LIFE-CYCLE ASSESSMENT AND PREFABRICATION. VALUATION OF THE ENVIRONMENTAL PERFORMANCE IN DIFFERENT NDUSTRIALIZED SYSTEMS IN THE BUILDING SECTOR

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ABSTRACT

The Building Sector has been traditionally established in craft production in both the manufacture of construction products and elements, and construction works. Thus it is required a correct arrangement between the different systems to achieve a correct implementation, higher comfort and habitability, and price and environmental impacts reductions.

As opposed to this, the prefabrication and industrial systems contribute to a construction process that involves reducing the amount of resources used, the increase of lifetime due to better quality control, reduction of waste, and reduction of indirect costs of works due to its higher velocity of execution.

However, to close the cycle of materials is necessary that the prefabrication system allows the reuse of the components. To do this, design, dimensional coordination and an exhaustive constructive definition of the elements and joints in their execution must reach the previous dedication and the main role necessary to avoid incoherencies and continuous faults that cause back and forth process on work.

A complete dry construction allows the assembly and disassembly of reusable elements. To achieve this, the previous control phase of work should be studied and adjusted to the smallest detail. Moreover, it is necessary to redesign the prefabricated elements so that recycling should be simple and the separation of the groups of materials does not hinder the end of its useful life.

Given this, the experience in different prefabrication projects with professionals and companies, in the development and definition of constructive elements, allow us to expose a framework of requirements, needs and limitations to be considered in any prefabrication project.

In the present communication, it will be shown the premises and design strategies in building prefabricated developed by considering the overall management of the life-cycle in the building. It will be determined what systems and prefabrication processes and industrialization have greater environmental benefit. This will establish the keys of starting points that allow technicians the efficient and sustainable use of those systems.

Keywords: Life-cycle, Prefabrication, Reusing, Design, Sustainability.

1.- Introduction

The use of prefabricated constructive systems in architecture has evolved since the early twentieth century to adapt to the needs of each epoch. Recently, the report prepared by the European Commission to achieve the objectives of Horizon 2020 [1] recognizes the prefabricated benefits of reducing costs compared to conventional constructive systems, and promoting their use.

During the last years, investments in modernization and R+D+i have enabled a great improvement of the prefabricated constructive systems, developing more reliable, complete and effective construction solutions that have allowed the industrialization of the construction with higher quality [2].

There is a general trend that recognizes the prefabrication and industrialization as sustainable and efficient constructive techniques; however, rarely there is a rigorous evaluation and quantification, using environmental assessment tools that demonstrate those benefits that are assumed: a better use of the material, reduced waste generation, reduced energy consumption or even the possibility of reusing resources throughout its life.

In this sense, the "Life Cycle Assessment" (LCA) allow us to identify and to evaluate those favorable and unfavorable factors that influence into the whole process of building, and contribute to the development of strategies to reduce environmental impact of the industrialized construction.

In this communication it is combined with a qualitative and thoughtful analysis, different systems of prefabrication and industrialization considering each of the stages which influence on the analysis of their life cycle. It seeks an assessment of the advantages and disadvantages of investing in various prefabricated building systems in relation to conventional construction.

2.- Definition of the different prefabricated and industrialized systems

Previous to evaluate different types of prefabricated and industrialized building systems in which the study will focus, it is defined the main terms and classifications that are going to be used in the process of evaluation and assessment.

Prefabrication, which etymologically means making before, is an industrial constructive method in which the elements are manufactured by productive mechanisms in the workshop, and then assembled in the works by appliances and lifting devices. Moreover, industrialization is defined as the process of reproduction of these prefabricated elements considering its distribution and marketing in large series.

