Life cycle assessment of building construction materials: case study for a housing complex

Evaluación de ciclo de vida de materiales de edificaciones: estudio de caso en complejo de viviendas

João Gabriel Gonçalves de Lassio (Main Author)
Universidade Federal do Rio de Janeiro / Escola Politécnica / Departmento de Construção Civil
jgabriellassio@poli.ufrj.br

Assed Naked Haddad (Contact Author)
Universidade Federal do Rio de Janeiro, Escola Politécnica / Departmento de Construção Civil
Av. Athos da Silveira Ramos, 149, CT - Bloco D, sala 207 - Cidade Universitária - Rio de Janeiro - RJ – Brasil
+55 (21) 97228-4072, CEP: 21941-909
assed@poli.ufrj.br

Manuscript Code: 562
Date of Acceptance/Reception: 01.08.2016/09.12.2014

Abstract
In the present work, environmental impacts of building materials used in the construction of a housing project in the city of São Gonçalo, state of Rio de Janeiro, Brazil, have been assessed through Life Cycle Assessment (LCA) methodology in order not only to assist the decision-making of private and public nature, but also to promote life cycle thinking in the construction industry. Based on the guidelines set by ISO 14040 and ISO 14044, the LCA methodology has been applied with available databases and SimaPro program. The results show a considerable consumption of non-renewable energy, intensification of global warming and toxicity to human health. Moreover, this study exposes a necessity of action on the chain of production of steel, cement and ceramic materials mainly. Ceramic materials usage is also a factor the must be observed in detail due its elevated consumption.

Keywords: life cycle assessment; building materials; civil construction; environmental impacts, sustainability.

Resumen
En el presente trabajo, los impactos ambientales de los materiales de construcción utilizados en la ejecución de un proyecto de vivienda en la ciudad de São Gonçalo, estado de Río de Janeiro, Brasil, se han evaluado a través de la metodología del Evaluación de Ciclo de Vida (ECV) con el fin de, no sólo ayudar a la toma de decisiones de carácter privado y público, sino también para promover el concepto de pensamiento ciclo de vida en la industria de la construcción. Teniendo como base las directrices de la normativa ISO 14040 e ISO 14044, la metodología del ACV se ha aplicado utilizando las bases de datos disponibles y el programa SimaPro. Los resultados muestran un consumo considerable de energía no renovable, la intensificación del calentamiento global y de la toxicidad para la salud humana. Por otra parte, este estudio expone la necesidad de la acción en la cadena de producción de acero, cemento y materiales cerámicos, principalmente. Utilización de materiales cerámicos también debe ser observada teniendo en cuenta su elevado consumo.

Palabras Claves: evaluación de ciclo de vida, materiales de construcción; construcción civil; impactos medioambientales, sostenibilidad.

Introduction

The construction industry is responsible for several impacts on the site and the region where it installs a particular work. These impacts extend from the manufacture and transport of materials to the execution of a particular project, and they are of environmental, social and even economic nature. This recurrent process has increasingly worried society. In fact, the environmental impacts have intensified as demand for the construction sector growth, consolidating the construction industry as one of the greatest consumer of supplies and energy inputs.

The growth in demand for construction materials is directly reflected in increased consumption of raw materials and energy, particularly during phases of extraction, processing and transportation. Furthermore, one should take into account the consequent expansion of waste generation, both due to surplus of unused materials as the demolitions leftovers. Santiago (2008) shows that the volume of construction and demolition waste amounts to more than half of municipal solid waste, and most of them are deposited erratically without any form of segregation. It is known that the great majority is from the housing sector. The call for reduction on environmental impacts seems progressively increasing in the pursuit of construction sustainability. To this end, Condeixa (2013) says that it is important to develop and specialize supply chains of building materials and seek sustainable materials: non-toxic to health, which is durable and / or reusable, source of renewable, clean and cost accessible to the consumer market.

Problem Description

The construction industry has consolidated itself as one of the most expendable of supplies and energy inputs. Indeed, throughout its lifecycle, buildings account around the world for approximately 40% of CO_2 emissions, 40% of natural resource consumption and waste generation near 40%, and because of this, it is sometimes referred to as "the industry of 40%" (Lasvaux, 2010).

