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## Cambio de paradigma en el sector de la construcción: evolución del sector hacia la industrialización y la economía circular

## Paradigm shift in the construction sector: evolution of the sector towards industrialisation and circular economy

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**Resumen**-- En los últimos años, el sector de la construcción ha experimentado un cambio sustancial en los modelos tradicionales alentado por los nuevos retos sociales, medioambientales y económicos a los que se enfrenta la sociedad pero que, sin embargo, nos obligan a adaptarnos a los recursos disponibles en cada lugar, volviendo a la «racionalidad». Este cambio implica la necesidad de reflexionar sobre cómo adaptarnos a este nuevo contexto al que nos enfrentamos.

En el caso concreto de Canarias, el hecho de que se hayan modificado las rutas comerciales conlleva un replanteamiento de los modelos, hacia un modelo donde la reducción de la huella de carbono, el aprovechamiento de los residuos y la tecnología disponible sean el marco de referencia. de un contexto local y marcado por la exigencia de que sea la economía de producción en ciclo cerrado de vida la que se postule como las nuevas bases de desarrollo en la construcción de este siglo XXI.

**Palabras clave**— Industrialización; construcción; economía circular; huella de carbonocc.

**Abstract**— In recent years, the construction sector has undergone a substantial change in traditional models encouraged by the new social, environmental and economic challenges that society has to face but, however, force us to adapt to the resources available in each place, returning to “rationality”. This change implies the need for reflection on how to adapt to this new context that we face.

In the specific case of the Canary Islands, the fact that trade routes have been modified entails a rethinking of the models, towards a model where the reduction of the carbon footprint, use of waste and available technology are the frame of reference. of a local context and marked by the requirement that the production economy in a closed life cycle be the one that is postulated as the new bases of development in the construction of this 21st century.

**Index Terms**— Industrialization; construction; circular economy; carbon footprint.

### I. INTRODUCTION

THE deterioration of our planet, recent economic and health crises, as well as protracted armed conflicts, have led to a change in the conception of industrial production from the Braudelian perspective towards local sufficiency, self-sufficiency and closed life-cycle production. (Helleiner, 2021)

To this circumstance, we can add the increase in population

and the growing social and environmental awareness of the limitation of natural resources and the scarcity of resources (Martins, 2016) which, however, already has the experience of the one lived in the second half of the 20th century, following the oil crisis in 1973 (Ontiveros & Guillén, 2013). This reflection addresses aspects that take a more holistic view, going beyond the ecological aspect in terms of social, economic and, of course, cultural repercussions, (Cameron, 2012) and

foresees a context in which an annual decrease of between 1-3% in gross domestic product worldwide is predicted until 2050 (Nordhaus, 2007).

The construction sector is one of the key sectors of the world economy, representing approximately 10% of global GDP and with a growing trend for the coming years. Likewise, this sector is considered to be one of the fundamental sectors in the transition towards decarbonisation and the circular economy due to the enormous consumption of materials associated with the sector, together with the generation of waste and the impact of the useful life of both buildings and infrastructures. This has led to constant regulations and legal frameworks of reference in the European context, as well as their transposition to the regulations of the member countries. In this context it is worth remembering the search for nearly zero energy buildings even in buildings to be rehabilitated in the quest towards decarbonisation (Directive 2010/31/EU of the European Parliament and of the Council, 2010) (Directive 2012/27/EU European Parliament and of the Council, 2012).

In addition, the high demand from the residential sector in terms of the need to update the existing building stock, government incentives in the renovation sector as well as the challenges of the sector in terms of energy efficiency and effectiveness in the light of climate change and the zero emission or positive energy buildings target, give the construction sector an important role in the economic recovery after the health crisis caused by COVID-19, as evidenced by the fact that this aspect has been considered as a key aspect in the European Green Deal (de Gatta Sánchez, 2020).

*A. The origin of industrialisation*

The satisfaction of the basic needs of human beings in their immediate environment is characteristic and dates back to prehistoric times. In this context, we must highlight the transition from the nomadic nature of the Palaeolithic, with constant adaptation to the environment that provided the resources necessary for life (Gonzalez et al., 2016), to the sedentary nature of the Neolithic. This change was undoubtedly one of the most important in the history of civilisations, in which the change was the fixation of places of residence and the emergence of agricultural activity. This permanent and

sustainable settlement made it possible to develop the basic functions of the society of the time. The change brought with it the use of the first basic building materials that are still present in our constructions, such as earth, stone and wood. At the same time, these materials required, for the first time, the need for tools for their manufacture and construction. This was the beginning of different evolutionary periods that have brought us to the present day.