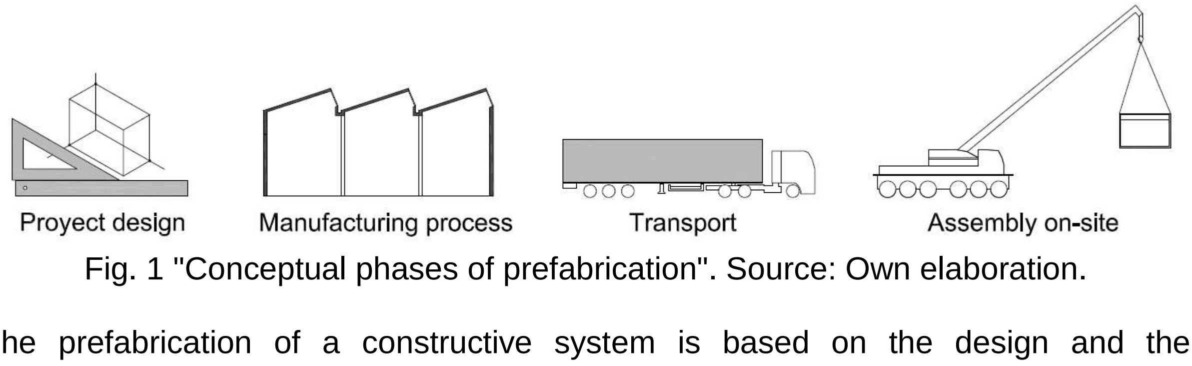

Fig. 1 "Conceptual phases of prefabrication". Source: Own elaboration.

The prefabrication of a constructive system is based on the design and the production of these components in an integral or in a partial way, using subsystems manufactured in series in the factory, outside of its final location. Under this prefabrication concept it’s defined an internal classification divided into two oscillating degrees [3]:

- A partial prefabrication, in which there are studied, designed and manufactured parts that will form the building itself. It is based on industrialization managed by the "Elements method" (open or component Industrialization).
- An integral prefabrication, which involves the creation at the factory of the building as a whole, only being necessary transportation to the final destination. This variant is associated with an industrialization handled by "Models Method", with closed systems completed workshop.

DEGREE OF PREFABRICATION

-PARTIAL…………………….Industrialization by “Elements method”
Components + Transport + Construction and assembly on-site

-INTEGRAL…………………...Industrialization by “Models Method”
Construction + Transport + Assembly on-site

Fig. 2 “Degrees of prefabrication”. Source: Águila, 2006 [3].

It arises in prefabrication other internal classification of prefabricated elements in light or heavy systems, referring to a density of its elements, which in turn influences the commissioning work, reducing the execution time or the need for heavy machinery, aspects that increase the final cost of the product.

One of the main contributions of prefabrication refers to the dimensional and modular coordination of its parts (UNE 41604: 1997 [4]):

- The dimensional coordination is defined as a rational system for fixing and relating the dimensions and the provisions of the elements involved in construction, acting as a determinant for joining between them.
- The modular coordination, when establishing a develop module type, is obtained from the dimensional coordination. It aims to remove the production, modification or adaptation of pieces in works by replacing the traditional process for the industrial.

The prefabrication allows developing a large quality control of the construction process. The industrialization attributed to the prefabrication of a building, previously has a stage of study and analysis of components in a process of continuous back and forth between design and implementation. The serialization of a model leads to a better study of each of its parts; therefore it is an advantage that prefabrication achieved towards creation in situ of traditional architecture.

Finally, another factor that directly affects to the process of industrialization is the transport and application phase, where prefabricated and industrialized systems can become competitive, designed to achieve the least possible waste generation, and increased resource optimization and costs.

- With a partial prefabrication, it involves a transportation way with a set of pieces in two dimensions (2D), so that transport is more economical and efficient but has a higher risk of inefficiency in the assembly in the implantation site.
- With an integral prefabrication, the transport is in a three-dimensional way (3D), it reaches greater demands and limitations for being transported, influencing dimensions, weights and measures in the transport mode. However, once transported the building, is simply to locate it and level it.

3.- Purpose, scope and methodology of evaluation

This communication analyses the existing environmental trends between different prefabricated building systems through a comprehensive lifecycle management in buildings. This procedure allows defining the boundaries of quantification and evaluation to determine the relationship between conventional and prefabricated and industrialized building systems, assessing trends in decreasing the consumption of resources during construction, waste generation, recovery material at the end of its useful life, etc.

The proposed methodology is based on the technique of life cycle assessment (LCA) established in the standards ISO 14040/44: 2006 [5], [6], which quantifies the potential environmental impact of a product or service determining their resource consumption and associated impacts.