Therefore it is necessary simultaneous improvement of quality and environmental management in the construction industry throughout significant investments in processes, procedures and technologies, constantly inserted into the sustainable sphere. In addition, one should also consider the preservation of the local to global association, in other words, the sector can no longer ignore the influence that a specific construction site has on the environment. Finally, for the sector to align its success growing responsibilities towards society, it is essential to adapt the context of sustainable development practices in the industry.

In this context, this study aimed to assess the environmental impacts of the main construction materials in the residential buildings subsector, such as steel, cement, ceramics and wood, thus defining the bad character of Brazilian building construction (Gama, 2010). Thus, we propose the application of the concept of sustainability of their supply chains and their life cycles, so as to assist in environmental decision-making and contribute to the lifecycle management of a building project.

State of the Art

Applied to buildings, sustainable development encompasses aspects related to the choice of materials, construction methods, use and operation and demolition of buildings. Essentially, this concept has the focus on the reduction of CO_2 emissions, energy consumption and the progressive depletion of natural resources by the construction industry (Costa, 2012). However, although environmental awareness is increasingly present in the construction industry, it has traditionally been limited to occasional reflections and short term, in other words, the overall view of the impact on the environment is often not taken into account.

Grigoletti (2001) shows that it is essential to sustainable development in the construction sector environmental assessment of building materials. This subject presents a vast field for research, taking into account the full life of the equipment, i.e. to evaluate environmental performance from the production of materials to be used until its final disposal at the end of the useful life of the building, and a wide range of materials available in the market.

However, most of these newer tools are characterized by limitation on single criteria approaches. In other words, the environmental impacts assessed by these tools boil down to a single dimension. For example, in developing practical alternatives, on one hand, one tool can ensure a reduction of carbon dioxide emission, but another tool may have the highest environmental impacts among other aspects.

In the case of a building construction, some material choice for example, may be preferable during its construction phase; however, this material may cause problems during the demolition phase due its handling. That means, waste produced globally may cause more negative impacts on the environment. Consequently, it is necessary to apply concepts that enable this broader consideration in the case, called as multi-criteria approaches.

In this context, the life cycle assessment (LCA) is the most successful tool among the available tools. Its practice and current dissemination contribute to be characterized as an gradually more efficient and recognized instrument, because it evaluates the impacts from the extraction of raw materials to final disposal of products by providing knowledge about the different phases.

Life Cycle Assessment

According to the life cycle assessment international standard ISO 14040 (International Organization for Standardization, 2010), LCA examines in systemic ways the aspects and environmental impacts of product systems, from the acquisition of raw materials to final disposal, according to the purpose and the field of study stipulated (Finkbeiner, Inaba, Tan, Christiansen, & Klüppel, 2006). As a supplement, it can be said that the evaluation made quantifies both globally and as thoroughly possible the potential effects of a product on the environment. Their approach consists in simultaneously quantifying the flows of materials and energy linked to the operations or activities and the translation of these data into a small number of indicators, measuring their impact on the environment.

Evaluation and interpretation of the results can be directed at identifying potential improvements in relation to the environmental performance of products at different stages of their life cycles, on the information to manufacturers and governmental and non-governmental organizations and even the choice of performance indicators environmental products. Hence, it is evident that the application of an LCA extends in many spheres, such as the business sector, community or in certifying bodies. In the case of private companies, the goals can be characterized by obtaining eco-labels and certifications, business marketing, compliance with laws, scenario comparison, materials and products among others. As for the collective, this methodology can be used as an aid in the policies regarding emissions of pollutants and waste streams. At last LCA can play an important role in defining criteria for an eco-label.

