

Prefabrication in the Lean Construction context: limitations and challenges in the current scenario

Corvello F¹, Hermosilla J², Amaral C³, Galati I⁴, Silva E⁵

Abstract. The prefabricated construction has become an important area over the last decade, not only for its agility, but also for its adherence to the Lean Construction philosophy, that promotes the reduction of the volume of waste in building and contributes to a lower environmental impact. The search for a more efficient and innovative prefabricated construction method has promoted the development of several different models, but all of them have advantages and disadvantages, mainly related to transportation, machinery, and labor, when applied to small buildings. This paper aims to identify through a literature review the main and most current models of prefabricated construction, identify the gaps on the operationalization of small constructions processes and propose new research to solve the problems of prefabricated construction. The lack of versatile prefabricated models that help to improve the efficiency on the filling stage in small constructions and that allows the reuse of materials is a gap existing processes that have yet to be explored.

Keywords: Lean Construction, Prefabrication, Small Building.

1 Introduction

The "thorough elimination of wasteful practices is the basic concept of the Toyota production system", according to Ohno (1982), and it was based on this concept that in 1987, team leader John Krafcik, from the automotive industry segment, decided to denominate it from Lean, as a reference to the principles of reduction of human efforts, defects, time, and investment, which began to mark the management of production at the time (Womack and Krafcik, 2013), however, the new philosophy was only disseminated around the world after the publication of the article "Triumph of the Lean Production System" (Ohno, 1982).

This concept, despite of having originated in the automotive industry, has also influenced other segments, such as the construction industry, giving rise to Lean Construction (LC) which is a new management method for the construction area. While traditionally construction considers only conversion activities in its management process, this new method is based on the transformation of the entire construction process into a flow, encompassing both conversion activities (activities that add value), and those of another nature, which generate waste (such as waiting time and movement) (Koskela, 1992).

Despite the gains provided by lean construction philosophy, there are still many losses present in the processes of construction production, especially traditional masonry, in the closing step, ceramic brick losses reach an average of up to 17% of blocks, while the mortar used in this method can reach up to 115% waste on average (Pinho and Lordsleem, 2009) . This stage of construction, considered one of the most critical from the point of view of its waste, has been investigated by several scholars and has led to the development of new production processes, in order to mitigate their associated losses, that is the one of the purposes of prefabrication processes, it is a concern that rise in the third stage of development of lean construction philosophy, from 2012 (Li et al., 2019).

¹Flávia Motta Corvello (✉e-mail: flaviamcorvello@gmail.com)

University of Araraquara/UNIARA, Voluntários da Pátria Street, 1309, Araraquara, SP 14801-320, BRA

²José Luís Garcia Hermosilla (✉e-mail: jlghermosilla@hotmail.com)

University of Araraquara/UNIARA, Voluntários da Pátria Street, 1309, Araraquara, SP 14801-320, BRA

³Creusa Sayuri Tahara Amaral (✉e-mail: c.sayuri.tahara@gmail.com)

University of Araraquara/UNIARA, Voluntários da Pátria Street, 1309, Araraquara, SP 14801-320, BRA

⁴Ingrid Simone Galati (✉e-mail: ingrid_galati@hotmail.com)

University of Araraquara/UNIARA, Voluntários da Pátria Street, 1309, Araraquara, SP 14801-320, BRA

⁵Ethel Cristina Chiari da Silva (✉e-mail: e-chiari@uol.com.br)

University of Araraquara/UNIARA, Voluntários da Pátria Street, 1309, Araraquara, SP 14801-320, BRA

However, these studies are still recent and do not present consistent solutions (prefabricated product) for the identified problems (waste) in the structure, closing and finishing stages of the construction process. In addition, existing prefabricated products are custom-made, and due to their dimensional characteristics, for the most part, require specialized labor, specific and high-cost equipment for their transportation and assembly (Sulzbach, 2015) which ultimately limits their use in low-cost residential buildings. Another characteristic of the existing methods is their low capability to reuse the materials used in the buildings processes in the end of the construction lifecycle, in the demolition stage, which increases the environmental impact due to disposal of the waste (Iacovidou and Purnell, 2016).

