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BIBLIOMETRIC ANALYSIS OF COMPARATIVE STUDIES BETWEEN A CONVENTIONAL AND A PREFABRICATED CONSTRUCTION USING LCA

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ABSTRACT

Aim: The article aims to identify and characterize comparative studies of Life Cycle Assessment (LCA) between conventional and prefabricated building systems.

Methodology: A bibliometric analysis was performed with the steps of formulating the question, defining strategy, selecting studies, collecting and analyzing data, results and conclusions.

Relevance: The construction industry is responsible for considerable environmental impacts from the extraction of raw materials to demolition. With the use of LCA, it is possible to identify the main causers and mitigate their environmental consequences.

Results: The studies are concentrated in Europe and Asia, with pre-operational assessments of global warming (CO2 emissions) and pre-operational energy consumption of construction. The most significant uses in the development of LCA were: SimaPro software, Ecoinvent database and IPCC, IMPACT 2002+ and TRACI methods. The advantage of prefabrication has been verified, however, it is not possible to generalize due to the great variability between the values found.

Contributions: This article allowed to identify the study gaps to be explored, the current research scenario in the area and the main definitions related to LCA studies for civil construction (e.g. software, database, method).

Conclusion: The term "conventional construction" has a different meaning for each country, so it is worth describing in detail the composition of the construction processes. Also, the importance of a structured scope for comparative studies of LCA, with the declaration of the adopted criteria, the description of the scenario in which it is inserted and the use of consistent parameters for reliable results is emphasized.

Keywords: Comparative. Conventional construction. Prefabricated. Life Cycle Assessment. Environmental impact.

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ANÁLISE BIBLIOMÉTRICA DE ESTUDOS COMPARATIVOS ENTRE A CONSTRUÇÃO CONVENCIONAL E A PRÉ-FABRICADA POR MEIO DA ACV

RESUMO

Objetivo: O artigo tem como objetivo identificar e caracterizar estudos comparativos de Avaliação do Ciclo de Vida (ACV) entre sistemas construtivos convencionais e pré-fabricados.

Metodologia: Foi realizada uma análise bibliométrica com as etapas de formulação da pergunta, definição de estratégia, seleção de estudos, coleta e análise de dados, resultados e conclusões.

Relevância: A indústria da construção civil é responsável por consideráveis impactos ambientais desde a extração das matérias-primas até a demolição. Com o uso da ACV, é possível identificar os principais causadores e mitigar suas consequências ambientais.

Resultados: Os estudos concentram-se na Europa e na Ásia, predominando avaliações de aquecimento global (emissões de CO_2) e de consumo energético pré-operacionais da construção. Quanto aos maiores usos no desenvolvimento da ACV se destacaram: o *software* SimaPro, a base de dados Ecoinvent e os métodos IPCC, IMPACT 2002+ e TRACI. Verificou-se a vantagem da pré-fabricação, no entanto, não é possível generalizar devido à grande variabilidade entre os valores encontrados.

Contribuições: Este artigo permitiu identificar lacunas de estudo a serem exploradas, o panorama atual de pesquisa na área e as principais definições relacionadas a estudos de ACV para construção civil (ex. *software*, base de dados, método).

Conclusão: O termo "construção convencional" possui um significado diferente para cada país, portanto, cabe descrever detalhadamente a composição dos processos construtivos. Ainda, ressalta-se a importância de um escopo estruturado para estudos comparativos de ACV, com a declaração dos critérios adotados, a descrição do cenário em que está inserido e o uso de parâmetros consistentes para resultados confiáveis.

Palavras-chave: Comparativo. Construção convencional. Pré-fabricada. Avaliação do Ciclo de Vida. Impacto ambiental.

ANÁLISIS BIBLIOMÉTRICO DE ESTUDIOS COMPARATIVOS ENTRE LA CONSTRUCCIÓN CONVENCIONAL Y LA PREFABRICADA POR MEDIO DE LA ACV

RESUMEN

Objetivo: El artículo tiene como objetivo identificar y caracterizar estudios comparativos de Evaluación del Ciclo de Vida (ACV) entre sistemas constructivos convencionales y prefabricados.

Metodología: Se realizó un análisis bibliométrico con las etapas de formulación de la pregunta, definición de estrategia, selección de estudios, recolección y análisis de datos, resultados y conclusiones.

Pertinencia: La industria de la construcción civil es responsable de considerables impactos ambientales desde la extracción de las materias primas hasta la demolición. Con el uso de la ACV, es posible identificar los principales causantes y mitigar sus consecuencias ambientales.

Resultados: Los estudios se concentran en Europa y Asia, predominando evaluaciones de calentamiento global (emisiones de CO2) y de consumo energético preoperativo de la construcción. En cuanto a los mayores usos en el desarrollo de la ACV se destacaron: el software SimaPro, la base de datos Ecoinvent y los métodos IPCC, IMPACT 2002+ y TRACI. Se verificó la ventaja de la pre-fabricación, sin embargo, no es posible generalizar debido a la gran variabilidad entre los valores encontrados.