According to Khasreen, Banfill, & Menzies (2009), the use of LCA as an environmental management tool began in the 1960s in different forms and with a variety of names. Especially in the literature of the 1990s, it is possible to find some similarities between terms used, types and levels of study. Since then, the term "life cycle assessment" has been adopted to refer to the studies on the environmental life cycle. In fact, in the early 90s the need for environmental impact studies approaches to multiple criteria, such as consumption of raw materials and energy, air pollution and water and waste production emerged, taking into account the set of steps the life cycle of a product, i.e., from manufacture to final disposal, also through the use phase. However, most of these studies were focused in the areas of energy efficiency, consumption of raw materials and final disposal of waste. Nowadays, the assessment includes the entire cycle via the product, process or activity, encompassing extracting and processing raw materials; processing, transportation and distribution, use, reuse, maintenance; recycling and final disposal. Regarding its application in the construction industry, we can consider analyzes of products in the industry, individual buildings and groups of buildings.

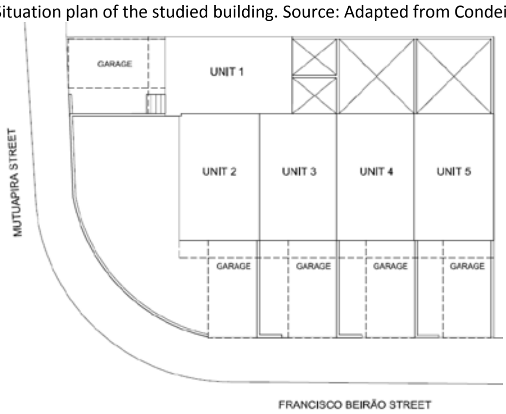
Several authors are developing studies regarding LCA in construction (Costa, 2012) (Zabalza Bribián, Valero Capilla, & Aranda Usón, 2011). A recent review of literature done by Cabeza, Rincón, Vilariño, Pérez & Castell (2014) approaches the subject in a comprehensive way, with very extensive information on the field. Other studies as Muñoz, Zaror, Saelzer, & Cuchí (2012) and Condeixa, Haddad & Boer (2014) and Condeixa, Qualharini, Boer & Haddad (2015) deal with specific questions, the first one dealing with energetic measures on buildings and the latter two with comparison between construction methods and materials. These studies show how this subject is being dealt with and various possible approaches existent.

Methodology

The study was characterized by the practical application of an LCA methodology in a case study, through the analysis of quantities of materials consumed and basic considerations of the most critical inputs in the construction of some common buildings in Brazil. Then in accordance with regulatory requirements and using SimaPro software and LCA methodology, hereby obtaining the results for interpretation and analysis perspective.

The Studied Building

Figure 1. Situation plan of the studied building. Source: Adapted from Condeixa, 2013.



As an object of study we selected a housing development consisting of five single family units targeted for lower middle class, each with two floors which is located in the city of São Gonçalo, state of Rio de Janeiro, Brazil. For its design we used the predominant traditional method of construction, with reinforced concrete frame and seal ceramic brick. Each residential unit has a living room, kitchen, utility area, bathroom, two bedrooms, garage and a yard deep, with a total built area of around 56 m² on average. The land has a total area of 309.00 m² with a building area of 280.03 m², generating an occupancy rate of 42.38%.

Results

The selected building materials studied were evaluated on the context of the lifecycle evaluation methodology. Thus, all phases of an LCA methodology set out in the regulatory framework were considered. Results of the analysis were presented by means of graphs generated by SimaPro software, based on the inventory of each material considered in construction.

Assessment Objectives

The purpose of this assessment is to quantify the flows of materials and energy to the boundaries of a building system, therefore measuring data in order to obtain the impact on the environment. Still, this analysis receive particular attention impacts that often are associated with construction activity, such as global warming, natural resource consumption, consumption of non-renewable energy and toxicity to human health.

Scope

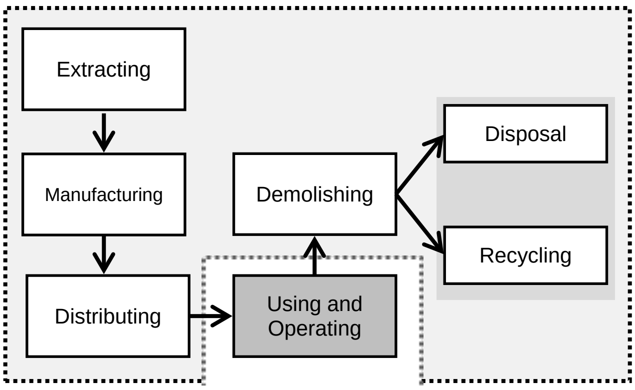
The analysis focused around the foundations of the structure, partition walls, jackets, window frames and roof of the building in question. The subsystems and their associated materials are listed in Table 1.