As has been mentioned, the complexity of human relations led to the evolution of this rudimentary fixed place of residence from the Neolithic period towards places that, in addition to satisfying the basic needs of their population, were also defensive bastions, places of surveillance and also belonged to the communication routes, whether by land, sea or river.

In this binomial configured by the inhabitants and their environment, we can see that earth, stone and wood have shaped most of the constructions and have also propitiated the main development of the necessary construction techniques for most of our history. Examples such as the traditional Maasai house, in the Maasai Mara, Kenya, or the traditional Norwegian houses, show us today a housing solution with basic materials, and of the place itself, where transport and the complexity of its execution is minimised, making the most of the accumulated and experiential knowledge over centuries.

During these first millennia of history, the use of materials continued, perfecting the construction technique associated



Fig. 2. Traditional Maasai housing. Masai Mara. Source: Self made



Fig. 3. Traditional Norwegian housing. Bergen. Source: Self made

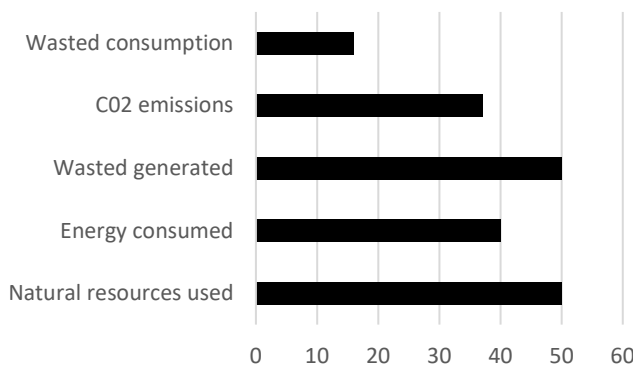


Fig. 1. Global impact of the construction sector.

Source: Anink, D., Boonstra, C y Mak, J.: Handbook of Sustainable Building. An environmental Preference Method. Source: Cop 27 Egypt



Fig. 4. Teatro Romano de Mérida. Cáceres. Source: Self made

with each one of them, see the difference between Romanesque and Gothic architecture, for example, when the materials that make up the spaces are the same. During this period, and until well into the 20th century, construction was based on the knowledge transmitted, and with a markedly artisan character.

The industrial revolution of the 18th century meant a break with traditional models, which, however, were not new in terms of the need for systematisation. In this sense, it is worth highlighting the experiences of Leonardo Da Vinci, in the Renaissance, with the development of the new cities in the Loire region, in which he established as the centre and origin of each city a factory of basic constructive elements that would guarantee a supply of elementary parts. This first approach can be understood as a first industrialisation in which the aim was to respond to different architectural types but systematising their processes by standardising and rationalising the process. (Escrig Pérez, 2010)

#### *B. The industrial era and the paradigm shift.*

In addition to the above, the first symptoms of globalisation, understood as the influence of some areas on others, can be found in the permanent evolution of maritime routes, and even the improvement of land routes, due to the appearance of the railway, in this case not only because of the technology itself, but also because of the material supports that made it possible. In this case, the development of steel, which brought about a revolution in construction methods. The architects of the Chicago School have left us notable examples such as the Home Insurance Building, 1885 Chicago, designed by the architect William Le Baron-Jenney, the first skyscraper with a steel structure, and the Daniel Burnham Flatiron building in New York.t

Therefore, steel, initially designed for public works, bridges and railways, was transferred to the building sector as the first alternative to traditional materials, which also allowed for greater compositional and architectural freedom. Later, in Spain, from 1905 onwards, concrete appeared as a structural element. At this time and with this new material, another turning point in industrialisation began, culminating in the Universal Exhibitions that have taken place since the end of the 18th century. The Crystal Palace built in Hyde Park, London,