Contribución: Este artículo permitió identificar lagunas de estudio a ser exploradas, el panorama actual de investigación en el área y las principales definiciones relacionadas a estudios de ACV para la construcción civil (por ejemplo, software, base de datos, método).

Conclusión: El término "construcción convencional" tiene un significado diferente para cada país, por lo que cabe describir detalladamente la composición de los procesos constructivos. Además, se resalta la importancia de un ámbito estructurado para estudios comparativos de ACV, con la declaración de los criterios adoptados, la descripción del escenario en que está inserto y el uso de parámetros consistentes para resultados confiables.

Palabras-clave: Comparativo. Construcción convencional. Prefabricada. Evaluación del ciclo de vida. Impacto ambiental.

1 INTRODUCTION

The construction industry is known to be relevant in its area of operation, either in national level, where it is responsible for the average contribution of 6% of Gross Domestic Product (GDP) of Brazil (Brazilian Chamber of Construction Industry [CBIC], 2017), or in global level for the environmental impacts due to its activities. The world consumption reaches 14% of water, 40% of generated energy and 30% of carbon dioxide emissions, with estimate of reaching 50% in 2050 (United Nations, (Nações Unidas, 2009; New Zealand Green Building Council [NZGB], 2016). As for the urban solid waste, the construction and demolition are responsible for up to 61% of total generated for each Brazilian city (BRAZIL, 2010).

In this context, it is understood that there is the need to assess the traditional form of construction and find ways to improve its performance. It was verified the existence of articles that compare the conventional construction to the prefabricated in terms of environmental impact, taking into consideration particular criteria defined for each case study.

The definition of conventional construction can be described as the one performed according to the standard practices of a country in a certain period, therefore with variation of the techniques and used materials (Sartori & Hestnes, 2007). The conventional construction was observed to be described for each country in a different manner, taking into account local aspects and availabilities, with the in loco or in situ performance as a common characteristic, in other words, its execution realized on the construction sites. (Meseguer, 1991)

Characteristics such as the fabrication of unique products, disqualified workforce with high turnover, being subject to the interference of climatic conditions and the existence of a constructive system already well established and accepted (Calmon & Vieira, 2014; Meseguer, 1991; Ribeiro, 2002) take the sector,and in particular the conventional system, to show low productivity indexes of materials management and constructive processes, with its consequential waste (Baldwin, Poon, Shen, Austin, & Wong, 2009; Nunes & Junges, 2008; Vasques & Pizzo, 2014).

The industrialization presents the process of prefabrication as a way to revert the negative points associated to the conventional construction (Jaillon, Poon, & Chiang, 2009), in which elements, components or modules are fabricated in advance, with the transfer of this activity to an off-site facility (Goodier & Gibb, 2007; Mao, Shen, Shen, & Tang, 2013).

Some characteristics such as the standardization, its application in the early stage of the project and mass construction (Goodier & Gibb, 2007; Shen, Tam, Chan, & Kong, 2002) has the potential to reduce the construction time and enhance the quality of the final product (Goodier & Gibb, 2007; Tam, Tam, & Ng, 2007). Besides, the anticipated predefinition of the system results in inflexibility of modifications and higher initial costs compared to the traditional technique (Tam, Tam, Zeng, & Ng, 2007).

In this context, this study has the generation of environmental impacts deriving from the civil construction as a problem. The goal is to raise comparative case studies of the environmental impacts of a construction executed in conventional system and in prefabricated, to gather information about the constructive methods and the LCA (Life Cycle Assessment) tool, to identify the main impacts and to compare them, in percentage terms. The studies applied the environment management tool of Life Cycle Assessment (LCA) to assess the constructive systems, which qualifies and quantifies the process impacts and materials of interest through their life cycle (ABNT ISO 14040, 2014).

Initially, the theoretical reference is introduced, composed by state-of-art LCA studies in the construction industry and through the research`s object article, followed by the method description, results and final discussion.

2 LCA AND ENVIRONMENTAL IMPACTS

The LCA has four stages: 1) Objective and scope definition, where the basic and initial information is presented for the study; 2) Inventory analysis, to gather and record data that will serve as foundation for the calculation of impacts, stage's relevant assignment; 3) Impact Assessment; The fourth and last stage, 4) Interpretation, must be iterative and continuous throughout the process, to ensure the consistency of information among all stages so that the results are truly useful to the proposed study (ABNT ISO 14040, 2014).

It is for the LCA developer to define the input information to entry on the Life Cycle Inventory (LCI) and calculate further impacts, which has also to be defined according to the study's purpose.

The impact category and impact assessment levels, the category indicators and the description models are used as possible ways to present the LCA results.