The purpose of this paper is to raise the main prefabricated construction models that can be applied to small building, identify their limitations, and propose new research fronts through the review of the Literature.

The search for solutions that reduce losses and waste in civil construction, and especially in small buildings, promote cost reduction and expand access to housing by lower-income social classes, in addition to environmental gains (Carvajal-Arango et al., 2019). The development of products whose design prolongs the life cycle of the building elements is pointed out as one of the solutions for this scenario, because it reduces the construction costs and relieves the load of the environment system due to lower needs of resources and less generation of waste in the eventual demolition stage, in addition to reducing the disposal of non-renewable materials (Iacovidou and Purnell, 2016).

2 Methodology

The review of the literature was used to identify the most recent research on the prefabrication theme, in order to identify the main gaps in its operationalization in small buildings, its environmental impact, and establish a comparison of research in relation to the publications raised, to solve the problems that present in the construction segment.

The journal bases used were Scopus, Web of Science and Science Direct. The first step to the search in the 3 journal bases was the selection of descriptors that best represented the theme of the investigation, and which were lean construction, prefabrication, and small building. The search using the 3 descriptors together revealed that there are no articles with these 3 words in the title or in the keywords of the articles. Thus, a new search was carried out with the combination 2 to 2 of these descriptors in the journal bases, which were "Lean Construction" AND "Prefabrication", "Lean Construction" AND "Small Building", "Prefabrication" AND "Small Building". In this second search, articles were selected that contain the descriptors in any part of the article, whether in the title, in the keywords or in the text. This procedure, disregarding the year of publication, resulted in 633 articles, which were reduced to 424, when considered only those from 2014. After deleting duplicate papers (36 articles), the survey was reduced to 388 publications.

A new filter was applied to the previous relationship, with the objective of eliminating articles that did not focus on prefabrication processes, excluding those that did not present in the title or keywords, the descriptors mentioned above, and which contained some of the words "BIM, "costs" or "supply chain", which resulted in 152 publications, which were selected for the analysis of the abstract.

It is noteworthy that, at first, topics such as *gas emission* and *green construction* were among the exclusion criteria, along with the terms mentioned before (BIM, costs and supply chain), however, after being observed in the securities raised to probable relationship between the research theme and the environment, we chose to keep them at this stage of selection.

The selection process classified 24 articles to be reading in their totality among 152 that were previous selected, cause the others were excluded for not being related to the objective of this article. The excluded ones were related to themes as determination of the resistance of prefabricated, certifications and old limitations of the philosophy.

The systematic adopted for the selection of scientific research articles can be visualized through prism workflow represented in Figure 1:

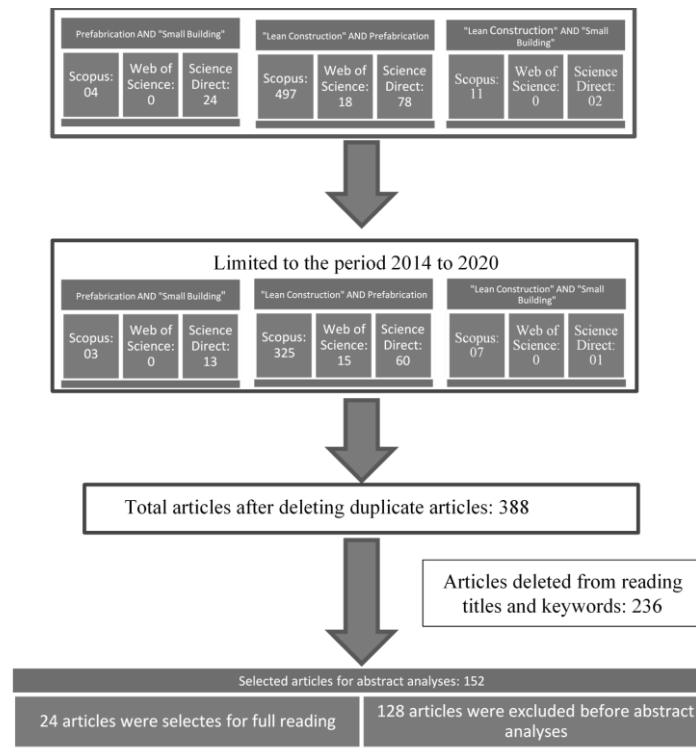


Fig. 1 Prism Workflow.

3 Results and analysis

Although different approaches have been identified in the bibliographic survey, as well as emphasis on aspects of prefabrication in constructions and in the relationship with the environment, the consensus among the authors regarding the problems still existing in the civil construction sector, which could not be solved by the prefabrication methods hitherto in force, is notorious.

The analysis of the 24 articles selected for full reading allowed the construction of an evolutionary scenario for prefabrication that can be characterized in 3 stages for better understanding: the rise of prefabrication in lean construction's evolutionary treadmill, its relationship with the environment in the context of civil construction, and the construction methods used in prefabrication (see Figure 2). Another aspect that the bibliographic analysis of the selected material revealed was the attention given to certain themes and the lack of it to others, considering the frequency with which they were referenced in scientific materials, as can be observed in Figure 3.

Sub-theme investigated	Number of articles
Prefabrication at Lean Construction	07
Environmental aspects of prefabrication	03
Prefabrication methods	14

Fig. 2. Number of articles per sub-themed.

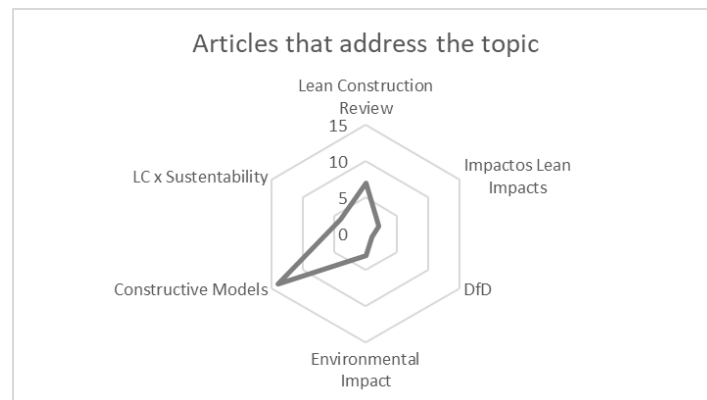


Fig. 3. Topics addressed by the 24 articles analyzed.

The evolution of Lean Construction and its phases over time can be better understood by observing the publications on this theme, which according to Li et al. (2019) can be divided into three periods: the first from 1997 to 2006, revealed the concern at the time with issues related to costs and cost management of buildings, quality management and control and sustainability; in the second period, between 2007 and 2011, the most recurrent themes in the area referred to issues related to supply chain management, workflow and planning and programming of the construction (P&S) and, finally, in the period from 2012 to 2016, attention turned to the rise of prefabricated construction and BIM (*Building Information Modeling*) in the construction industry.

The specialized literature shows that the characteristics of this last period are still in force today. Prefabrication (on-site and off-site) and BIM are currently considered the two main tools for improvement in construction. BIM for its evolution and technological integration, and prefabrication for achieving zero waste on construction sites, reducing construction time and reducing the impact on the environment (Li et al., 2019; Carvajal-Arango et al., 2019; Baijou et al., 2019; Babalola et al., 2019; Solaimani and Sedighi, 2019; Antillón et al., 2014; Jin et al, 2018).

The concern with the environment is also another recurrent aspect in research involving prefabrication in the context of Lean Construction because it is an alternative that is viable within certain circumstances to mitigate the impacts of civil construction activities on the environment.