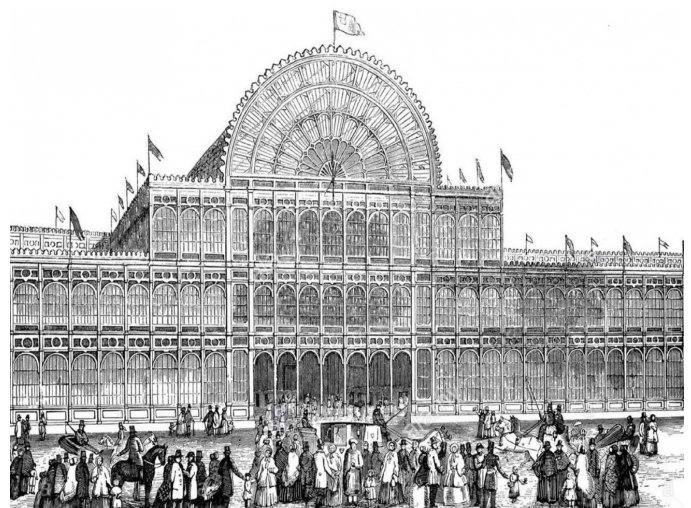


Fig. 5. Sketch of the main facade .Crystal Palace por Joseph Paxton. Source: Metalocus.es

designed by Joseph Paxton, in 1851, as part of the First World Exhibition is perhaps the most emblematic case and can be considered as the mark of a significant change in the way of building. Firstly, the use of cast iron and glass completely replaced the previous materials. The conception of the building, to be assembled, disassembled, moved and reassembled. It required optimisation, modulation and prefabrication. For the first time, on-site construction could be accelerated and systematised into the construction of a Meccano.

In this search for quick solutions, the industrialisation of traditional materials also arose, of which wood has a great impact and the possibility of systematisation, in this case, in the United States, due to the simplicity of manufacturing and processing processes, giving rise to the balloon frame which, in reality, is nothing more than the traditional system of systematised and structured framework to be assembled like a Meccano (Turan, 2009).

In short, construction processes are modified from the handcrafted to the industrial, systematising and standardising



Fig. 6. First graphical scheme of the system Baaloon frame. Source: Woodward 1860, 220

processes which, on the one hand, involve costs associated with transport and installation in a place other than where it was manufactured, but which can notably reduce lead times, especially in terms of time.

This process would not end there but, later on, during the 20th century and all the emigration from rural areas to the countryside and the so-called ‘hunger for housing’ would lead to this systematisation of processes, of which another of the singular points would be the system presented by Walter Gropius under the name ‘The packaged House System’ and was characterised by the construction of houses in the repetition of components.

This stage marks a turning point in the way of understanding construction from the global perspective of saving time and budget in execution, which we will develop below.

## II. INDUSTRIALISATION VS CONSTRUCTION

### A. Industrial processes.

The drive associated with the industrial revolution, the modification of traditional materials and the emergence of others with greater technical performance (Fdez. Ordóñez et al., 1974) as well as the acceleration of the speed of construction and the generalisation of the ‘machine’ advocated by Le Corbusier, led to a change in the approach to construction, transforming it from a mainly artisanal industry to a technified industry, whose dilemma: tradition vs. innovation, still remains to this day. This approach encompasses not only materials, but also processes, including construction site and auxiliary means, such as formwork, falsework, etc., promoting a radical change in the way of building.

In effect, the construction production process underwent a global modification.

The production process, understood as that which, starting from elaborated raw materials, generates materials or products that are manually put on site in such a way that, when combined with other elements, allows the configuration of the global building. That is to say, material  $\square$  manually put on site adapted to a specific construction technique  $\square$  construction system  $\square$  building. With the change of paradigm, this process changes from manual execution to assembly, i.e. the bricklayer is transformed into an assembler, starting from products (not materials). These prefabricated products, which are mass-produced components and subsystems in the factory, prior to their installation on site (Gómez, 2009: 24), allow processes to be accelerated, minimising on-site installation times.

In this context, a distinction should be made between prefabricated and industrialised. Prefabrication For an element to be prefabricated (and not an industrial product), it must be possible to manufacture it on site. ‘According to this definition, we would not consider a washbasin, a laminated profile or a brick as prefabricated, but we would consider a façade panel or a floor-ceiling partition as prefabricated. (del Águila, 1987)’. In this regard, it is worth making a brief comment on the four processes of prefabricated production: closed systems, partial use of components, mechano-type and open systems (Salas, 2008).

**Closed systems:** the elements are manufactured exclusively for the system and the project must be subject to the constraints of the system.

**Partial use of components:** corresponds to a relatively fixed range of products and services with a relatively small number of minor variations. Its use does not require a high level of industrialisation and can be used in the traditional construction process.

