impacts during their processes. In addition to studying the CO2 emissions in the life cycle of two housing of social interest, Azevedo et al. (2020), Morales et al. (2019), and Braga (2018) also applied LCA in social interest housing.

The first compares two wall systems and two roof systems for social housing in the city of Florianópolis. The analyzed wall systems are composed of ceramic brick and adobe brick, and for the roofs, the systems composed are of ceramic tile with wood lining and ceramic tile with a solid concrete slab. The results of the simulations showed that the dwelling with adobe brick wall and roof with solid slab had the lowest energy consumption, regarding environmental impacts, the set with the smallest impacts was the adobe brick with roof with wood lining. Morales et al. (2019) evaluated the impacts from a case study, covering the entire building, identifying the greatest impacts in each constructive system analyzed. Braga (2018) compared different vertical fence systems for these dwellings, concluding that the reinforced concrete system is more advantageous compared to the conventional fence system in ceramic blocks.

According to Oyarzo and Peuportier (2014) and Atmaca and Atmaca (2015), the operational phase is where the greatest impacts occur. However, Agopyan and John (2011) emphasize that the production chain and construction components even analyzed in isolation, present significant impacts that must be mitigated since the materials used influence all stages of a building, in maintenance throughout the cycle of its life cycle, the energy consumption in the operational phase, and the impacts related to the disposal of these components.

In Brazil, LCA studies in the civil construction sector show that they are still in early stages, as claimed by Castro et al. (2015), and only from the 2000s onwards was there an increase in the number of LCA studies published in the country. The authors also cite the advanced stage of other countries regarding regulations related to the LCA of civil construction products.

The National Ceramic Industry Association (ANICER) administered two relevant Life Cycle Assessment studies. Comparative life cycle assessment of ceramic tiles and concrete tiles (Souza et al., 2015) and comparative life cycle assessment of ceramic, concrete, and cast-in-place concrete brick walls (Souza et al., 2016). ANICER provided data for both studies and supplemented it with the inventory available at Ecoinvent 2.2. Both studies demonstrated that ceramic materials resulted in smaller impacts compared to the studied concrete elements.

As it is a tool under development in Brazil, difficulties are often encountered in applying the studies. As stated by Martínez-Rocamora et al. (2016), these obstacles are mainly related to available databases that often do not have all the information needed for a more complete assessment. In their analyses, the authors concluded that, despite the considerable amount of databases available, few have an inventory for building materials. These authors cited Gabi Database and Ecoinvent as sources of more complete inventories with reliable data that deliver available inventories for construction materials.

Methodology

To achieve the desired results, a Life Cycle Impact Assessment was performed following the guidelines of NBR 14,040 (ABNT 2009a) and NBR 14,044 (ABNT 2009b), adopting a case study for identification and quantification of materials. This process produced the LCA of the construction systems of a residential unit of a housing complex (*Residencial Canaã*) located in Passo Fundo / RS (Brazil). The housing units in the subdivision have an area of 45.19m² each, the ground floor consists of a living room, kitchen with integrated service area, two bedrooms, a bathroom, and an open garage (Figure 1). The housing complex has

210 housing units. As it is housing of social interest, the project was developed based on the criteria defined by CAIXA.

Figure 1

Floor plan of the residential unit at Residencial Canaã

Source: Martins *et al*. (2013).

As a form of delimitation in the present study, the elements of the building envelope and floor were considered. The analyzed systems were divided into five parts for a better understanding of the elements, namely: slab, roof, walls, cladding, and floor.