The impact categories are described according to the ABNT ISO 14040 (2014) as relevant environmental aspects based on the results found on the Inventory Analysis stage from the Life Cycle. They can be classified according to two impact levels: from midpoint, where the LCI outputs are grouped according to cause and effect characteristics on the environment, as potential impact indicators. And for endpoint, where the final consequences of categories of midpoint impacts are considered, called damages, which are basically: human health, ecosystem and natural resources (Cavalett, Chagas, Seabra, & Bonomi, 2013).

Besides this classification, it is also possible to assess if the category may impact global (such as potential of global warming), local (e.g. Residual disposition) or internally (e.g. allergic reaction in human beings).

Besides, the category indicators are tied to the environmental mechanism of cause, in other words, how the impact category will be measured, also having to be environmentally relevant. For instance, the Climate Change category impact may have the Infrared Radioactive Forcing (W/m²) as category indicator (ABNT ISO 14040, 2014).

The characterization factors derive from the characterization models, in which the impacts are grouped according to a common unit and considered in the same impact category. In the previous example, the infrared radioactive forcing can be measured equivalently in terms of CO2 kg (ABNT ISO 14040, 2014).

3 LIFE CYCLE ASSESSMENT IN CONSTRUCTION

Large scale impacts stemming from the construction sector and the singularity of their products lead to distinct and useful LCA results to support the decision making process and create a database.

Different stakeholders have particular interests over the found results: Zabalza Bribián, Aranda Usón, & Scarpellini (2009) show, for example, that professionals in service of a municipality can be based on the LCA to define and encourage the development of commercial and residential area, whereas architects and engineers have the possibility to compare technical order questions such as the definition of materials and methods. When applied early in the planning stage of a site, it allows to simulate the impacts and perform changes in the project to mitigate them (Li, Zhu, & Zhang, 2010). However, the results must be interpreted with proviso, since the author has autonomy to take a series of decisions that will influence the end result. This allows the manipulation of impacts, also the reduction of harmful effects derived from the specific materials and processes, what is called greenwashing (Institute of Applied Economic Research [IPEA], 2016).

The use of LCA in Brazil, mainly on the construction industry, is limited due to the lack of national data and entry data access in LCA (Castro, Silva, Arduin, Oliveira, & Becere, 2015; Miyazato & Oliveira, 2009).

Internationally, it was verified several comparative studies of constructive systems to a building. There were some cases in China (Cao, Li, Zhu, & Zhang, 2015; Liu, Guo, Sun, & Chang, 2016; Mao et al., 2013), Malaysia (Marsono & Balasbaneh, 2015; Omar, Doh, Panuwatwanich, & Miller, 2014; Wen, Siong, & Noor, 2015), United States (Alshamrani, 2015; Memari, Solnosky, Tufano, & Dillen, 2014; Quale, Eckelman, Williams, Sloditskie, & Zimmerman, 2012), Australia (Aye, Ngo, Crawford, Gammampila, & Mendis, 2012), Spain (González & García Navarro, 2006; Pons & Wadel, 2011), Portugal (Konig et al., 2007; Monteiro & Freire, 2012), Netherlands (Ottelé, Perini, Fraaij, Haas, & Raiteri, 2011), Hong Kong (Chau, Hui, Ng, & Powell, 2012; Dong, Jaillon, Chu, & Poon, 2015), Germany, Canada, United States, Sweden (Eriksson, 2001), Italy and Germany (Takano & Pittau, 2013), Italy (Guardigli, 2014), Poland (Pajchrowski, Noskowiak, Lewandowska, & Strykowski, 2014a, 2014b), Luxembourg (Iribarren et al., 2015), Taiwan (Chou & Yeh, 2015), Lithuania (Motuzienė, Rogoža, Lapinskienė, & Vilutienė, 2016), Serbia (Maodus, Agarski, Misulic, Budak, & Radeka, 2016) and a Brazilian study (Caldas, Lira, Melo, & Sposto, 2017). To evaluate the big amount of work regarding the LCA application in constructions, there has been performed researches such as from Chastas, Theodosiou, & Bika (2016), which conducted studies to evaluate the energetic cycle of residential buildings. Kamali & Hewage (2016) analyzed publications of LCA studies in modular buildings. Säynäjoki, Heinonen, Junnila, & Horvath (2017) analysed the variation of results from 116 LCAs of buildings in its pre-operational stage. Geng et al. (2017) conducted a bibliometric review of LCA articles published between 2010 and 2014. Anand & Amor (2017) revised LCA studies in the general construction, presenting challenges and opportunities for future researches.

Due to the lack of studies that gather comparative LCAs among conventional and prefabricated constructions, information such as the most used categories of impact, as well as software and databases and the constructive system presented the best results in terms of environmental impact, the present study examined the published researches in the last five years and after extracted data treatment, the described results was reached as follows.

4 METHOD

In this bibliometric analysis of comparative studies of executed construction in conventional and prefabricated system, the steps described on Figure 1 were performed as the strategy for article selection and further content analysis.