**Meccano-type system:** This is the combination of parts made from different origins that can be combined in multiple ways and provide multiple solutions. The manufacturers produce them with a previously defined and delimited combinatory language. It is the evolution of the closed system towards a flexibility of its limitations.

**Open systems:** The most flexible system of all, valid for industrialised or traditional construction, it uses the modulation or universal joint system. It is made up of elements or components from different sources.

#### 1) Industrialisation

Industrialisation is a broader concept than prefabrication, which, in the words of Professor Alfonso del Águila:

‘according to Blachère’s famous equation, in which:  
 $INDUSTRIALISATION = MECHANISATION + RATIONALISATION + AUTOMATION.$

This triangle is a clear expression of the set of fundamental means to be used for industrialisation. It will be understood that mechanisation is the greatest possible, rationalisation is of the whole process (design, management and technologies) and automation is present to the maximum in all tasks’ (del Águila, 1987).

One of the best examples of mass production or assembly line production is the automotive industry, from which some conclusions can be drawn that can be extrapolated to the construction sector, since it also starts with raw materials, from which components are made in different parts, which are then assembled on the assembly line by specialised personnel. However, this industry has been able to evolve towards simplification and efficiency in execution, as can be seen in Figure 8.

Despite the correlation between the automotive industry and the construction industry, the construction process has followed completely different patterns, as can be seen in Figure XX, in which two buildings of the same use can be observed, and in which the construction solutions are practically similar, except for the incorporation of small industrialised elements such as half-joists and vaults.



Fig. 7. (left) SEAT 600 factory. 1960, Zona Franca. Barcelona. Cataluña. Source: Fernando Díaz Villanueva. (Right), New factory of Hyundai Motor en Nosovice 2008. República Checa. Source: Wordpress.com



Fig. 8. Modular prefabrication. Source: Fuente Clement Canopy Condo. Singapur

Technological resources and accessibility to digital technology have led, in recent years, to profound changes that substantially modify work procedures and the processes into which they can be broken down. Artificial intelligence, telecommunications, 3D printing, robotics, open up a wide field of possibilities where technology to meet our needs is not a limitation. (José et al., 2021)

In spite of the scarce evolution that has taken place in the last decades, modification has been gradually incorporated, becoming a viable option available to the architect. In this sense, training becomes a basic tool for the architect to be able to know the possibilities and potential for change, as well as to control the construction processes.

### B. Changing construction processes

The first reflection on the implementation of industrialisation in the construction sector stems from the inefficiency of the traditional construction process, which is associated with a large amount of waste generation and a high level of work-related accidents, and which, in recent years, has also faced a shortage of labour for its execution.

The industrialised construction process, in turn, is a sequence of processes that has its starting point in the design of the project. The conception of the project to be executed industrially requires an adaptation of the design from the preliminary phases, that is, from the preliminary project if an effective and efficient solution is to be provided. In many cases, the options for subsequent variation are limited. In this sense, this model implies a modification of the creative process that is commonly followed in architectural design. In effect, the traditional system is much more flexible, allowing changes and modifications to be made throughout the execution of the work, however, this is not feasible in the case of industrialised works in which the project decisions are taken at the beginning of the construction process. This means that one of the biggest demands today is the digitisation of the sector.

This change of process also implies the need to carry out complex construction details from the beginning, anticipating and foreseeing possible difficulties and variations that may occur during the construction process. This is perhaps one of the most important challenges derived from the multi-criteria decisions that commonly involve the construction process, as well as the aspects of compatibility, availability, etc. In the face of this, the so-called ‘open industrialisation’ is proposed,



Fig. 9. Coexistence of traditional and industrialised construction. Tenerife. Canary Islands. Spain Source: Self made.

understood as ..... and in which universal compatibility is proposed as one of the goals. (Salas, 2008)

In terms of the construction process, the manufacture of materials and products as well as the structuring of the building into parts which can then be assembled is the main part of the process which, like all industrial processes, is based on efficiency. In this aspect, one of the solutions proposed is the standardisation or modulation of construction elements, on which the highest possible degree of mechanisation or technology is applied.

As mentioned above, digitalisation is one of the most important international commitments, essential for making the changes demanded by the sector. This digitalisation and control of processes could lead to better quality in execution, not only because of the exhaustive quality control indicated, but also because of the working, safety, health and environmental conditions that can be controlled in the workspace or factory and, therefore, reduce the number of accidents at work. On the other hand, the automation of the manufacturing process should reduce the need for a highly specialised workforce. Therefore, the working conditions of the environment for workers are much more favourable.