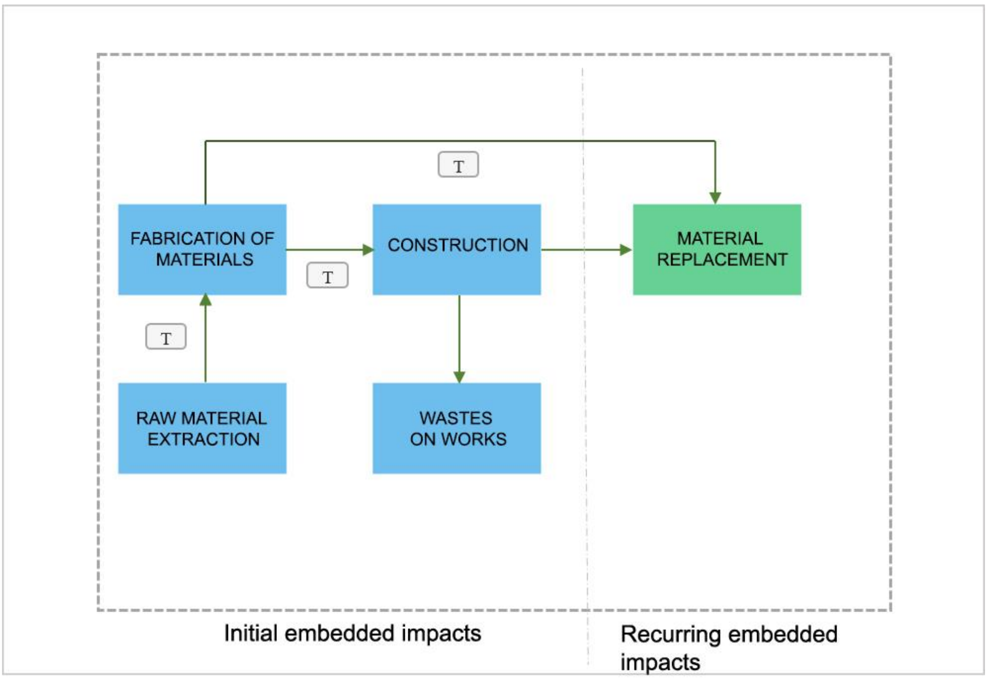
Purpose and scope

This article presents initial analyses for the identification and evaluation of the impacts generated in the project of the residential units of *Residencial Canaã* the embedded and maintenance impacts of the construction materials of the adopted construction systems were analyzed.

The product system adopted (Figure 2) is the life cycle of the construction systems of a single-family house of social interest with an area of 45.19m². The study period adopted for the building was a life cycle of 50 years, taking into account the time used in related studies found in the literature (ATMACA and ATMACA, 2015; CALDAS et al., 2016; MORALES et al., 2019). The scope adopted for the life cycle comprises the steps of raw material extraction, production of construction materials (including transport from the factory to the distributor and later from distribution to the construction site), construction of the building, and material waste during the construction and maintenance of building systems.

Figure 2

Product system



Source: Authors (2021).

It is common in an LCA study to adopt cut-off criteria to delimit and enable the work, this criterion can be related to the mass, energy, or environmental relevance of the products. In this article, the cutoff criterion defined per EN 15.804:2012+A1 (CEN, 2013) was adopted, where it is acceptable to use the cutoff criterion in processes with mass less than 1%. However, the sum of these flows cannot be greater than 5% of the total mass and energy of the product system. Thus, within the analyzed systems, the components that showed little participation in the total analyzed and that would not compromise the development of the study, such as elements of the electrical system, connections, and hardware, were not considered.

Pedroso (2015) attests that the functional unit aims to provide references for the study of LCA. Therefore, to ensure compatibility, civil construction adopts functional units. In this sector, this author indicates that the unit generally used is the constructed area per square meter (m²). Thus, the functional unit adopted in this study is the built-up area per square meter (m²). For this study, as a form of delimitation and due to the difficulty of finding compatible data, the structural systems were not analyzed. In the present study, analyses were carried out considering 1m² of each construction system executed.

Inventory survey and analysis

For the quantitative survey of the construction systems, primary data referring to the project of the housing unit found in the descriptive memorial of the work were used. Missing data were calculated from SINAPI data (2019) on the materials used in the residential unit at *Residencial Canaã* and the material yield data per m² were found in the manufacturers' specifications. The quantitative inventory of materials used is shown in Table 1.

Table 1

Quantitative inventory, for 1m² of the construction systems evaluated

System	Items	Kg/m²	Vol m³
Roof	Concrete	-	0,11
	Steel mesh	1,80	-
	Colonial Ceramic Tiles	38,4	-
Walls	Ceramic blocks 8 holes 11,5x19x19 cm	82,5	-
	Cement	2,45	-
	Lime	2,18	-
	Sand		0,01
	Concrete (mooring strap, lintels, and counter lintels)		0,09
	Steel (mooring strap, lintels, and counter spars)	0,4	-
	Roughcast - cement	3,60	-
	Roughcast - sand		0,02
	Plaster – cement	13,50	-
	Plaster – sand		0,08
	Plaster – lime	12,00	
Coatings	Tiles on the hydraulic walls of the kitchen and ½ wall bathroom shower, dimensions 30x30 cm	13	-
	ACI adhesive mortar for ceramics	4,86	-
Floor	Concrete subfloor		0,055
	Ceramic floor 30x30 PEI 4 commercial	13	-
	ACI adhesive mortar for ceramics	4,86	-

Source: Authors (2021).

