Impacts of Prefabrication in the Building Construction Industry

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Interest in sustainable construction has been increasing due to recent events. The limitations of natural resources and the scale of global impacts, specifically as a result of the effects of global climate change, have consequences for the construction sector. These changes are giving rise to a need to reassess the way we face the built environment and rethink new solutions for construction systems or methods that contribute to mitigating negative consequences, among which we highlight the prefabrication method. This new scenario, characterised by the need to meet the decarbonisation goals set for 2050, as well as the effects of the spread of the pandemic crisis, emphasizes the importance of understanding the impacts that may occur in the construction industry, which are essentially understood as increases in sustainability, productivity, quality and, consequently, as reductions in deadlines, costs, and dependence on labour. Therefore, this entry seeks to study on the existing literature on prefabrication, seeking to gather relevant information on the new advances, challenges, and opportunities of this construction method whose approach has been mostly focused on partial or specific aspects for case studies, both highlighting the potential and identifying the gaps and opportunities of prefabrication in this new context. The prefabrication method brings benefits compared to the conventional method, and may be an alternative, as it has more positive global impacts on the environment, the economy, and society, and consequently on the sustainable development of construction, despite some limitations that have been reported and that should be looked into in the future.

Keywords: prefabrication ; off-site construction ; sustainable development ; building industry ; comprehensive benefits of prefabricated buildings

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Recent data show that the construction sector accounts for 32% of global resource consumption and the emission of about 40% of anthropogenic greenhouse gases (GHGs). The waste generated by the sector represents, by mass, about 40% of the materials consumed. In 2019, carbon dioxide emissions, at around 10 $GtCO_2$, reached their highest level, representing 28% of the CO_2 emissions associated with energy production worldwide [1][2].

The main targets identified by the European Union (EU) to meet the objectives of the Paris Agreement (Paris Agreement, 2015) include a reduction in the impact of buildings, especially residential buildings. There is a commitment to decarbonise buildings by 2050, setting ambitious targets for tackling climate change. Its realisation in 2030 aims to achieve at least 32% renewable energy in energy consumption and at least a 32.5% improvement in the energy efficiency of buildings in the EU. Based on these data, the International Energy Agency predicts that direct CO_2 emissions from buildings should decrease by about 50% and indirect emissions from the sector by 60% in terms of the generation of emissions associated with energy production by 2030. This will result in emissions decreasing by around 6% annually between 2020 and 2030 [3].

However, in 2019, with the spread of the COVID-19 pandemic, another scenario with a relevant global impact in all sectors of activity arose, one of which is the construction industry sector. Despite the changes caused being operational in the first phase, mostly through a reduction in the production and supply capacity of the markets, resulting in a reduction in global growth, investment, and exports, in the long term, other dynamic scenarios will tend to occur, with some of the consequences beginning to be noted, despite attempts to minimize their impact, mainly on the economy. Among the most mentioned for the construction industry is the acceleration in the integration of digital tools, as they allow for better collaboration, greater control of the value chain, a change to a more data-driven decision-making process (such as the so-called "Digital Twins", which mimic the thermal and energy behaviour of building stock and allow the industry to respond to the problems of the climate crisis), as well as investment in the standardisation of building codes, especially in terms of safety and sustainability, in addition to a greater focus on industrialisation with modularisation, off-site production automation, and on-site assembly automation [3][4].

These recent measures and events, in order to comply with the decarbonisation of buildings so as to mitigate the effects of climate change, will have implications in the construction industry sector, and modifications in the markets are likely to arise with greater constraints on the stabilisation of the skilled workforce and the costs of infrastructure and raw materials, creating the need to develop new digital technologies (the digitisation of products and processes) and new regulations on fundamental matters such as sustainability, with a new emerging dynamic being necessary. In light of these changes, the construction industry sector is beginning to undergo considerable transformations in an ongoing process, transformations which have meanwhile been sped up by the pandemic crisis.

It is therefore pivotal to highlight the role that prefabrication (including modular construction) could play in the medium and long term, since its potential in contributing to an effective reduction in overall building impacts and costs has been discussed. With more environmentally sustainable policies, it will be possible to ensure more energy-efficient and carbon-reduced buildings. The main benefits are the type of use of materials, waste reduction, cost and construction time reduction, the increase in the safety and quality of products, greater efficiency in quality control, the growth of productivity, and the improvement of the performance of buildings [5][6][7][8].

One of the main potentials of prefabrication refers to the increase in productivity and the role of construction costs and quality. Essentially, productivity, costs, and the quality of construction are directly affected by their dependence on extensive and complex value chains, by the high number of people involved in these chains, and by labour shortages. One of the potentialities of prefabrication is precisely to allow for an increase in productivity, in cost reduction, and in the rigour and control of the quality of construction.

In fact, many of the obstacles to higher productivity and ways to overcome them have been known for some time, but the industry has been at a standstill. However, there are factors that reduce the obstacles to change: more transparent markets; increased requirements and demands; new technologies and more readily available materials; and also the increasing cost of labour [9]. Those in the construction sector should rethink their operational approaches so as to prevent obsolescence in what could be the next big story of global productivity [10].