Table 1. Subsystems and associated materials. Source: self-elaboration.

Building System	**Characteristics**	**Materials**
Foundations	Reinforced Concrete Structure	Cement
		Steel
Structure	Reinforced Concrete Structure	Cement
		Steel
		Wood
Masonry	Brick blocks and mortar applied	Cement
		Ceramic
Wall covering	Tiles, flooring, mortar applied	Cement
		Ceramic
Frames	Doors and wood windows	Cement
		Steel
		Wood
Roofing	Roof with two slopes on ceramic tiles and wooden structure	Steel
		Wood
		Ceramic

The boundary established for the system under study was delimited from the extraction of raw materials, through manufacturing, distribution and final disposal, as shown in Figure 2. Despite significant period of time and impacts due mainly to the use of energy and water, the use phase of buildings was excluded from the analysis. On the one hand, regarding the use of water and energy considerations do not relate to the materials studied, and second, the potential of building renovations and maintenance are borne by the user and the need of setting. Thus, we chose to simplify the analysis. Infrastructure processes were not taken into account, namely the construction of factory or manufacturing equipment and vehicles necessary for the production, operation and transport of materials, respectively.

Figure 2. Layout of the system's boundary. Source: self-elaboration.



As the end of life, although regulatory recommendations, it is known, however, that in practice most construction waste in Brazil has its final destination or not in specific landfills. In fact, about 1% of rubbish is recycled in Brazil, and the vast majority has its final disposal in landfills and vacant lots. On the other hand, one should also consider the effective reuse of some materials and products when the demolition of a building, especially when dealing with frames and other wooden elements. This very process is through the sale of used parts. With this, the end of life scenario considered, in which industrial landfills and recycling plants will be covered, is described below in Table 2.

Table 2. Distribution of waste at its end of life. Source: self-elaboration.

Material	**Quantity**	**Treatment**
Cement and ceramic	25%	Recycling
	75%	Landfilling
Steel and wood	50%	Recycling
	50%	Landfilling

As database, we used the Ecoinvent and in addition, we also used the 2001 data base Idemat Regarding the quality of databases, particularly stands out the fact of them being of foreign origin and therefore portray the European reality. In addition, the technology of construction in the country itself is in large part craft, unlike what happens in the reference countries. Thus, if sought-adapt the modelled constituent processes inventories wherever possible, such as necessary displacements and the type of energy used.

Data collection

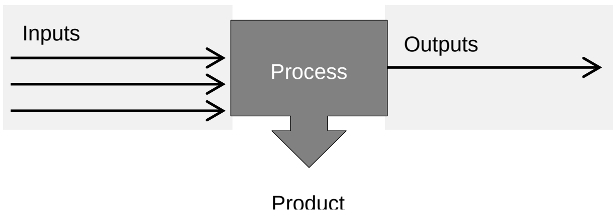
Quantification of the materials was based, in general, at the 13th edition of TCPO - Tables compositions Prices for Budgets (PINI, 2010), which is characterized as the one of the reliable databases in the Brazilian building construction. The amounts of each material can be observed in Table 3 with the appropriate information.

Table 3. Quantities of materials. Source: self-elaboration.

Material		**Quantity (kg)**
Steel		5034,37
Ceramics		131798,13
Cement		28369,30
Wood	*Paraná Pine*	5853,76
	Peroba-Rosa	4197,82

The life cycles of the materials used were modelled as flows of inputs and outputs of the processes, as shown in Figure 3. Note that the inputs and outputs were based on the databases used in this work.