The slab for the ceiling is made with 20 MPa machined concrete, with a total thickness of 10 cm above the bathroom as support for the upper reservoir. The roof is comprised of colonial-style ceramic tiles. The walls of the housing units are composed of ceramic blocks

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drilled horizontally in the dimensions of 11.5x19x19 cm, laid with mortar prepared in a concrete mixer in the trace 1: 0.5: 8. The coating system consists of mortar coating (external and internal) and ceramic wall coverings. The mortar coverings are composed of roughcast with a thickness of 5 mm, consisting of mortar in a 1:3 trace, prepared in a concrete mixer and applied manually with a trowel. Plastering, or single mass, is made in mortar in a 1:2:8 mix with mechanical preparation in a concrete mixer and manually applied at a thickness of 25 mm.

The hydraulic walls of the housing units have commercial grade ceramic cladding in the dimensions of 30x30 cm, laid with ACI adhesive mortar for ceramics. This element is performed on the hydraulic walls of the kitchen and bathroom shower at ½ wall, that is, tiles laid up to half the height of the wall. The flooring system refers to the subfloor running along the entire length of the floor to receive the ceramic elements. The subfloor is composed of machined concrete with a thickness of 5 cm under a clean and compacted surface plus 5 cm of gravel ballast. The ceramic floor used has dimensions of 30x30 cm and is commercial class PEI 4, laid with ACI adhesive mortar for ceramic tiles.

For the construction stage of the building, the electrical consumption by equipment for the execution of construction systems is considered. For the execution of areas in concrete, slab, and subfloor, the use of machined concrete is considered. According to NBR 7212 (ABNT, 2012), machined concrete is dosed, mixed, and transported for delivery before concrete sets. The consolidation of the concrete in the formwork is done by an immersion vibrator, with a tip diameter of 45 mm, with a three-phase electric motor, as specified by SINAPI (2020). The preparation of the laying mortar and mortar for roughcast and plastering is carried out in loco, with a concrete mixer with a mixing capacity of 280 liters and a 220/380 three-phase electric motor, following SINAPI specifications (2020).

To analyze environmental impacts, the inventory survey was carried out using secondary data available in the Ecoinvent database version 3.6 and the cut-off system model with market processes (Market). Market data represents data referring to product transformation activities plus transportation. To help organize the inventory data, OpenLCA software was used. All data available at Ecoinvent have a geographic location, therefore, at first, BR geography data was prioritized, that is, with representative processes for the Brazilian reality. However, some materials studied here are not available in this geography, requiring the use of data with the geographic classification GLO (Global) and RoW (Rest of the World).

GLO-type data represent activities that consider an average valid for all countries in the world. Data with RoW geography are data sets that were calculated from an estimate of several countries, that is, it is a copy of the GLO data with adjusted geography uncertainties (ECOINVENT, 2020).

Regarding the availability of information about the constructive systems of the case study, as in the database adopted for the survey, data equivalent or similar to the adopted frames were not found, thus, these were not considered in the present study. Still, on the data adopted, inventories were not found referring to the paints used in the case study.

Maintenance and material replacements

To define the maintenance and replacement scenario of the construction materials analyzed, over the 50-year life of the building, the guidelines established in NBR 15,575-1 were considered: residential buildings: performance: Part 1: General requirements (ABNT, 2013) and the minimum project lifetime (MPL). Table 2 defines the MPL of the construction systems studied and the number of necessary replacements during the 50-year life cycle of the building.

Table 2

Minimum Project lifetime (MPL) and number of replacements for the analyzed elements

Description of Materials	MPL (NBR 15,575-1)	Substitutions
Ceramic tiles	13	3
Internal coating mortar	13	3
Exterior coating mortar	20	2
Wall tiles	13	3
Ceramic floor	13	3

Source: Adapted from NBR 15,575-1 (2013).