This paper makes a comprehensive analysis on the different materials and processes used at every stage of life cycle analysis, which are taken from EN 15804: 2012 [7]. Since the adoption of this regulation all national and international systems of the European Union on Environmental Product Declarations (EPD, ISO 14025: 2006 [8]) are working on adapting their certification systems. However, the interpretation of that rule for complex prefabrication systems varies considerably between different studies. This work aims to contribute to eliminate the uncertainty by the dispersion of established criteria for the different systems.

To do this, the tendency will be evaluated in the environmental performance of different systems, with reference to conventional construction.

3.1.- Reference system. Conventional construction

According to available research, operational energy in residential buildings accounts for the 80-85% of total energy of it [9]. However, we emphasize that the overall trend promotes performing buildings with low energy consumption during use stage. As a consequence of this change in trend previously described, the relationship is evolving to 40% of impact associated with building materials and 60% belonging to the use stage of the building [10].

For non-residential buildings, the energy consumption relative to the total varies depending on the number of floors of the buildings. According to an investigation of a building with 6 floors and 7300 m^2, located on the campus of the University of Michigan (United States), the 83% of total primary energy is due to the use stage of the building [11]. The building is located in Ann Arbor, Michigan, and the life cycle assessment (LCA) was performed according to ISO standards and an estimated useful life of 75 years. On the other hand, the study of a typical office building in the city of Bangkok, Thailand [12], composed of 38 floors and estimating a lifespan of 50 years, the use stage represented a 52% energy total primary. These examples show the difference in other buildings typologies, influencing factors such as climate, use,…

Furthermore, if we evaluate in detail, according to the review articles by Cabeza et al. [9], transport, construction and demolition processes states that only represent the 1% of total energy demand.

3.2.- Boundaries of the evaluation system for prefabricated construction

The system boundaries for the phase of prefabrication are limited; moreover, the studies differ between the boundaries used. Taking as a reference their assignments of the standards [7], [13], there are specified those boundaries which are more diffuse for prefabrication system (Table 1 and Figure 3):

- In the product stage (A1-3), there are incorporated some processes: extraction, transportation, manufacturing and prefabrication of those prefabricated elements which are processed previous to the work transportation.
- In the transport stage (A4), there are included the processes for gathering materials in an intermediate supplier. It is considered a part of the transport, because there is no including a material processing but it’s a part of the supply chain [14].

- In the construction stage (A5) are attributed all processes that occur on the site where the building will take place.
- The use stage (B) must include the requirements for an equivalent building performance. To define that equivalence, is necessary to consider: basic habitability requirements (thermal comfort, acoustic…), fire resistance and maintenance elements.
- The end of life stage (C) starts when it is substituted, dismantling or deconstructed the building and has no additional functionality.
- The Stage D refers to the benefits that the system will develop out of their life cycle: feasibility of reuse as material, fuel, etc.

Product stage A1-3			Construction A4-5		Use stage B1-7							End of life stage C1-4				D
Raw material supply	Transport	Manufacturing	Transport	Construction – Installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational waste use	De-construction demolition	Transport	Waste processing	Disposal	Benefits and load beyond the system boundary

Table 1 "Different stages to assess the environmental performance of different building systems." Source: EN 15804: 2012 [7]