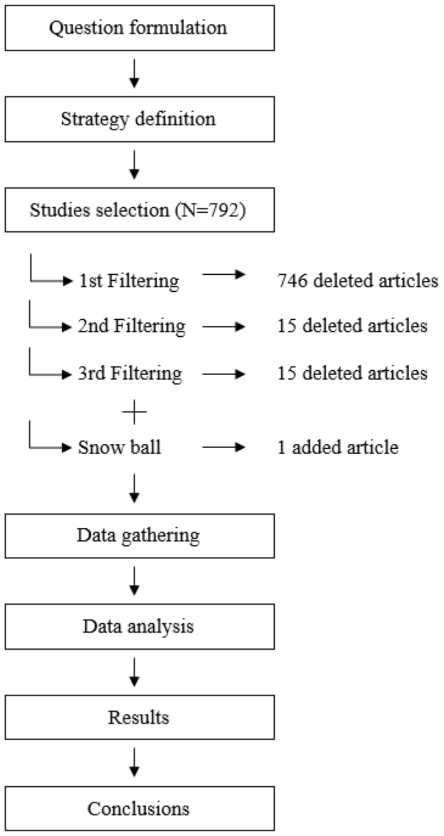

Figure 1 – Stages applied to review
Source: The author (2017)

Initially there was the question about whether the possible trend of a prefabricated construction presented less environmental impacts compared to the conventional one, such that this comparison would only be possible for equal or equivalent study cases. Therefore, the comparative studies that use the LCA tool were selected, frequently found on articles geared for environmental questions. The profile of these comparative studies were questioned as well, in terms of the applied tool and the study characteristics.

Table 1 – Selection of articles for review

Database	Results	1st Filtering	2nd Filtering	3rd Filtering	Snow ball	Final Filtering
Google Academics Articles	557	25	31	16	1	17
ScienceDirect Articles	81	5				
Web of Science Articles	79	4				
CAPES Journal Articles	75	12				

Source: The author (2017).

For articles selection, the defined strategy included the use of four databases: Google Scholar, Science Direct, Web of Science and CAPES Journals, using the keywords LCA building construction conventional prefabricated "life cycle assessment", to select articles that treated LCA applied comparably to buildings or prefabricated and conventional elements. The criteria included only considered articles published between 2013 and 2017, in which the keywords were applied in all the fields.

Author, year and country	**Title**	**Publication**	**Material Description: conventional system**	**Material Description: prefabricated**
(Mao et al., 2013) China	*Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects*	*Energy and Buildings*	*Frame shear-wall structure* e *reinforced concrete, cast in situ*	Elements in pre-molded (semi-prefabrication: prefabricated facade, scale and slabs – 10.5%) (remaining is equal to conventional)
(Takano & Pittau, 2013) Italy, Germany	*Greenhouse gas emission from construction process of multi-story wooden buildings*	*Proceedings of Sustainable Building Conference*	Wooden structure and walls (CLT panels with low level of prefabrication – just sections, drillings and metal fixing)	Wooden structure and walls (sawn wood panels – basically all the prefabricated elements
(Memari et al., 2014) United States	*Comparative study on multi-hazard resistance and embodied energy of different residential building wall systems*	*J. Civil Eng. Architect*	Load-bearing masonry walls with concrete blocks	Precast concrete load-bearing walls with central isolating layer
(Guardigli, 2014) Italy	*Comparing the environmental impact of reinforced concrete and wooden structures*	*Eco-efficient Construction and Building Materials*	Edification with walls composed of: plaster finishing, ROFIX winopor insulating, *Wienerberger porotherm* ceramic blocks, hydrated lime plaster, interior painting, slab: floor, subfloor, layer for floor warming, insulating layer, cellular concrete, wire mesh, latticed slab	Edification with walls composed of: wood fiber panel, TYVEK[1], shingle, steico pre-insulating, OSB[2] panel, steam barrier, plaster layer; slab: floor, stabilizer membrane, OSB panel, steico pre-insulating, TYVEK
(Omar et al., 2014) Malaysia	*Assessment of the embodied carbon in precast concrete wall panels using a hybrid life cycle assessment approach in Malaysia*	*Sustainable Cities and Society*	Edification with structural elements in reinforced concrete (beams, pillars, slabs) and wall sealing with ceramic brick (the latter was not considered in the study)	Edification with structural elements of precast reinforced concrete (slabs and walls)
(Pajchrowski, Noskowiak, Lewandowska & Strykowski, 2014a) Polônia	*Materials composition or energy characteristic – What is more important in environmental life cycle of buildings?*	*Building and Environment*	Masonry edification with concrete blocks (only the roof structure in wood)	Wooden edification (OSB, MDF[3], HDF[4] and cellulose – roof, walls, floor, Windows) (prefabricated walls and roof)
(Cao et al., 2015) China	*A comparative study of environmental performance between prefabricated and traditional residential buildings in China*	*Journal of Cleaner Production*	Edification in reinforced concrete *in-situ* (*reinforced concrete shear wall system structure*) (molded walls *in loco* with polystyrene panel)	Edification in precast concrete (integrated mounting of structure in *precast concrete shear wall system*) (prefabricated walls composed of polystyrene) (38% of concrete volume is prefabricated: external walls, floow, slabs, balconies, stairs, *bay windows* and technical slabs of air conditioning)
(Wen et al., 2015) Malásia	*Assessment of Embodied Energy and GlobalWarming Potential of Building Construction using Life Cycle Analysis Approach: Case Studies of Residential Buildings in Iskandar Malaysia*	*Energy and Buildings*	Edification in concrete *in-situ* (composed of concrete, bricks, steel bars, wood, plaster slabs, glass, aluminum, mortar, painting and tiles)	Edification in precast concrete (composed of precast concrete, concrete, steel bars, wood, plaster slabs, glass, aluminum, mortar, painting and ceramic tiles)