Life cycle impact assessment

For the life cycle impact assessment stage, OpenLCA 1.9 software was used to calculate the impact assessment. The selected impact method follows the approach of the Institute of Environmental Sciences (IES 2001). The impact categories used are those recommended by EN 15,804 (CEN, 2013). This standard contains indicators to be used in describing the environmental impacts of civil construction products and also provides rules for the calculation of impact assessments including impact assessment indications to be considered for studies of civil construction products (CEN, 2013). The categories of impacts analyzed are specified in Table 3 and all are calculated based on the IES 2001 method.

Table 3

Impact Categories Used

Impact Category	Unit
Depletion of abiotic potential - non-fossil resources (ADP)	kg Sb eq.
Depletion of abiotic resources potential - fossils (ADP f)	MJ
Acidification potential (AP)	kg SO_2 eq.
Eutrophication potential (EP)	kg $(PO_4)^{3-}$ eq.
Global warming potential – 100 (GWP)	kg CO_2 eq.
Ozone depletion potential (ODP)	kg CFC-11 eq.
Photochemical oxidant creation potential (POCP)	kg C_2H_4 eq.

Source: Adapted from EN 15,804 (CEN, 2013).

Results and discussions

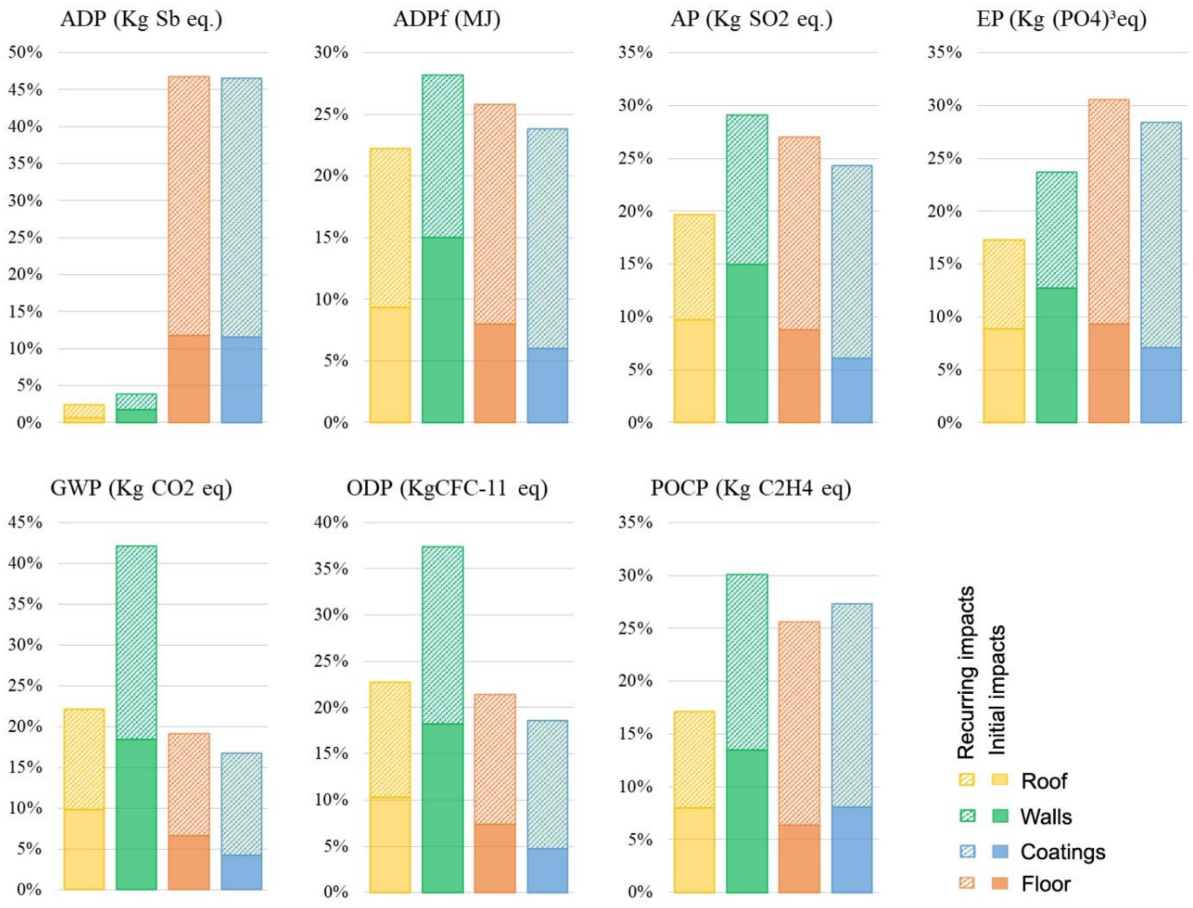
The LCA sought to indicate the impacts of each system for the impact categories analyzed. For a better understanding, the results into two stages, initially the total impacts of the systems and the contributions of each system to the environmental impacts considered in the study were generated. Afterward, the systems were analyzed separately, analyzing and comparing the built-in impacts and maintenance impacts of the systems.