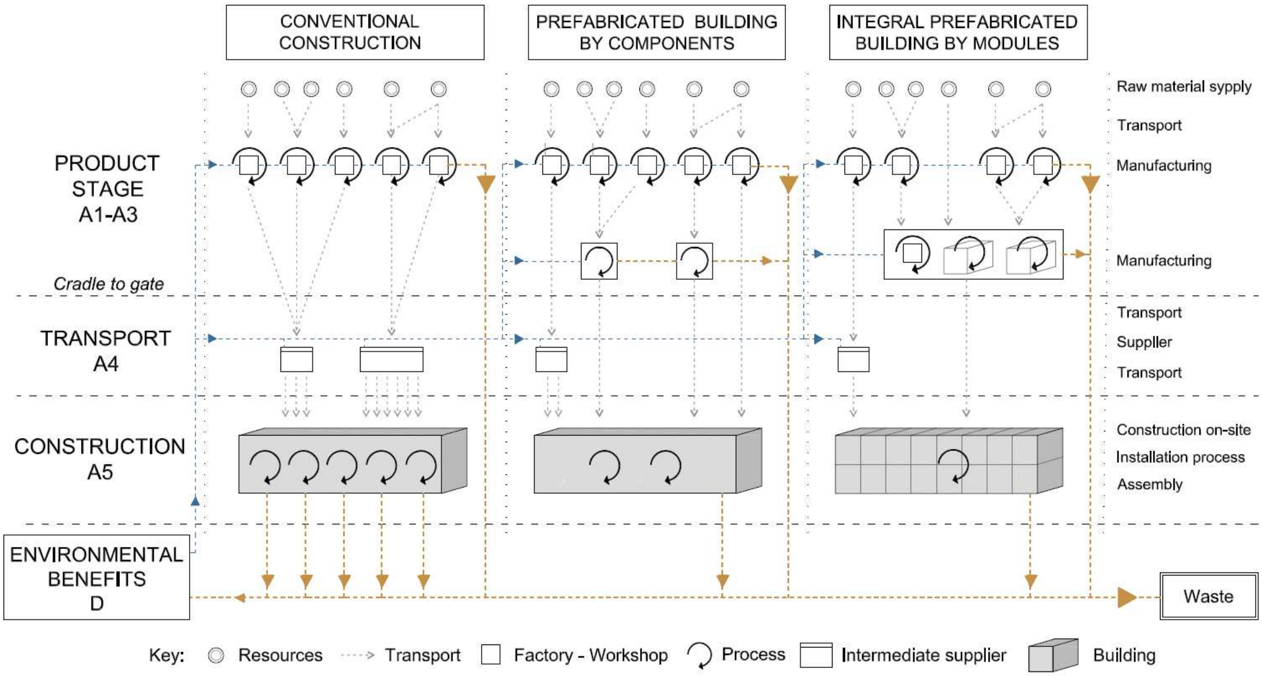

Fig. 3 "Comparison between A1-A5 and D stage of different prefabricated systems with the conventional construction." Source: Own elaboration.

4.- Results

The stages A1-A3, A4, A5, B1-2, B3-5, B6, C and D of each construction system according to the EN 15804:2014 [7] are sequentially exposed below in order to properly connect each of unit processes that are developed. Considering that there are some differences due to the used material (concrete, wood or steel) by a particular system, the evaluation of each of the processes involved between different building systems allows us to justify the following statements, and when the type of material is decisive it is commented:

4.1.- Stage A1-A3. Product stage

The energy included in the prefabricated systems compared to conventional construction, varies mainly due to the consideration of heavy or light systems. This consideration implies the type of material used.

Heavy systems are derived from using large amounts of material resources with low units in their environmental impacts (Ex.: Ceramic, cement and aggregates). High levels of volume used contains a considerable overall impact [15]. Nonetheless, researches show that the optimization of prefabricated structural elements have better environmental performance than conventional construction [16].

Furthermore, the light systems, despite their low density, are mostly formed by energy-intensive materials (for example steel, aluminum, synthetic polymers ...). This fact causes that the embedded energy of the systems would be often greater than the conventional construction.

		Product stage	Construction process		
Prefabricated building by:		(A1-3)	Transport (A-4)	Installation (A-5)	
Heavy integral modules	Embodied energy	=	+	+ + +	Relationship to the reference system
Lightweight integral modules		-	+	+ + +	
Heavy components		=	+ +	+	
Lightweight components		-	+ +	+	

(=): environmental performance equivalent | (+): benefits in environmental performance | (-): detrimental environmental performance

Table 2 "Evaluation of the trends in the environmental performance referring to the embedded energy in the different energy systems." Source: Own elaboration.

The resources used vary with the type of prefabrication (integral or component) and the weight of the building. It should keep in mind that heavy building systems require bigger amounts of material section for structures and foundations, due to the great bearing capacity demanding.

Against this, the light systems can reach ratios lower than 20% of the weight of conventional and heavy construction, resulting in smaller material sections associated to structures and foundations.

		Product stage	Construction process		
		(A1-3)	Transport (A-4)	Installation (A-5)	
Conventional construction		kg/m^2 of material on-site			Reference system
P.B. by heavy integral modules	Resources consumed	-			Relationship to the reference system
P.B. by lightweight integral modules		+ +			
P.B. by heavy components		=			
P.B. by lightweight components		+ + +			

(=): environmental performance equivalent | (+): benefits in environmental performance | (-): detrimental environmental performance

Table 3 "Evaluation of trends in environmental performance relating to resources used from different systems." Source: Own elaboration.