Among the main impacts that civil activity causes, we highlight all non-renewable materials that are used in constructions and renovations, removed from the environment and that cannot be renewed, a situation that is aggravated in many cases by the transformation of these materials into waste and waste from the building, accumulated during the construction phases, with losses intensified by the disqualified labor existing in traditional construction; these losses are further enhanced in other stages of the construction as possible reform processes, where part of these materials are discarded, in addition to the other losses of resources for the reprocessing of activities that had already been finished, and more intensely in the demolition processes, where all this non-renewable material is lost (Polat and Purnell, 2015). An alternative that presents itself to this challenge is the reuse of these materials to promote sustainability in the construction sector, however, for this alternative to be viable it should be preceded by incentive and training programs, and to rely on materials that presented appropriate conditions that would allow its remanufacturing, a fact that is advocated by Iacovidou and Purnell (2016), who propose a tool to manage this reuse. Iacovidou and Purnell (2016) also point as an alternative and solution to the environment building models that have a reusable design (they are called Design for Deconstruction or Design for Reuse), which would reduce the use of non-renewable resources and make the construction process more sustainable; the design of models aimed at reuse or disassembly could also be the solution to environmental problems related to the demolition of buildings, with the end of the life cycle of these resources and the need for landfills for the disposal of debris. However, this design is only available for some construction items, which makes it impossible to completely disassemble the construction for the reuse of the parts.

On the other hand, the concern about the large amount of carbon emissions during the various stages of the construction process has gained strength. The high levels of carbon emissions produced in the construction and demolition processes, has become one of the biggest and limiting problems in the

construction segment, for the sustainable development of the business. This fact is explained in large part by the intensive use of machines throughout the life cycle of the construction, from the production of the elements and basic items for the construction, with emphasis on the exothermic process of concrete, the transport of raw materials and finished products, to a possible stage of demolition. The use of some prefabrication methods can actually reduce the production of waste at the construction site at the stage of construction or assembly, but the need to adapt the methods for low carbon construction still exists, since these processes are not free of the machines for assembly and transport (Kesidou and Sorrel, 2018).

Recent specialized literature presents 4 main groups of prefabricated building models, which differ in assembly activities, limitations and benefits provided (Ayinla et al., 2019; Mostafa et al., 2016; Bamana et al., 2017; Baghchesaraei et al., 2015).

The construction in panels and wood is one of the prefabricated processes mentioned, which has as characteristic the versatility since it can adapt to the different construction designs. The evolution of this constructive technique allowed the replacement of the construction activity by the assembly activity, which tends to reduce the construction time and its costs, besides allowing its disassembly and the reuse of the products. On the other hand, the construction in panels and wood has limitations regarding fragility and resistance, which restricts its acceptance. Another disadvantage is the requirement of skilled labor for its assembly (Bhattacharjee et al., 2016; Serra Soriano et al., 2014; Bamana et al., 2019).

Prefabricated concrete construction is another process that can be carried out on site (on-site) or in the industry (off-site). Because it is like traditional construction, this type of prefabrication has better acceptance by the market, when compared to the others, since it uses material with the same resistance characteristics and technical recommendations as major works. The use of this technique reduces waste and time to perform the work and increases the productivity of construction processes. On the other hand, the materials used in the execution of the construction are difficult to move, requiring special conditions for transport and construction, increasing the costs of the building, in order to make this process impossible for small constructions (Li et al., 2020; Shahpari et al., 2020; Galhardo et al., 2014; Tam et al., 2015).