Impacts of the construction systems analyzed

The initial analysis sought to identify the total contribution of each system to each of the selected eight impact categories. Figure 3 represents the results for the seven categories in each analyzed system and the total impacts in each category. The results were interpreted for 1m² of each of the constructive systems, namely: roof, walls, floor, and coatings.

Figure 3

Participation of each system in the initial embedded impacts and recurrent embedded



Source: Authors (2021).

The results show that the data set referring to walls presents the greatest impact contributions for 5 of the 7 categories analyzed. This system proved to be the main aggravating factor of the total impacts analyzed, thus becoming the focus of more detailed analyses. Figure 3 demonstrates that among the impact categories, the wall system does not present the greatest results only in the potential for depletion of abiotic resources (ADP) and in the potential for eutrophication (EP). However, for the initial embedded impacts, this system does not result in the greatest impacts only in the ADP category.

In the ADP category, the initial embedded impacts of the wall system account for only 2% of the total impacts, the recurrent embedded impacts also resulted in 2% of the total percentage of impacts. In this category, the results reveal the largest share of impacts is in flooring and cladding systems, where both presented contributions of 12% in initial embedded impacts and 35% in recurrent embedded impacts. The coverage system had the lowest potential impact in the category, with only 1% in initial impacts and 2% in recurring ones.

In the Eutrophication Potential (EP) category, the floor system has the greatest total impact. In this system, the recurrent embedded impacts (EI) are responsible for the worsening of the results, since the initial embedded impacts (EI) of the system for the category represent 9% of the total, whereas the recurrent ones contribute with 21% of the total impacts. This trend is repeated in the coating system, where EI results in 7% of impacts and ER in 21% of the total. The wall dataset results in 13% EI and 8% ER. In this category, coverage impacts were the least severe, resulting in 9% EI and 8% ER.

The ADPf results reveal that the coverage system has the smallest share of impacts among the other systems, however, the differences between each element are not discrepant. This impact category is directly related to the consumption of fossil fuels. Thus, the total impacts (EI+ER) referring to coverage represent 22% of the participation in the total impacts, while the total impacts of walls, the system with the largest contribution of impacts in the category, present participation of 28% in the total impacts of ADPf. The coating and flooring system expresses results of 24% and 26% share respectively.

In the PA category, following this trend, the results did not differ significantly between each system analyzed. The wall system with the greatest participation in the total impacts, presented 29% of the contribution, while the covering system, an element that showed the lowest impact results, participates in 20% of the total impacts of the category. As in the previous category, the impacts referring to coating and flooring were similar, with shares of 24% and 27% respectively. The approximation of the result of these systems is mainly associated with the similarity of the data used, where both are formed by adhesive mortar and ceramic coatings (ceramic floor and ceramic tile). The substantial difference is that in the floor system there is an increase in screeds, however, as it is considered to be a small portion, this element did not present large participations in the impacts.

According to Pedroso (2015), global warming potential (GWP) is considered one of the main environmental impacts in civil construction. In this category, it is possible to observe the importance of the wall system (Figure 3). This element concentrates 42% of the total impacts. Of this portion, the EI participates in 18% and the ER in 24% of the results. The coverage system is the set with the second-largest contribution, resulting in 10% EI and 12% ER. The flooring and coating systems showed similar results, both with 13% ER, however, the initial impacts for the flooring set were smaller, with only 4% of the total portion of the results.