Author, year and country	Title	Publication	Material Description: conventional system	Material Description: prefabricated
(Marsono & Balasbaneh, 2015) Malásia	*Combinations of building construction material for residential building for the global warming mitigation for Malaysia*	*Construction and Building Materials*	Edification with walls in in concrete *in-situ* and bricks (composed of concrete, bricks and mortar)	Structure and walls in precast concrete (composed of concrete)
(Dong et al., 2015) Hong Kong	*Comparing carbon emissions of precast and cast-in-situ construction methods - A case study of high-rise private building*	*Construction and Building Materials*	Front in reinforced concrete *in-situ* (concrete, ironwork, wooden formwork)	Fronts in reinforced precast concrete (precast concrete, ironwork and steel die)
(Iribarren et al., 2015) Luxemburgo	*Life cycle assessment and data envelopment analysis approach for the selection of building components according to their environmental impact efficiency: a case study for external walls*	*Journal of Cleaner Production*	External walls with concrete blocks (layers: casting compound, concrete blocks, mineral wool, gypsum board and lime and cement mortar)	External walls in reinforced precast concrete (layers: casting compound, reinforced precast concrete, mineral wool, gypsum board and lime and cement mortar)
(Alshamrani, 2015) Estados Unidos	*Life cycle assessment of low-rise office building with different structure–envelope configurations*	*Canadian Journal of Civil Engineering*	Structure and walls in reinforced concrete *in-situ* of masonry with concrete blocks and bricks	Structure and walls in precast concrete panel
(Chou & Yeh, 2015) Taiwan	*Life cycle carbon dioxide emissions simulation and environmental cost analysis for building construction*	*Journal of Cleaner Production*	Edification in reinforced concrete *in*-situ (simulation in substitution to the pre-molded concrete of beams and columns – the remaining materials were considered the same)	Edification in pre-molded concrete (beams and columns – remaining elements are the same in the conventional method)
(Liu et al., 2016) China	*Assessing Cross Laminated Timber (CLT) as an Alternative Material for Mid-Rise Residential Buildings in Cold Regions in China-A Life-Cycle Assessment Approach*	*Sustainability*	Edification with structure and walls with cement, bricks, insulation and finishing; slab with insulation, concrete, cement and finishing	Edification with structure (and slab) and walls with plasterboard, CLT[5] panel, insulation and finishing
(Motuzienė et al., 2016) Lithuania	*Construction solutions for energy efficient single-family house based on its life cycle multi-criteria analysis: a case study*	*Journal of Cleaner Production*	Edification with external walls with: cement panel, silicate blocks, polystyrene foam and cement mortar; roof: bitumen, stone wool, expanded polystyrene, aerated concrete slab, cement mortar; ground floor: gravel, expanded polystyrene, concrete, floor (remaining materials are the same)	Edification with external walls with: cement panel, OSB boards, *timber frame*, stone wool and cement mortar; roof: metallic cover plate, stone wool and *timber frame*; ground floor: gravel, expanded polystyrene, concrete and ceramic slabs (remaining materials are the same)
(Maodus et al., 2016) Serbia	*Life cycle and energy performance assessment of three wall types in south-eastern Europe region*	*Energy and Buildings*	Walls composed of: mortar of lime and cement, masonry bricks, expanded polystyrene, external finishing	Walls composed of: gypsum panel, OSB slab, PVC water steam retarder, amount of wood, mineral wool, expanded polystyrene, external finishing
(Caldas et al., 2017) Brazil	*Life cycle carbon emissions inventory of brick masonry and light steel framing houses in Brasilia: proposal of design guidelines for low-carbon social housing*	*Constructed Environment*	Masonry walls with bricks	*Light steel framing walls*

Figure 1 – Characteristics of case studies by article

Source: The author (2017).