The prefabrication systems by components, unlike the whole systems, do not require a production chain that supplies construction, but instead of this fact, many items are usually made from local suppliers located near the building. This results in an increased consumption of local or regional resources to benefit more distributed economies and reducing the environmental impacts that result from transportation.

In addition, for a more thorough analysis, it is necessary to add to the environmental variables, the economic viability of each system.

The integral prefabrication, contrary to the prefabrication by components, has associated high manufacturing costs resulting from the production scale that requires a large demand of infrastructures which enable the development of the entire building, in a three-dimensional storage, in workshop before its assembly on site. This fact makes it difficult for the movement of the production chains.

Also, this need often difficult the development of these systems without the presence of high demands of buildings. Against this, nowadays are appearing some industrialized systems which include the open and integral prefabrication, where an open design is allowed under the possibilities of the system (Ex.: World Metor System: industrialized production of compact modules 6-sided reinforced concrete). It is still persisting a radius of action around the origin limit for the production because of the economic infeasibility of the transport.

4.2.- Stage A4. Transport

Transport constraints, both dimensions, functional and economic, are very important in the development of systems of prefabrication. The dimensional and modular coordination of prefabricated and industrialized systems allows greater efficiency in the movement of resources.

The main difficulty is that as it increases the degree of completion of the factory building, higher difficulties. Therefore, it is necessary to know the existing dimensional and economic constraints, in comparison to the functional needs of the building, to determine the feasibility of a prefabrication system or another.

At the national level, according to the DGT (National Department of Traffic), the allowed dimensions for transport are:

	Maximum width	Maximum height	Maximum length
Truck	2,55-2,60m	4-4,5m	12m
Articulated lorry	2,55-2,60m	4-4,5m	12+2,04=14,04m
Especial transport	>2,55-2,60m	>4-4,5m	>14,04m

Table 4 "Dimensional Limitations on the transport of merchandise". Source: National Department of Traffic (DGT), Spain.

As for the degree of transport efficiency, the prefabrication by components allows further optimization in the transportation stage, compared to the integral prefabrication, where most of the transported volume ends up being air.

4.3.- Stage A5. Construction. Assembly on-site

The processes of work, defined as those constructive actions that require electricity and fuel consumption, achieve higher efficiency as they reach a higher degree of prefabrication and industrialization. Comparing between different constructive systems for the same material group (fig. 3), the benefit in prefabrication is mainly in the reduction of direct and indirect costs associated with short periods of construction, transport equipment and workers, as the pre-construction in the workshop allows develop a high degree of quality control. Most of the constructive processes must occur in number (before or during the work), but the dimensional and modular coordination as well as prefabrication and industrialization allows reducing

The opposite happens when instead of making the comparison between different systems under the same material group is evaluated between the processes associated with different materials. These differences are observed in the research developed by Cole [17] in Vancouver, 1998. Cole did a study on a sample of 39 buildings, for the quantification of indicators took into account the associated transport of workers, transport of the material and processes needed for installation on site of such materials. From this research it took for the construction of steel structures implied the lower average for embodied energy, obtaining values between 3 and 7 MJ/m^2 for buildings with wooden structure obtained between 8 and 20 MJ/m^2, while for concrete buildings in-situ were between 20 and 120 MJ/m^2 (Fig. 4).

Furthermore, although is not on the figure above, for buildings of prefabricated concrete structures obtained values between 20 and 35 MJ/m^2.

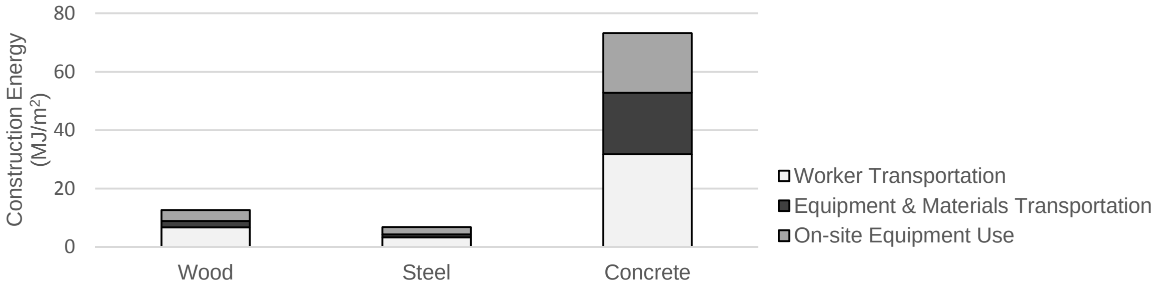

Fig. 4 "Comparison of energy consumption in conventional construction processes in different groups of materials." Source: Cole, 1999 [17].