In the stratospheric ozone layer depletion (OLD) category, the results follow the same trend as the impacts referring to GWP, where the coating and flooring system presents the smallest contributions to total impacts. In this case, the results of the set referring to coverage do not differ much from those mentioned. The coating element with the least impact, resulting in 7% EI and 14% of share referring to ER. The floor system has the participation of 7% for EI and 14% for ER, and the initial impacts of the coverage have a contribution of 10% in the total impacts and the recurring 12%. The wall system, which has the largest share in the impacts, holds 18% of EI and 10% of ER. For flooring and coating systems, replacements (ER) directly influence the total impacts of these elements.

The last category of impacts considered corresponds to the photochemical oxidation potential (PCOP). In this group, the initial embedded impacts of the wall system pointed to a participation of 14% and the recurrent embedded 17% of the total. Coatings and flooring systems share the second-largest share of impacts, where the first presents 8% of EI and 19% of ER. The floor contributes with 6% of initial impacts and 19% of recurring ones. The coverage system, with the smallest share of impacts, participates in 8% of EI and 9% of ER.

It is possible to identify that recurrent impacts decisively influence the portion of each system. Another point to consider is that systems with greater total mass also presented a greater impact results. From the analyses and interpretations in the next subchapter, the elements that compose the construction systems are analyzed to identify aggravating factors of impacts in each set.

Built-in and maintenance impacts of the construction systems analyzed

This stage of the study comprises the analysis of the built-in impacts and maintenance in each construction system for 1m² executed, where the impacts of the materials that make up these systems are analyzed (Figure 4).

The analyses prove that mainly in the wall system, the expressive participation of the mortar elements in the studied impacts emphasizes the impacts related to the maintenance and replacement of these elements. The mortars used in the study are composed of cement, lime, sand, and water. This composition is dosed and mixed on site using concrete mixers, and the execution is applied manually by professionals in the field using a trowel. Thus, as identified by Crivelaro and Pinheiro (2016), the impacts on these elements are primarily concentrated in the use of cement, since the production of clinker is directly linked to this aggravating factor, releasing high amounts of CO2 in its transformation processes.

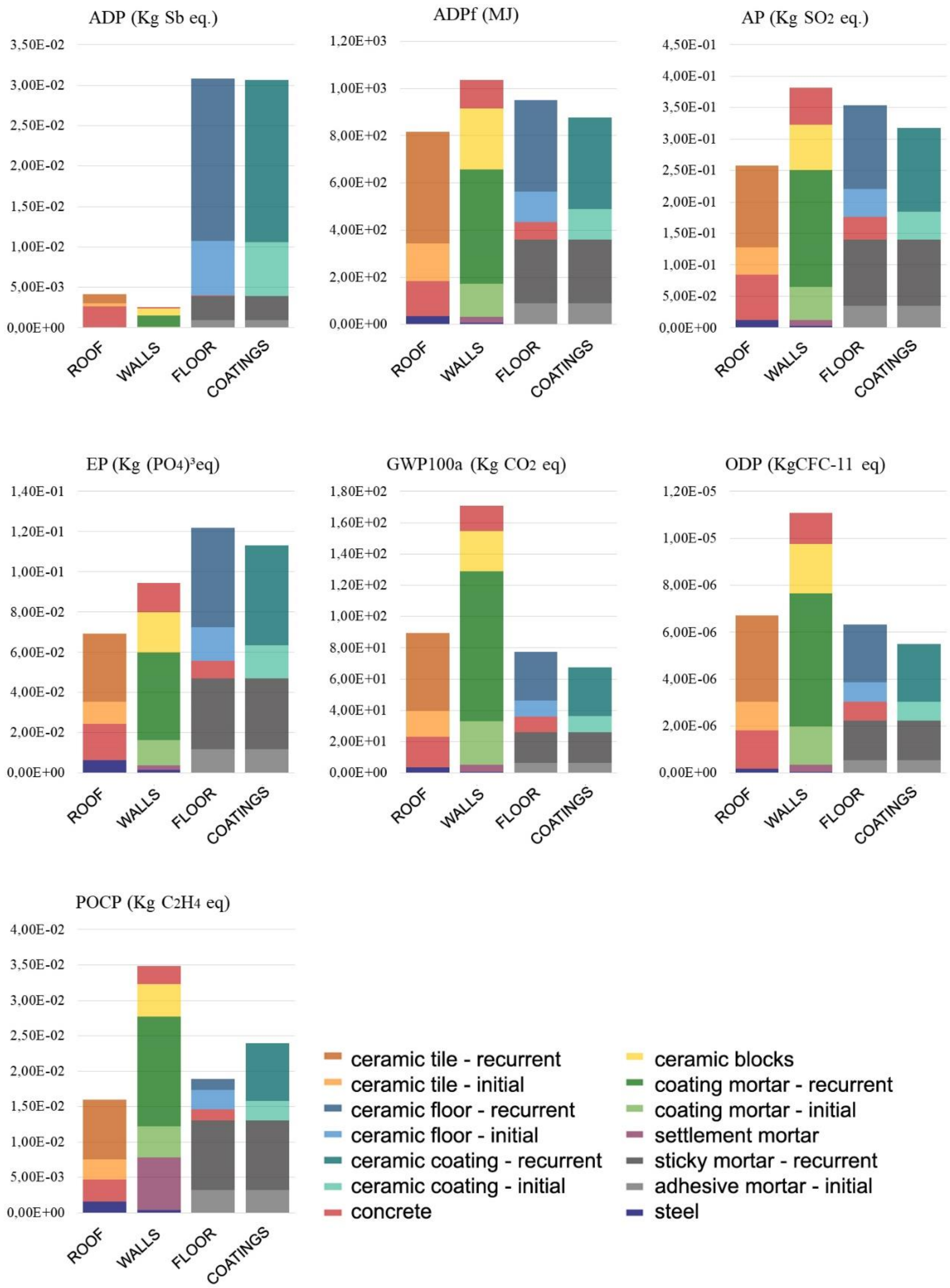
It is possible to identify that in the GWP category, with emphasis on the wall system where the use of cement is more expressive, the mortar elements concentrate the most expressive results. However, as it has little total mass in relation to the mass set of the wall system and does not require maintenance, the settlement mortar has smaller impacts, and only in the PCOP category does it reveal more relevant impacts. The greatest impacts of the coating mortar elements (roof and plaster) are concentrated in the recurrent coating mortar, that is, the greatest results are in the maintenance of this element.