Figure 3. Schematic of the modeling life cycle. Source: self-elaboration



On the subject of modes of transportation, road transportation was favoured in all stages, given the proximity of the sites and the field of road network in the country. Regarding the manufacturing phase, it was considered as the site of its achievement, the same site of the extraction of raw materials. With respect to the distribution phase, it was considered an average of the distances between existing suppliers nearby the construction site, this distance being equal to 10 km. Finally, at the end of life stage, we have taken into account only those scenarios in which the waste is destined to landfill and processed for recycling, with displacements of 12 and 55 km, respectively. The other displacements between the different stages of the life cycle can be observed below in Table 4.

Table 4. Displacements between phases of the material's life cycle. Source: self-elaboration.

Material	**Process**	**Origin - Destination**
Steel	Extraction	540 km
	Manufacturing	100 km
Ceramic	Extraction	0 km
	Manufacturing	24 km
Cement	Extraction	0 km
	Manufacturing	180 km
Wood – Peroba	Extraction	25 km
	Manufacturing	345 km
Wood - Pinus	Extraction	25 km
	Manufacturing	1230 km

Inventory

At this stage the identification of non-elementary streams and quantification of elementary streams occurs. These differ in that they are inputs and outputs of existing processes in the different stages of the life cycle, occurring between the agents and the environment. In other words, this phase documents data inputs and outputs system reported to the study, which was performed in SimaPro software. Materials like wood, cement, steel and ceramic are the most important due to its heavy participation on the total inventory of products. Ceramic materials appear as the most important contributor in weight mass due to this type of construction largely found in Brazil.

Assessment of impacts

Assessment of impacts translates consumption and waste identified in the inventory phase, environmental impacts, such as greenhouse effect, hole in the ozone layer, smog, acid rain, eutrophication, toxicity, among other layer. For this, we used the for calculation the IMPACT 2002+ methodology, which proposes a combination of classical approaches (midpoint) and targeted to the damage (endpoint), thus grouping the strengths of methods, such as IMPACT2002+, Eco Indicator99, CML 2000 and IPCC. Categories selected for further observation are those related to global warming, natural resource consumption, consumption of non-renewable energy and toxicity to human health.

The results presented below were based on comparison between materials considered for the studied building. In Figure 4, through the type of characterization, one can observe the translation of incoming and outgoing flows in the IMPACT2002+ method. We note that the most significant impacts come again, life cycles of steel, cement and ceramics. Furthermore, it was also observed that the 15 types of impacts in two (carcinogens and mineral extraction) steel is characterized as almost exclusive most significant agent. Global warming (global warming) and the use of non-renewable energy (non-renewable energy), which are somewhat inter linked, have as main agent lifecycle of ceramics. The categories non-carcinogens and ionizing radiation were those in which the cement showed greater expressiveness. Applying the method of normalization by IMPACT2002+ method, it is observed that the most significant impacts, taking into account all the materials are related to global warming, the use of inorganic non-renewable and respiratory energy (air emissions of NO_X and SO_2), as Figure 5 When applying the single score, we can consider that global warming is the most obvious impact on the life cycles of all materials considered, followed by the use of inorganic non-renewable energy and breathing, as shown in Figure 6. Materials like wood, cement, steel and ceramic are

Figure 4. Comparison of the life cycles of selected materials, Impact2002+ method, characterization. Source: self-elaboration.