The existing literature further shows that the approach to analysing the impacts of the prefabrication method mainly refers to those of an environmental and economic nature.

With regard to the environmental and economic impacts of the construction industry, it is easily observed that poor performance is associated with the intrinsic characteristics of the sector, namely poor quality of buildings, the benefit of price to the detriment of quality, construction errors and defects, the complexity of the value chain, poor integration (of processes, products, and systems), and reduced industrialisation.

Social impacts have not yet been fully analysed. However, there may now be much greater interest as a result of recent changes following the pandemic crisis that has taken place. In the corporate sector, with companies having a social responsibility, the adoption of prefabrication allows for some improvement in the conditions and safety of work, producing effects on the increase in labour productivity [11][12].

This document presents a comprehensive and integrated review of the various scenarios of prefabrication development in the construction industry compared to conventional construction. Moreover, with the aim of outlining the potential of prefabrication in the construction industry in the current context and in light of the goals set forth for 2050 and the consequences of the impact of the spread of the new SARS-CoV virus in this market, the entry will also include an assessment of this conjuncture, seeking guidelines for the future.

One of the strong points of this document is that it aims to aggregate a broad set of bibliographies on this topic, which is somewhat dispersed, identifying gaps and opportunities.

Background

Historically, prefabrication in the construction industry had a greater growth with the industrial revolution, in terms of the emergence of new construction solutions and equipment, as well as material processing techniques that allowed for a systematic use of new materials, with large-scale application and series production of standardised prefabricated construction elements.

After the end of World War I, there was a great need for housing, and the best response to this lack was found in the development of serial housing construction, with its rapid assembly and economically acceptable conditions. With the main work being performed in the factory, the output and the economy of means were increased, while the time factor was decreased. This process led to the possibility of developing a large-scale mass production system on a continuous and regular basis over time. For the feasibility of the system, it was necessary to find a standardisation and normalisation of the dimensions of the various components in order to guarantee a standard that would allow for compatibility between the elements and subsystems.

The greatest growth occurred in the post-war period, occurring in Germany from the 1920s–1930s, in the United States during the 1940s and 1950s, and in the United Kingdom, in the 1960s–1970s, and resulted from the need for rapid reconstruction, especially of residential and educational buildings, as a result of the need for construction in short periods of time and at reduced costs. Since the 1970s, architectural firms have begun to show an interest in new building technologies and industrialised construction. In their projects, they incorporate materials and products from the construction industry, seeking flexible systems, as was the example in Wales with the program for the development of school building systems, the School Construction Systems Development (SCSD). However, in this period there were some incidents in the implementation of this type of prefabricated system, such as the collapse of the Ronan Point apartment tower in east London, or the fire in a residence for the elderly built through the Consortium of Local Authorities Special Programme (CLASP) in the United Kingdom, which raised concerns about the safety of prefabricated buildings. Other examples in the context of social housing have also gained negative reputations because they are considered to be of lower quality. Japan was one of the other countries that capitalised on synergies with other manufacturing industries. A high volume of modular units ensured economies of scale and lower production costs, allowing for a greater focus on quality, specifically with regard to earthquake resistance. In the decade between 1950 and 1960, the prefabricated system gave rise to a new approach to the traditional Japanese construction method—the meticulous cutting of wooden parts, which is later complemented by the use of fibre and aluminium panels, fixed to steel frames.

Industrialisation therefore radically transformed construction, since its essence aimed at the mechanised production of an object, having as its main techniques prefabrication, transport, and series production.

Although still without great relevance in terms of scale, the interest in modular constructions and prefabricated systems continued to grow, as it was understood that it allowed, above all, for an increase in efficiency, productivity, and profit in the construction sector, through the reduction of skilled labour, waste, energy, and emissions [5][6].

In the scientific community during the 1990s there was a greater interest in the field of prefabrication in the construction sector, as a result of the introduction of recent innovations. Some of these innovations included computer-aided design (the CAD/CAM connection), manufacturing mechanisation, and the robotisation of the construction process. Together, the development of new technologies and materials and the use of computer systems made it possible to learn about more flexible construction systems capable of providing shorter construction times and fewer work accidents, as well as a new capacity for the execution and assembly of structures of a higher quality than had previously occurred [13][14][15][16].

Since then, there has been extensive discussion on this topic, first around trying to understand the advantages and disadvantages compared to conventional construction, clarifying why it was not a more evident alternative, and then focussing on more specific factors and seeking to highlight its strengths, such as the fact of improving productivity (due to mass production), the benefits for the construction industry, or through life cycle assessments (LCA) in terms of time, as it allows for a time reduction of about 40% compared to conventional construction, as well as its environmental performance, and the reduction of construction costs (labour, waste production, use of materials) [17].

However, one of the problems that has been reported is that the benefits and challenges of the widespread adoption of prefabrication as an alternative to conventional construction still need to be carefully evaluated [1][18].