Solid waste generated during the manufacturing process are attributable to: waste generated in processes of extraction of raw materials and manufacturing processes; packaging waste from transport; and construction waste from the excess of material [18] and lack of dimensional coordination.

		Product stage	Construction process		
Prefabricated building by:		(A1-3)	Transport (A-4)	Installation (A-5)	
Heavy integral modules	Waste			+ + + 90-100%	Relationship to the reference system
Lightweight integral modules				+ + + 90-100%	
Heavy components				+ + 75-100%	
Lightweight components				+ + 75-100%	

(=): environmental performance equivalent | (+): benefits in environmental performance | (-): detrimental environmental performance

Table 5 "Evaluation of trends in environmental performance regarding solid waste generated from different systems." Source: Own elaboration.

The establishment of an integral prefabricated system or by components hardly affects to the waste caused in stages before the construction process. Its main contribution is thanks to the dimensional and modular coordination [4] elements, which prevents between 75 to 100% of construction waste [19], [20]. In addition, work on workshop allows an easy revaluation and reuse of elements, allowing reaching up to 2% of waste in relation to the resources consumed [18].

For a proper ecodesign, is necessary to know the functioning of the production systems. Knowing the standardized dimensions of the pieces manufacturing and their systems (Ex.: Standard lengths of steel, panels, facade systems,…) allows us to project from design decisions regarding the fixed modular coordination.

As for the union systems, conventional construction is closely linked to the chemical union of materials and systems (conglomerates, polymers ...). However, lightweight construction systems allow dry construction of most of the different systems that compose the building, which facilitates the replacement, revaluation and selective recovery of materials and products. This is not an intrinsic benefit at the stage of product and construction (A1-A5), but makes possible the development of environmental benefits (fig. 3, stage D). In this line, actually there are more drywall systems, coming from wood systems "Balloon Frame" and "Platform Frame". This system has evolved in a light construction, using a steel thin sheet "Light Steel Framing" to a greater or lesser degree of prefabricated and industrialization (Ex.: Teccon System).

4.4.- Stage B1-7. Use stage

The LCA methodology requires an equivalent functional unit for comparing two products, in this case buildings [8]. This functional unit should include same technical and functional features of the building, so it is necessary to highlight certain characteristics that determine the prefabricated systems. This requires going beyond the initial materials that are assigned for the construction of the structure and identify the influence of prefabricated systems have on the needs of other materials such as thermal insulation, acoustic, fire protection and those needed for maintenance which logically leads to an increase in environmental impacts to do the building habitable in safety and comfort. In Table 6 are related the modules of the stage B with the different prefabrication systems.

Prefabricated building by:		Use stage (B)				
		Use and Maintenance (B1-2)	Repair and Replacement (B 3-4)	Refurbishment (B5)	Energy use (B6)	
Heavy integral modules	Environmental indicators associated	=	=	-	Depends on climate	Relationship to the reference system
Lightweight integral modules		-	+	-		
Heavy components		=	++	++		
Lightweight components		-	++	++		

(=): environmental performance equivalent | (+): benefits in environmental performance | (-): detrimental environmental performance

Table 6 "Evaluation of prefabrication systems in stage B - Use".
Source: Own elaboration

4.4.1- Use and maintenance (B1-2)

Different prefabricated systems have different impact on the performance of the buildings. Because of that, depending on the chosen system election it gets more difficult the justification of the different regulatory requirements.

Faced with the impossibility of justification of the systems used under regulatory benchmarks, the only option ends up hand in-situ or laboratory tests and endorses certifying compliance with the limits established by binding regulation.