In the wall system, the ceramic blocks also participate in an expressive way in the impacts. Since this material is not subject to replacement, the impacts analyzed in Figure 4 only refer to the initial embedded impacts. This element adds significantly to the total mass of the system, and its participation in the impacts is mainly related to this aspect. Crivelaro and Pinheiro (2016) highlight that the block's burning processes directly influence the impacts related to polluting gas emissions – highlighting the GWP category – and may be the stage with the greatest potential for impacts on the material.

In the set referring to the roof, the greatest impacts are located in the element of recurrent ceramic tiles, that is, in the replacements of this element to meet the minimum MPL defined by NBR 15.575-1 (ABNT, 2013). The initial embedded impacts for ceramic tiles were also significant, however, lower than the results of the set referring to concrete for the execution of the slab of the upper reservoir. Considering only the initial impacts of the roofing system, concrete participates with the highest results in all impact categories. In flooring and covering systems, the greatest impacts were found in elements susceptible to replacement, adhesive mortar, and ceramic coverings.

Figure 4

Results, per m², of environmental impacts on building systems



Source: Authors (2021).

Regarding the elements composed of cement, analyzing the quantitative survey of materials, it is observed that the element is used in small quantities in wall and floor systems, where it is used in the execution of lashing straps, and lintels for 1m² of masonry and for 1m² of subfloor, resulting in smaller impacts. In the covering system, concrete is used in the execution of the slab to receive the upper reservoir, thus having greater participation in the quantity of materials and, consequently, presenting expressive participation in the impacts of this set.

In the systems used, concrete does not require replacements, thus the results for concrete refer only to the initial embedded impacts of the material. Therefore, as seen in Figure 4, in the coverage system where the use of concrete is more expressive when only the initial embedded impacts are compared, this element participates with the highest results. However, when analyzing the total impacts of the materials (EI + ER), ceramic tiles began to concentrate the highest results in 6 of the 7 categories, since the number of replacements factors into the useful life of the ceramic tile.

The small participation of steel in the impacts is mainly explained by the small amount used, both in the covering system and in the walls, thus resulting in little total mass. In the covering system, steel is considered for the execution of 1m² of covering slab for the upper reservoir, requiring only 1.80 kg of steel. At this stage of the study, Market data was used, that is, the impacts generated by the transport of these elements are already accounted for in the material itself.