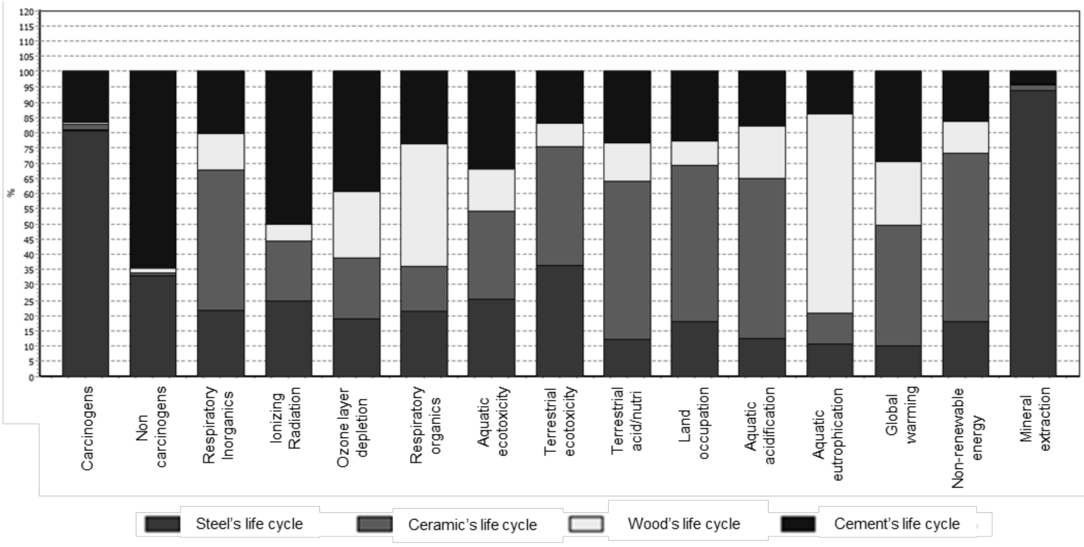


Figure 5. Comparison of the life cycles of selected materials, Impact2002+ method, normalization. Source: Authors.

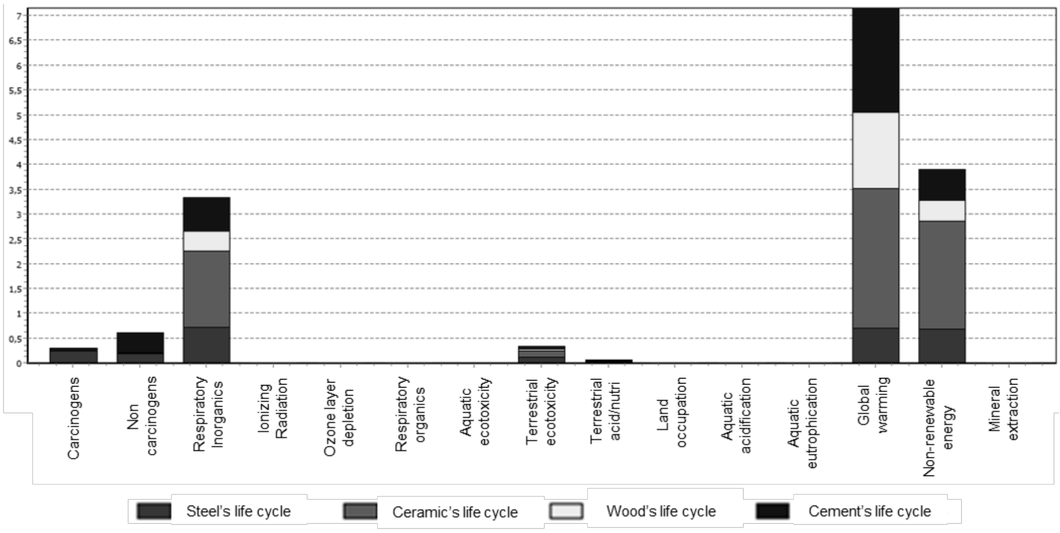
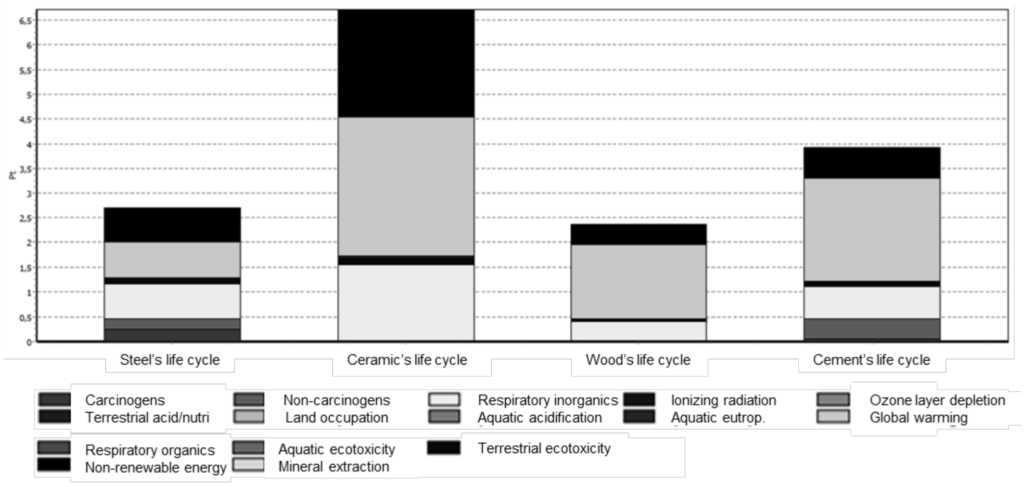