Notes:

[1] TYVEK: Works as a barrier against water and air

[2] OSB: *oriented strand board*

[3] MDF: *medium-density fiberboard*

[4] HDF: *high density fiberboard*

[5] CLT: *cross laminated timber*

With a total of 792 articles, the first filtering was proceeded to refine the results on the subject of interest through title, summary evaluation and content superficial verification. Afterwards, the repetitive articles that were duplicated in the databases were deleted, and as a third filtering, a detailed study analysis was conducted.

Author and year	Study object	ICV Database	LCA Software	AICV Method
(Mao et al., 2013)	Edification	"Embody Energy and CO2 Coefficients for NZ Building Materials" - Centre for Building Performance Research in New Zealand "The Inventory of Carbon and Energy" - University of Bath	-	IPCC 2007
(Takano & Pittau, 2013)	Unit area	Ecoinvent v. 2.2	-	-
(Memari et al., 2014)	Edification	Athena Impact Estimator for Buildings 2011	Athena Impact Estimator for Buildings 2011	TRACI
(Guardigli, 2014)	Edification	Ecoinvent, Swiss database, NREL, free US database by NREL, ELCD, database of the Joint Research Center of the European community	openLCA (GreeDeltaTD)	Eco-indicator 99
(Omar et al., 2014)	Edification	Inventory of (embodied) carbon & energy (ICE) v 2.0. UK: University of Bath (carbon emissions), Department of Climate Change and Energy Efficiency, International Energy Agency (2005), Malaysia Energy Centre and Malaysia Energy Commission	-	Calculated category indicator
(Pajchrowski, Noskowiak, Lewandowska & Strykowski, 2014a)	Edification	Ecoinvent v. 2.2, ELCD	SimaPro Analyst 7.3	IMPACT 2002+, Ecoindicator 99/E, CML e IPCC
(Cao et al., 2015)	Edification	Athena	Athena 2004	TRACI
(Wen et al., 2015)	Unit area	GaBi 6.0	GaBi 6.0	calculated category indicator
(Marsono & Balasbaneh, 2015)	Unit area	-	Simapro 7.3.3	IPCC 2001
(Dong et al., 2015)	Unit volume	Ecoinvent	SimaPro 8	calculated category indicator
(Iribarren et al., 2015)	Unit area	Okobau.dat database	-	Okobau.dat database
(Alshamrani, 2015)	Edification	Athena 2011	Athena 2011	TRACI
(Chou & Yeh, 2015)	Edification	-	-	IPCC (calculated category indicator)
(Liu et al., 2016)	Edification	IKE (Chinese Life Cycle Database - CLCD 2016)	Athena 2013	TRACI (calculated category indicator)
(Motuzienė et al., 2016)	Unit area	-	SimaPro 7.2	IMPACT 2002+V2.10
(Maodus et al., 2016)	Edification	Ecoinvent 3	Simapro 8	IMPACT 2002+
(Caldas et al., 2017)	Edification	-	DesignBuilder	Calculated category indicator

Figure 2 – Characteristics of case studies by article
Source: The author (2017).

In this stage, a search was conducted to look for foreign specialized literature, which was considered as conventional technique in the country. The techniques that did not fit in the comparison between conventional constructive systems and prefabricated ones were discarded.

The selected articles compared, besides edification as a whole, structural systems and unit areas, such as walls of different composition of materials. Moreover, some studies compared more than two variables, and it was agreed that the recurring materials among the analyzed articles would be chosen.

With a final result of 16 articles to be reviewed, the technique known as snow ball was applied to look for its references in other possible studies that fit in the proposed review. Finally, 17 articles were evaluated (Table 1).

Figure 2 shows the revised articles, disposed according to the publication year, with their corresponding authors, years, countries and material descriptions (composition of constructive systems) used in the comparison of environmental impacts. Figure 3 defines the study object, the used database on Life Cycle Inventory, the used software and chosen method of impact evaluation.

All of the environmental impacts calculated by the authors were collected for a comparative assessment between articles, both for the conventional system and for the prefabricated, transforming their sum in 100%. Thereafter, the relative percentage to the impact of each system was calculated to verify which one of them was prevailing.

In the results interpretation, the relative percentage to the conventional construction and to the prefabricated was presented for each considered impact.

Finally, the conclusions are presented, verifying the accordance to the review's initial objective, discussions regarding the presented results and suggestion for further studies.

5 RESULTS AND DISCUSSIONS

The concentration of comparative studies in the Asian continent and European was verified, with eight and seven articles, respectively. As for the system's limits on life cycles, the Table 3 divides in three general stages: pre-operational, which corresponds to sub-steps: raw materials extraction, fabrication of construction materials, materials transport, equipment and energy use on site, waste (residues) and residues transportation; operational: maintenance, renewing and consumed energy during use; post-operational: recycling, demolition (residues generation) and residues transportation.

Studies of impacts regarding the pre-operational stage were predominant. On the "raw material extraction" sub-step, eleven out of seventeen articles analyzed the environmental impacts originating from the activity, in other words, 65% of articles. Only the "fabrication of construction materials" sub-step was evaluated in all articles.