The volumetric construction and DfMA can be understood as another alternative prefabrication process, which is characterized by the individualized production of construction rooms, such as bathrooms and kitchens, which resemble large concrete boxes, which are fitted to other prefabricated parts in the construction, by means of cranes and large equipment. This alternative has as positive points the agility of local construction and the reduction of waste on the construction site, since even the finish is completed in this process. A variation of this volumetric construction technique is prefabrication in containers, which can be used to build from small houses to large buildings, reusing containers that would no longer be used, eliminating the use of some non-renewable materials used in the closing stages of the work. The main positive aspect of this construction model is the significant reduction in the time of major works, however, they depend on large specific machinery for the transport and assembly of the construction, which increases the use in small buildings (Gao et al., 2018; Navaratnam et al., 2019).

The 3D printing is the newest form of on-site prefabrication, in which large printers print the previously designed construction in concrete. Among the advantages of this technology is the agility in construction, which allows the printing of small houses in hours, does not present waste of material and has low cost due to the more rational use of raw material. The disadvantages of this process focus on the difficulty of access to this technology, since it is still little widespread, besides the impossibility of reusing the material, which cannot be disassembled, and the lack of quality in the finishing of the walls (Wang et al., 2018).

The analysis of the various processes mentioned revealed common points, mentioned in all the investigations raised, which allow a better understanding of the current scenario in which the world civil construction is located, and the pillars of this new era in this segment of the economy: Lean Construction, Prefabrication and the concern with sustainability. The chronology of the evolutionary process of Lean Construction as shown in Figure 4 more clearly reveals the evidence stemming from the above, also showing the advantages and disadvantages of recent constructive models from this third phase of LC, specifically linked to prefabrication and the environment.

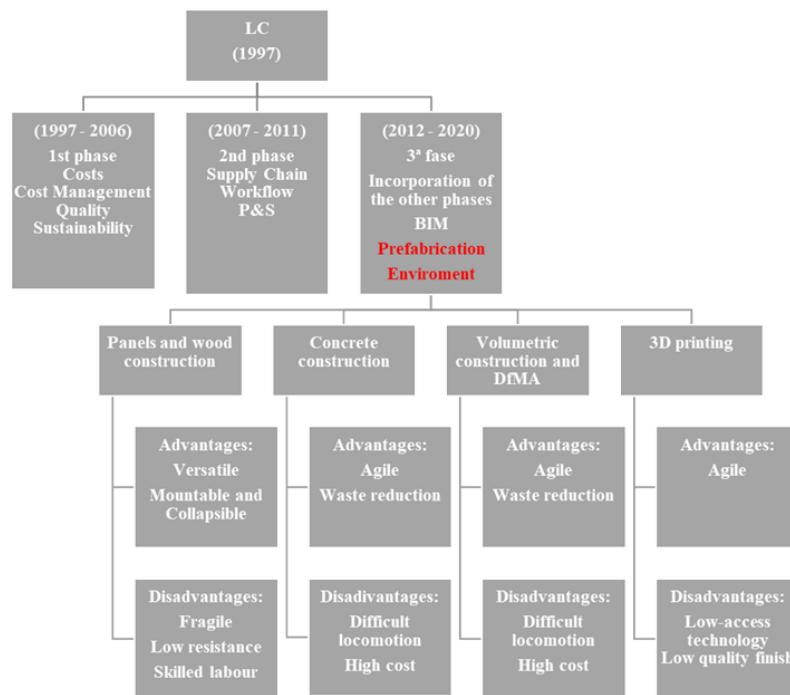


Fig. 4. Evolutionary synthesis of Lean Construction to construction processes.

Waste of time and materials is no longer tolerated, as is garbage on construction sites; the environmental impact has become a real concern and it is considered that there is already technology and skilled labor for this to be applied in large buildings with the use of prefabrication techniques. What still needs an appropriate solution is the development of a constructive method for small buildings, which is accessible to the lower-income population or people in vulnerable situations, such as refugees, who need shelter in different regions of the globe and are itinerant. This gap that distances the prefabrication from full sustainability becomes clearer when the main disadvantages observed in the analyzed articles are highlighted (see Figure 5).