Figure 6. Comparison of the life cycles of selected materials, Impact2002+ method, single score. Source: self-elaboration.

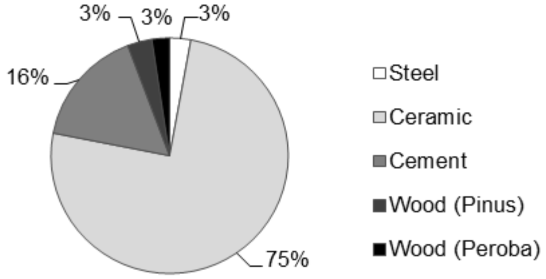


Interpretation

Analyzing the results obtained we found that the most severe impacts are related to global warming, consumption of non-renewable energy and toxicity to human health. In relation to global warming, it was found that it is more responsible represented by the life cycle of ceramics. We know that global warming occurs largely by burning fossil fuels, both used in manufacturing processes and in the distribution, transport. Moreover, it is important to note that the ceramic material was in greater quantities, corresponding to about 75% by weight of the materials considered for the construction of the building studied, as shown in Figure 7 Thus, it is expected that it be responsible for higher impacts.

Also in the context of global warming, the life cycle of cement also stands out, this can be explained by the natural process of manufacture of clinker, called calcinations, that is responsible for significant emissions of carbon dioxide, which contribute significantly to the global warming. Regarding toxicities in general, it was found that the performance of steel and cement, key materials and difficult to replace the traditional system of construction. Considering its effects on human health, the most significant impacts were cancer and respiratory inorganic substances. The first is, for the most part, from the life of the steel and the second cycle of pottery.

Figure 7. Composition of the building materials studied in kg. Source: self-elaboration.



It was observed therefore that the ceramic stood out as the most responsible for the impacts, perhaps because of that require a larger amount of mass between materials. Moreover, the life cycles of cement and steel also had significant impacts, most often related to toxic substances.

Conclusions

Intended to assess the environmental impacts of the most essential building materials of the housing sector buildings and promote the concept of sustainability by thinking about its life cycle, this study included a simplified analysis of the phases of the entire supply chain of steel, ceramic, cement and wood used in a specific building through the LCA methodology. During this study, it was possible to highlight some critical points, such as the considerable consumption of non-renewable energy and fossil fuels, the resulting contribution to global warming and toxicity to human health. The extraction of natural resources and therefore its scarcity, though much quoted, did not show a significant influence in relation to other impacts.

As a base of support for future decision-making, this study showed a need for action through the chain of production of steel, cement and mainly of ceramic materials. In the latter case, make complementary analyzes are necessary for the feasibility of replacing the material or structural system. These actions should also cover the end of life of the materials, which in this work was considered in a more favourable situation than really occurs in the current scenario. In fact, there is a lot of waste on vacant lands without adequate storage and treatment, contributing to all impacts mentioned above, and this could, in some way, help to reverse this situation, if being reused or recycled in larger proportions in the country. In addition, and consequently the results presented in some way at this study contributes to the promotion of life cycle thinking directed to the construction industry, with its applications and limitations, exposing problems, disseminating, analyzing and interpreting results and discussing solutions. Observing the construction industry, in detail the housing sector suitability to the concept of sustainable development is still pursued yet.