In agreement with the results, the evaluation conducted by Braga (2018) indicates cement and ceramic block as materials that most influence the percentage of CO2 emissions. Regarding the aggravating factors for greater results in these materials, the author mainly cites the mass representation of these elements and the use of high temperatures in their production processes. Azevedo et al. (2020), also reinforces cement as an important factor in the environmental impacts of construction systems.

This article has similar results to those in the study by Morales et al. (2019), where, when considering the stages of the life cycle until the construction of the building, the masonry system also presented significant environmental impacts. Cement materials also made the greatest contributions to global warming potential. For the results referring to the maintenance stage, the authors' results are in line with those found in this research, where the greater the need for material replacements, the greater the recurrent built-in impacts of a building. However, it is important to consider that the LCA performed in the Morales et al. (2019) uses data adapted to the Brazilian reality, which may result in some differences in the results, however, the trends in the results are in accordance.

It is possible to reaffirm the interpretation of the LCA results of the case study at *Residencial Canaã*, where the total mass of a system is an aggravating point that directly contributes to its initial embedded impacts and that the impacts related to maintenance can be much higher than the initial impacts, resulting in the aggravation of the total impacts of the construction system.

Final considerations

Given the constant discussions related to sustainable development in civil construction and the environmental impacts of the manufacturing processes of construction materials, this article aimed to quantify and compare, through Life Cycle Assessment, the impacts of masonry systems, coverage, coating, and flooring of a residential unit at *Residencial Canaã.* This process comprised the steps of extracting and transporting raw materials, manufacturing, transport, distribution, transport to construction, construction, and maintenance. The results referring to the steps of raw material extraction, transport to the factory, manufacturing, transport of materials and products necessary for the construction to the construction site, and the construction of the building, are called initial embedded impacts; the impacts related to maintenance and replacement of materials are called recurrent embedded impacts. The replacement factors were determined from the minimum MPL recommendations defined by NBR 15.575-1 (ABNT, 2013) for the 50-year lifecycle.

Thus, it is possible to conclude that among the stages considered in the study, the maintenance and replacement stages have the greatest environmental impacts, noting that the number of maintenances decisively influences the environmental impacts of a system. With each replacement, its impacts are accumulated, and at the end of the 50 years of the life cycle, the recurrent impacts, in most cases, become greater than the initial embedded impacts.

The greatest results in recurrent embedded impacts were already expected, since with each replacement for system maintenance, its impacts are accumulated, and at the end of the 50-year life cycle, recurrent impacts, most of the time, become greater than the initial embedded impacts. Thus, the results of the recurrent embedded impacts presented between 59% and 73% of participation while the initial embedded impacts resulted in shares ranging between 27% and 40%. Another factor found was that the massive participation of the system for the total building, especially in the impacts related to the transport of materials, directly influences the aggravation of its environmental impacts. It was also possible to identify that certain materials predominate in the environmental impacts of the system, such as cement elements and ceramic blocks.

Based on the analyses, it is worth highlighting there is a need to use products that have cleaner production and that use renewable or environmentally certified raw materials. Another highlight is to reduce the use of cement materials, in addition to prioritizing the use of local materials or materials manufactured close to the construction site, opting for elements with technologies that are less harmful to the environment or that use alternative elements and/or recycled elements in its composition. Regarding the maintenance and replacement stages, it is extremely important to analyze the useful life of the materials used in the projects, checking the necessary numbers of maintenance and replacements throughout the building's life cycle, opting for materials and construction systems with a longer useful life and, consequently, a lower substitution factor.

It is verified the importance of defining and choosing the construction systems and materials for the building since the elements can contribute to reducing or leveraging the generated impacts. Therefore, the results demonstrate that LCA allows professionals in the field to obtain the information needed to develop and manage buildings that are less environmentally impactful.

As future studies, it is recommended to conduct the adaptation of the inventory data, covering a greater scope for the study, with the insertion of new materials and considering the entire life cycle of the building, with the analysis of consumption of energy and operational impacts of buildings, as well as the end of life of housing. It is also recommended as a future study to compare different maintenance and replacement scenarios and verify in practice whether the standard recommendations are applied.

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