However, the least evaluated processes were related to residues transportation and recycling. After performing the same procedure for the stages, the conclusion was that 100% of articles analyzed the pre-operational impacts, 53% operational and 41% post-operational.

Regarding the used database, the Ecoinvent was the most used with 23.5%, supported by different application programs. With respect to the recurring software, the SimaPro, one of the most used in the world, was present in 29.4% of studies. Next, Athena comes with 23.5%, specific for the construction industry. The IPCC methods (carbon footprint), IMPACT 2002+ and TRACI (only available method in Athena software) were applied in 58.8% of articles.

The survey of presented results for each article was also performed (Chart 1), in where 26 different measure units related to environmental impacts were identified, of which: midpoint impact categories (19), endpoint (4), category indicator (1) or input flow on AICV (2).

Table 2 – System limits on life cycle by article

% of articles that calculated sub-step impact	65%	100%	88%	88%	24%	18%	35%	24%	47%	12%	41%	18%
Amount of articles that calculated sub-step impact	11	17	15	15	4	3	6	4	8	2	7	3
1 (Mao et al., 2013)	x	x	x	x								
2 (Takano & Pittau, 2013)	x	x	x	x					x			
3 (Memari et al., 2014)	x	x	x	x			x	x			x	x
4 (Guardigli, 2014)		x	x	x								
5 (Omar et al., 2014)	x	x	x	x								
6 (Pajchrowski, Noskowiak, Lewandowska & Strykowski, 2014a)		x	x	x	x	x						
7 (Cao et al., 2015)	x	x	x	x	x							
8 (Wen et al., 2015)	x	x	x	x								
9 (Marsono & Balasbaneh, 2015)	x	x	x	x	x	x	x		x			
10 (Dong et al., 2015)	x	x		x	x							
11 (Iribarren et al., 2015)	x	x										
12 (Alshamrani, 2015)		x	x	x		x	x		x		x	
13 (Chou & Yeh, 2015)		x	x	x				x	x		x	
14 (Liu et al., 2016)		x	x	x					x	x	x	
15 (Motuzienė et al., 2016)		x	x	x			x	x	x	x	x	x
16 (Maodus et al., 2016)	x	x	x	x			x		x		x	
17 (Caldas et al., 2017)	x	x	x				x	x	x		x	x
Article authors	Raw material extraction	Construction materials fabrication	Materials transportation	Equipments and energy use on site	Waste (residues)	Residues transportation	Maintenance	Renewing	Consumed energy during use	Recycling	Demolition (residue generation)	Residues transportation
	Pre-operational						Operational			Post-operational		
% of articles that calculated stage impact	100%						53%			41%		

Source: The author (2017).

Of these, the potential of global warming, equivalent CO2 emission and energy consumption had the most recurrence, followed by the ozone layer depletion, human health, ecosystem quality and resources.

Figure 4 presents the calculated impacts for each system, converted in relative percentage to the total impact generated by the sum of the prefabricated and conventional constructive systems, in order to check their respective contributions.

For instance, the article of numbering 1, from Mao et al. (2013) authors, calculated that the prefabricated construction generated less amount of greenhouse gases, since of all produced by the systems, 49.2% was coming from the prefabricated construction, against 50.8% from the conventional.

Alternatively, the article 4, from Guardigli (2014), evaluated the impacts on human health,on ecosystem quality and on natural resources, which are categories of endpoint impact. The prefabricated construction impacted in 32%, 52.6% and 28.6%, in the same order, presentind better results in the first and the last category.

When calculating the overall average of impacts's percentages for each system, it was verified that the impacts on prefabricated edification was 47.2%, whereas 52.8% in the conventional, with 9% of standard deviation.

As for the choice of impacts to be calculated, the energy consumption, the equivalent CO2 emission and the potential of global warming had the biggest occurrences in the studies.

Name	Classification
Incorporated energy	Input flow
Energy consumption	Input flow
Equivalent CO2 emission	Category indicator
Greenhouse gases	Category indicator – *midpoint*
Global warming potential	Category indicator – *midpoint*
Minerals extraction	Category indicator – *midpoint*
Land occupation	Category indicator – *midpoint*
Land acid./nutrification	Category indicator – *midpoint*
Land ecotoxicity	Category indicator – *midpoint*
Water ecotoxicity	Category indicator – *midpoint*
Ozone layer depletion	Category indicator – *midpoint*
Ionizing radiation	Category indicator – *midpoint*
Inhalable organic	Category indicator – *midpoint*
Inhalable inorganic	Category indicator – *midpoint*
Non-carcinogenic	Category indicator – *midpoint*
Carcinogenic	Category indicator – *midpoint*
Photochemical oxidant formation	Category indicator – *midpoint*
Acidification	Category indicator – *midpoint*
Eutrophication	Category indicator – *midpoint*
Emission index – water	Category indicator – *midpoint*
Emission index – air	Category indicator – *midpoint*
Emission index – land	Category indicator – *midpoint*
Human health	Category indicator - *endpoint*
Ecosystem quality	Category indicator - *endpoint*
Climate changes	Category indicator - *endpoint*
Resources	Category indicator - *endpoint*

Chart 1 – Classification of units presented as results in the articles
Source: The author (2017).