Recommendations for future work, indicates the consideration on the use phase of buildings, in which one should consider the inputs needed for remodelling and maintenance of dwellings, as well as, other building construction products. In addition, it would also be interesting to explore the use a wider range of materials such as glass and plastic. Finally, given the possibility that the LCA methodology provides, it is essential to perform a comparative analysis of materials and products in the construction sector that perform the same function. Hence, decision making is facilitated by comparative results of impacts and can therefore justifiably substitute materials and products.

Acknowledgments

We wish to thank all people involved in this study, foremost the ones who provided material and information that allowed the fulfilment of this study. Assed Haddad also acknowledges a grant from CNPq / Brazilian National Council for Scientific and Technological Development.

Cabeza, L. F., Rincon, L., Vilariño, V., Perez, G., and Castell, A. (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renewable and Sustainable Energy Reviews*, *29*, 394–416. http://doi.org/10.1016/j.rser.2013.08.037

Condeixa, K. de M. S. P. (2013). *Comparação entre materiais da construção civil através da avaliação do ciclo de vida: sistema drywall e alvenaria de vedação*. Universidade Federal Fluminense.

Condeixa, K., Haddad, A., & Boer, D. (2014). Life Cycle Impact Assessment of masonry system as inner walls: A case study in Brazil. *Construction and Building Materials*, *70*, 141–147. http://doi.org/10.1016/j.conbuildmat.2014.07.113

Condeixa, K., Qualharini, E., Boer, D., & Haddad, A. (2015). An Inquiry into the Life Cycle of Systems of Inner Walls: Comparison of Masonry and Drywall. *Sustainability*, *7*(6), 7904–7925. http://doi.org/10.3390/su7067904

Costa, B. (2012). *Quantificação das Emissões de CO2 Geradas na Produção de Materiais Utilizados na Construção Civil no Brasil*. Universidade Federal do Rio de Janeiro.

Costa, K. A. (2012b). *A utilização da avaliação do ciclo de vida no processo de tomada de decisão em sustentabilidade na indústria da construção no subsetor de edificações*. Universidade Federal Fluminense.

Finkbeiner, M., Inaba, A., Tan, R., Christiansen, K., & Klüppel, H.-J. (2006). The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044. *The International Journal of Life Cycle Assessment*, *11*(2), 80–85. http://doi.org/10.1065/lca2006.02.002

Gama, A. (2010). *Análise ambiental e económica da produçãode tijolos*. Universidade Tecnica de Lisboa.

Grigoletti, G. (2001). *Caracterização de impactos ambientais de indústrias de cerâmica vermelha do estado do Rio Grande do Sul*. Universidade Federal do Rio Grande do Sul.

International Organization for Standardization. (2010). ISO 14040 Environmental management -- Life cycle assessment -- Principles and framework.

Khasreen, M. M., Banfill, P. F. G., & Menzies, G. F. (2009). Life-Cycle Assessment and the Environmental Impact of Buildings: A Review. *Sustainability*, *1*(3), 674–701. http://doi.org/10.3390/su1030674

Lasvaux, S. (2010). *Étude d'un modèle simplifié pour l'analyse de cycle de vie des bâtiments*. Paris Institute de Technologie.

Muñoz, C., Zaror, C., Saelzer, G., & Cuchi, A. (2012). Estudio del flujo energético en el ciclo de vida de una vivienda y su implicancia en las emisiones de gases de efecto invernadero, durante la fase de construcción Caso Estudio: Vivienda Tipología Social. Región del Biobío, Chile. *Revista de La Construcción*, *11*(3), 125–145. http://doi.org/10.4067/S0718-915X2012000300011

PINI. (2010). *TCPO Tabelas de Composições de Preços para Orçamentos* (13th ed.). Editora PINI.

Santiago, E. (2008). *Utilização de agregados de EVA e RCD para a obtenção de concretos leves*. Universidade Estadual de Feira de Santana.

Zabalza Bribian, I., Valero Capilla, A., & Aranda Uson, A. (2011). Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Building and Environment*, *46*(5), 1133–1140. http://doi.org/10.1016/j.buildenv.2010.12.002