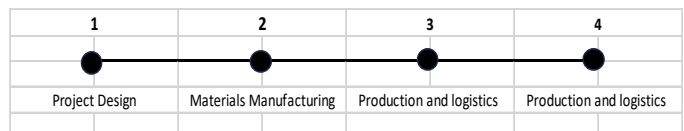


Fig. 10. Industrialised construction process. Source: White Paper on the Industrialisation of Construction.

Industry 1.0	Industry 2.0	Industry 3.0	Industry 4.0
Mechanisation	Mass Production	Automatisation	Cybernetic Systems
Steam Energy	Assembly Line	Computers	Internet
Loom	Electrical Energy	Electronics	Networks
●	●	●	●
1784	1870	1969	Currently

Fig. 11. Industria 4.0 for Lupeon. 3D printing as tool.

Also, in this business, industrial and innovation framework, the proliferation of I+D+i departments must provide the necessary feedback and evolution of the construction process to guarantee the suitability of the resource in the current legislative framework.

In short, a quantitative and qualitative improvement of the sector that is determined by the application of technical developments in the construction sector.

C. Implications for the profession

In this context, it is considered pertinent to address the radical change in the role that this will imply for each of the agents involved in the process, especially the builder.

In the traditional construction system, the builder executes the drafted project, with a direct link and relationship with the Developer. This intervening agent, the Builder, in turn subcontracts the parts into which the work can be divided according to the different trades to obtain the final result.

In industrialised construction, this participatory scheme changes substantially, as the design phase is conditioned by the construction system and, consequently, the manufacturer of the ‘building’ or its system must form part of the design and, therefore, this implies the need for this agent to have the appropriate technical training for the building environment.

In the assembly phase, the constructor may be present but will rely on the system manufacturer itself or a company specialising in assembly. In this case, the change of role will be that his work will be exclusive to the assembly of the system but not the subcontracting of trades.

This substantial modification of the figure of the builder in the change of sector is key to the implementation of this model as it requires a total reconversion of its business model, with a heavy investment to manage this change and consequently is one of the major drawbacks of the change.

Finally, within the industrialised construction scheme, as shown in figure 12, there is the assembly phase, which is one of the biggest differences. In situ’ execution is minimised or eliminated and industrialised systems are sought that reduce

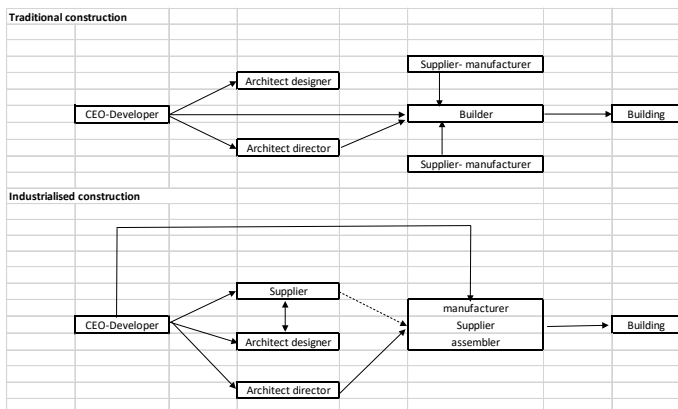


Fig. 12. Traditional construction vs industrialized construction.

execution times, and, in this sense, dry construction is promoted. In addition, unskilled labour is being replaced by personnel specialised in each system, technique or phase, which will result in a reduction of deadlines, quality of execution and above all, as mentioned above, in the number of work accidents. One of the most notable examples of the reduction of deadlines, at an international level, is the Wolverhampton Student hall, one of the tallest prefabricated buildings in Europe. Its assembly time, 10 months, meant a reduction of less than half of the time if it had been executed with the traditional system, 24 months.

D. Circular economy, sustainability.

Although we have seen and analysed the advantages and disadvantages of the industrialised construction system. We must consider other aspects that go beyond the sector. Sustainability and the circular economy are another of the determining factors derived from the need to reduce environmental impacts. In order to minimise the impact of the construction sector, the following strategic lines are formulated at European level:

- a) the reduction of energy consumption associated with use by limiting energy demands to near-zero energy buildings, both new and renovated, according to the regulations that came into force in 2023 (Directive 2010/31/EU of the European Parliament and of the Council, 2010) (Directive 2012/27/EU European Parliament and of the Council, 2012).
- b) Improving the durability of products and systems incorporated in buildings.
- c) Reducing the impact associated with the manufacturing and life cycle, in short, closed life cycle production (Circular Economy Action Plan, 2020).