The need to write a paper about prefabrication in the construction industry today comes, on the one hand, from the fact that there are no papers in the literature review that address the state of knowledge of this theme in a comprehensive and integrated way, but rather they approach it in a partial way, and on the other hand, because it is understood that a new scenario has emerged, with the need to comply with the objectives of the Paris Agreement and the 2050 decarbonisation goals, cumulatively with the dissemination of the new SARS-CoV virus, which will also have an impact on the construction industry and the even greater role that prefabrication can have in the future.

As prefabrication (and modular construction) is not a new construction concept, it has attracted a wave of interest due to the changes that should occur under the Paris Agreement, as it has the capacity to offer faster construction processes with less environmental impact. Several factors lead one to believe that the renewed interest is here to stay in the markets, primarily due to digitisation. The new digital tools are contributing to the solid maturation of modular project design, ensuring significant savings throughout the process, such as reduced turnaround time, manufacturing, and assembly, and construction cost savings. The construction industry has also been adopting new materials and the development of prefabricated and modular construction systems, focusing now on environmental, energetic, and sustainability issues.

A report prepared by McKinsey & Company [19] suggests that the construction sector and clients themselves are beginning to develop strategies which adopt more industrialised models, giving as an example another study in the report on modern construction methods in the UK, in which 40% of builders claim to be investing in industrial facilities in the framework of prefabrication or plan to do so in the near future.

The most evident benefits of prefabrication compared to conventional construction, identified by several authors, are associated with:

1. Increased Productivity. According to several studies, the industrialisation of construction results in increases in productivity, quality, and sustainability and, consequently, reductions in deadlines, cost, and labour dependence [20][21][22].

The productivity of the construction industry benefits from the implementation of production optimisation techniques already tested and demonstrated in other industries, such as: the transfer of tasks to a controlled manufacturing environment—increase in prefabrication; standardisation/repeatability—panelisation and modularisation; robotisation—optimisation of the amount of labour employed in off-site tasks; rationalisation of production chains—the cancellation of intermediate agents optimizes the efficiency of processes and their continuous improvement.

2. Effectiveness in quality control. The benefits in the environmental dimension cannot be realised without integrating the value chain of industry or improving the quality of final products (either by the introduction of new technologies or by specialisation, or by abandoning the approach based on individual projects and replacing this with an approach based on the manufacture of standard products, which in turn requires the development of new materials, products, processes, and possibly industrial units).

3. Reduction of costs (construction costs and the overall cost of a building over its useful life). It is, however, stressed that this should be seen from two perspectives: the lifecycle costs and the impact that prefabrication can have on them; and the cost of the prefabrication and installation investment itself and how this affects the overall cost savings. Nevertheless, it is still evident that there is no history of cost savings among the projects that follow this model. Indeed, one of the main drivers of cost savings comes from economies of scale, and this requires investment in facilities as well as production optimisation. One study identified that companies achieve a rapid and substantial increase in productivity when they start producing around 1000 units.

4. Reduction of work execution deadlines. The optimisation of the project is pivotal to ensure production efficiencies, with mass standardisation and customisation combined with ease of transportation and assembly. If there is a tendency for more time to be needed at an early stage of the construction process, since every design model is already outlined for the execution and manufacturing process, this allows for earlier decision making. It is therefore an advantage over conventional construction because late changes and adaptations are common in the latter, often at a stage when a project is already in the execution/construction phase which will make the process more expensive as a rule. In a second phase, the definition of all elements and components will allow for the development of modular block libraries, which will then make the process more systematised and lower costs. However, the ideal would be, even within the optimisation of the project, to have feasibility for a certain amount of customisation of the models, allowing the client to have some customised features.

5. Greater control of construction time and costs. It allows for a 20%–50% faster construction time than conventional buildings (on-site). The integrated processes involved in prefabrication (including modular construction) are able to eliminate subcontracting costs with on-site labour savings and their associated profit margins in the subcontracting process. With increased repetition of the elements/components or modules, it will be possible to further reduce the associated costs.

6. Automation. With the introduction of these technologies in the manufacturing process being possible, an improvement in productivity will be viable, knowing that this implies a significant initial investment, which then, with successful growth and economies of scale, will be covered by the production costs and respective profit margins.

All of these changes and transformations that are taking place at a global level are leading to measures that re-evaluate the way the built environment is inhabited, and how sustainable development will have to be addressed and ensured for future generations. Regarding the construction sector, the goal of achieving an overall improvement in terms of energy resources and their use is implicit. In this context, the construction carried out in various types of buildings will have to find more appropriate systems and methods to ensure better and more capable energy and resource efficiency.

The construction industry has already been developing other systems which tend to substantially increase productivity, in addition to the conventional construction system, seeking to find innovative solutions that validate a better optimisation of resources and charges and a better life cycle performance, such as prefabricated and modular construction systems.

The literature on prefabrication in the construction industry shows that it is possible to reduce costs and impacts compared to conventional construction; however, most approaches generally analyse the various factors and areas involved partially or for specific contexts [23].

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