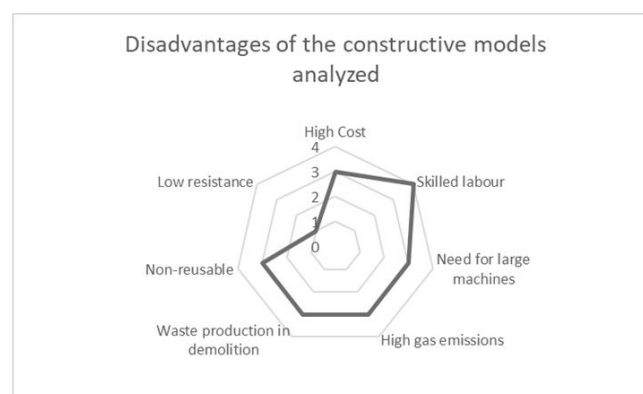


Fig. 5. Disadvantages raised in the four groups of constructive models obtained in the articles analyzed.

The methods that can be applied to small construction, require skilled labor (such as prefabrication with panels) or else require large machines and high technology (such as 3D printing on site), which increase the cost of these methods, in addition, do not allow the reuse of the material, either by the plastered design

or by the inability to dismount the parts, and any modification or reform of the construction results and losses of materials or demolition.

4 Conclusions

The Lean Construction philosophy is well established in the world, especially in developed countries. The concern with the generation of waste and emission of gases in the stages of construction and demolition has been the main reasons for the development of new construction systems. Prefabrication is capable of addressing the three dimensions of sustainability: economic, social and ambiental (Bhattacharjee et al., 2016), but most prefabricated models depend on large machines for their assembly and transportation, which increases the construction process and increases the total emission of gases from the construction (Serra Soriano et al., 2014).

Among the various prefabricated models analyzed and contextualized with the maturity of Lean Construction, it is possible to affirm that technological evolution in the construction sector has grown exponentially in the last two decades, reducing construction time and its waste. However, they are still expensive technologies, which use labor and specific equipment, making construction in certain regions unfeasible and limiting access to the lower income population.

These limitations of current construction processes, which restrict access to residential civil works by a large part of the world's population in a state of vulnerability and, on the other hand, the possibilities of improvement in current processes that allow increased environmental efficiency in the use of resources, open exciting perspectives for the sector. One of the alternatives, which has been little explored in the literature, but which presents itself as an alternative and complementary way to the techniques mentioned, is the investment in design of the construction elements, which could allow the more rational use of natural resources as well as their reuse in constructions that had the flexibility to be assembled and disassembled with minimal losses. The investment in this sense, also improving the ability to handle these materials without the need for high technical training or mechanical support, would be an alternative that would greatly add to the social and economic viability of processes of this nature. The design of the construction elements used in civil construction, addressed in several scientific productions with the name of DfD, is a path that proves promising in the search for sustainability in this segment, since it allows the inclusion of social needs (accessibility, practicality, usability and comfort) and also of more rational construction practices, however, it demands greater attention and investments in order to make these expectations (assembly and disassembly) a reality and accessible to vulnerable populations.

It was little until the time of solutions that consider the element of filling or structural as an important part of the solution to the challenges posed. The attention of the research work raised, is more focused on the techniques of construction itself and industrialization of civil construction processes, however, the development of products can be an important alternative that will provide gains in scale in the process as a whole, due to its effects throughout the sequence of civil activities.

The development of prefabrication techniques still has major challenges ahead such as the difficulty of access to this type of construction by the low-income classes, the difficulty of locomotion of the prefabricated parts and the high amount of waste and gases that affect the environment, but these barriers also present themselves as opportunities that gradually seem to mature in an increasingly clear horizon. The product development with more appropriated design that has interchangeability and the more rational use of resources as characteristics, presents itself as a possible solution for low cost constructions and great social reach. Additionally, the benefits will be greater if it was considered in this kind of strategy the possibility to manufacture these products using some materials that are nowadays disposed in an unappropriated way as plastic and ceramic.

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