	Impact/ article*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
PRÉFABRICATED SYSTEM	Incorporated energy			29.7					41.0									
	Energy consumption						48.8					56.6	49.4		37.7	47.9		
	Equivalent CO_2 emission					42.4					47.3		49.5	50.3	35.1			51.3
	Greenhouse gases	49.2	49.0															
	Global warming potential						48.2		46.4	52.0		54.7	49.4			47.1		
	Minerals extraction						36.1											
	Land occupation						51.4											
	Land acid./nutrification						47.3											
	Land ecotoxicity						48.9											
	Water ecotoxicity						49.7											
	Ozone layer depletion						49.0					49.7				46.6		
	Ionizing radiation						44.5											
	Inhalable organic						51.7											
	Inhalable inorganic						44.6											
	Non-carcinogenic						51.3											
	Carcinogenic						49.3											
	Photochemical oxidant formation											60.6						
	Acidification											56.7						

	Impact/ article*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Eutrophication											54.1						
	Emission index – water												49.0					
	Emission index – air												49.4					
	Emission index – land												48.5					
	Human health				32.0					48.3							60.7	
	Ecosystem quality				52.6					49.1							77.7	
	Climate changes																20.5	
	Resources				28.6					39.1							26.9	
CONVENTIONAL SYSTEM	Incorporated energy			70.3					59.0									
	Energy consumption						51.1					43.4	50.6		62.3	52.0		
	Equivalent CO_2 emission					57.6					52.7		50.5	49.7	64.9			48.7
	Greenhouse gases	50.8	51.0															
	Global warming potential						51.8		53.6	48.0		45.2	50.5			52.8		
	Minerals extraction						63.9											
	Land occupation						48.6											
	Land acid./nutrification						52.7											
	Land ecotoxicity						51.1											
	Water ecotoxicity						50.3											
	Ozone layer depletion						51.0					50.3				53.4		
	Ionizing radiation						55.5											
	Inhalable organic						48.3											
	Inhalable inorganic						55.5											
	Non-carcinogenic						48.7											
	Carcinogenic						50.7											
	Photochemical oxidant formation											39.4						
	Acidification											43.3						
	Eutrophication											45.9						
	Emission index – water												51.0					
	Emission index – air												50.6					
	Emission index – land												51.5					
	Human health				68.0			51.7									39.3	
	Ecosystem quality				47.4			50.9									22.3	
	Climate changes																79.5	
	Resources				71.4			61.0									73.1	

Figure 3 – Relative percentages by impact for the prefabricated and conventional systems
Source: The author (2017).
Notes:
*Articles numbering according to Table 3 in: Article authors

6 CONCLUSION / FINAL CONSIDERATIONS

Studies regarding the generation of environmental impacts in the construction industry had an expressive growth in the last decade, which highlights the need to find more environmentally sustainable solutions.

When raising the comparative studies of environmental impacts in conventional and prefabricated constructions performed in the last five years, some articles produced in different countries were found. This highlighted the variability of applied materials and techniques according to the regional characteristics, which in their majority, due to its lack of information, demanded the search in specialized literature over the execution to understand the constructive method and materials application for further classification on a conventional, prefabricated system or article exclusion in case it did not fit in the comparison.

Therefore, the description of the constructive method and the applied materials is recommended in future studies to help international researches understand the national constructive systems.

When it comes to the raised impacts for each system, the prefabricated showed better results compared to the conventional in most categories. However, due to the found value for the standard deviation, it is not possible to state as a general conclusion, what express the variability on impact values.

Each LCA has unique characteristics that influence the impact calculation, such as the site place, the transportation distance, the applied materials and its quantities. The used databases in the life cycle inventory stage are still scarce in Brazil and are based on international values to adapt to the Brazilian circumstances.

Besides this, some decisions are taken during the development of an LCA that will generate a singular outcome. For this reason, it is important to describe all the stages during implementation and the choices made, which was not verified in several of the revised studies, inhibiting its reproduction and quality assessment.

Finally, the accomplishment of the LCA is a complex activity, and simplifying it considering only the relevant activities and processes may reduce the spent effort and time.

In addition, comparative LCAs must be performed in a consistent way for a proper and equivalent comparison, once in the current scenario in where environmental sustainability has been discussion focus, the statement that one item in more sustainable than another must be assessed with criteria, to avoid the greenwashing experience and manipulation of information to distort them.

As a suggestion for further researches, the difference between the impacts of constructive systems may be analyzed, which even though is small in percentage, it is not conclusive about its relevance. Still, the development of comparative studies are encouraged, applying the LCA tool in the construction industry, given the sector’s importance for the environmental questions in local and global levels.

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