The European Commission presented the Circular Economy Action Plan in March 2020. In February 2021, the Parliament voted on the Circular Economy Action Plan and in March 2022, the Commission unveiled the first package of measures to accelerate the transition to a circular economy, as part of the Circular Economy Action Plan.

These aspects are essential in the transition towards a more environmentally friendly economy in order to reduce the



Fig. 12. Traditional construction vs industrialized construction.

environmental impact of buildings. For we cannot ignore the fact that the construction sector, especially the residential sector, consumes around 50 % of all extracted materials and is directly responsible for more than 35 % of the total waste generated in the EU.

In order to address this issue, it is proposed, on the one hand, to look for innovative measures to make the most of local 'waste', which can be used and incorporated back into the industrial process. On this point, the industrialisation of the construction sector, due to its centralised location, offers great scope for saving waste for incorporation into buildings. In contrast, in the traditional model, waste management is complex due to the need for space to be able to separate waste as well as the reuse of waste generated and its storage which, in most cases, is unfeasible due to the demand for storage space and the lack of systematisation for the reduction of waste.

At the national level, Spain has drawn up the Spanish Circular Economy Strategy, which lays the foundations for promoting this new model of production and consumption with the aim of achieving a sustainable, decarbonised, resource-efficient and competitive economy. Adopting this model will require, among other elements:

- An instrumental framework and coordinated activity between administrations, economic sectors and society as a whole to facilitate synergies.
- New knowledge and capabilities, leading to new technological developments, innovative processes, products and services.
- The adoption of innovations, not only technological, but also organisational and social, which are essential to drive the necessary change in production and consumption models.
- The transformation of manufacturers from sellers to service providers, since the service provided by an object must prevail over its ownership.

In March 2022, and at the proposal of the Ministry for Ecological Transition and the Demographic Challenge, the Council of Ministers approved the Strategic Project for Economic Recovery and Transformation (PERTE) for the Circular Economy, which has, among other objectives:

- Accelerate the transition towards a more efficient and sustainable production system in the use of raw materials.
- Exploit the potential of the circular economy to generate employment.
- To alleviate the dependence of the Spanish economy on foreign trade, especially in times of uncertainty about the availability of raw materials.

This strategic project is focused on all productive sectors, as well as on consumption and waste management.

### III. CONCLUSIONS

The construction sector is of great importance to the world economy, and current data on energy consumption and waste show that the current system requires a profound change in the face of the new challenges posed by the climate crisis, among others. To this must be added the inefficiency and the volume of waste generated by the construction industry, together with the high level of occupational accidents, which will undoubtedly be the driving force behind changes in the sector.

The technological development experienced in the last century has led to the development of other productive sectors, but has not had the same impact on the construction sector and its evolution towards construction or industry 4.0. There are several reasons for this anchoring to the traditional construction system that go beyond the technological advances themselves:

- Closed industrialised construction models that do not allow for the compatibility of different prefabricated elements. Therefore, the objective is open and flexible systems in which local products and local labour can be accommodated.
- The rigidity of the system. The lack of modular coordination that leads to the generation of a high number of waste products before they are put into operation. Therefore, it is proposed that the design should be flexible, so that it is not restrictive but, on the contrary, adaptable to each circumstance. That a project, designed with common guidelines, can be executed by one or several construction systems.
- Economic viability for use.
- Lack of reconversion of the sector, especially the intervening agents whose functional model does not fit.
- The lack of social acceptance of these models due to their poor aesthetic quality, initially, and energy efficiency and finishes, subsequently, although there are significant examples in the rest of Europe to the contrary.
- Lack of legislative regulation, in relation to sustainability and waste, which has enabled the sustainability and waste values of this system.

The viability of industrialised systems, with the experiences that exist in the rest of Europe, do not currently raise any doubts about their optimisation and functionality. However, we must dimension and delimit its use where it really provides great differences with respect to traditional construction with which, undoubtedly, it will coexist depending on the locations, techniques and construction processes, and even the viability of labour, among others.

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