In this line, we find the difficulties of light prefabricated in compliance with the requirements concerning noise behavior. The misuse of these solutions can lead to a lot of indirect transmission or low performance to airborne and impact noise. The justification of such systems in the Spanish area leads to high economic costs for developing testing and certification that guarantee solutions. We must use international technological institutes in order to find solutions tested in this area [21].

There are also difficulties in justification in the fire behavior of metal or similar light systems. This implies the above said, or the use of coating materials tested to provide the required performance, with an increase in costs associated to the stage (A1-3).

4.4.2- Repair, replacement and refurbishment (B3-5)

In the stage of maintenance, repair and replacement (B3-5) prefabricated by component systems provide the flexibility to remove existing elements in the building once repaired by adding or replacing them with new ones in good condition.

Rehabilitation of integral systems implies a limitation in adapting the existing building for new space requirements due to the rigidity of this system. While it is difficult to include this scenario in a calculation of life cycle analysis is necessary to emphasize it influences the durability of the building, which influences the overall environmental impact caused.

4.4.3- Energy use (B6)

The energy performance of the building in its use stage is determined by the mass of the materials that make up the building. A study by Lu Aye et al. [19] compares the energy behavior in the use stage of a conventional building made of concrete; another performed using prefabricated of steel construction and the last one with prefabricated of wood in Melbourne, Australia. The building was modeled on TRNSYS, the envelope contained 90mm of cellulose insulation in enclosures and 100mm of cellulose in the slab in contact with the outside. The results show that the energy consume, due to the thermal inertia of concrete in the annual energy consumption for heating and cooling, is lower, 32,2 kWh/m^2, which for steel and wood constructions, 34,3 kWh/m^2 and 33,5 kWh/m^2 respectively. Beyond the specific values, it stands out the importance of the type of material and construction system energy performance. Logically light prefabricated systems have a low thermal inertia because it depends directly of the mass of material. However, heavy prefabricated systems have greater inertia which results in better damping control passive of the thermal wave.

In addition, the perception of thermal comfort is linked to the way in which heat is transferred, in this sense radiation systems against convection are better perceived by users. The heavy constructions rely more on their climate strategies absorption and radiation of heat, while light systems often use systems air conditioning installations, such as heat pumps, which heat the air having an effect by convection.

4.5.- Stage C. End of life

The end of life stage of the buildings is important for the benefits to future construction by reusing and recycling materials, which when evaluated as a whole represents a reduction of environmental impact in the construction sector.

The advantages and disadvantages on the stage of end of life are directly related to the type of union between prefabricated elements systems, which can classified between chemical or mechanical. Those prefabricated systems use mechanical union with a dry joint that allow a bigger ease of disassembly of the structure and therefore better separation and classification of waste.

The processes used for deconstruction (C1) of the building, are crucial to the ability to reuse and recycling materials. They must be selective, through a separate system that allow separate the materials between them and trying to avoid demolition by blasting or traction systems of the structural elements that make more complex the work of waste separation.

Pons et al. [22] did a comparison between the performance of a school by a non-prefabricated system facing with several prefabricated systems, one of steel, one of wood and another of concrete. In the deconstruction stage, the non-prefabricated system generated more residues, 4178 kg/m^2, while the steel prefabricated systems, wood and concrete obtained 1253kg/m^2, 2229kg/m^2 and 2490kg/m^2 respectively. At these values, the authors added the recycling percentage of the previous systems, being non-prefabricated constructions 5%, for steel structures 35%, for wood structures 45% and concrete structures 25%.

As it can be seen, the prefabricated systems not only require less material, in addition its use is higher.

Prefabricated building by:		End of life stage (C)			
		De-construction (C1)	Transport (C3)	Disposal (C4)	
Heavy integral modules	Environmental indicators associated	=	=	+	Relationship to the reference system
Lightweight integral modules		+	+ +	+ +	
Heavy components		+	+	+ +	
Lightweight components		+ +	+ +	+ +	

(=): environmental performance equivalent | (+): benefits in environmental performance | (-): detrimental environmental performance

Table 6 "Evaluation of prefabrication systems in stage C - End of Life."
Source: Own elaboration

4.6.- Synthesis of the overall evaluation of the results

All these assessments have identified what are the existing benefits of prefabricated buildings in comparison with the conventional construction. It is shown a table where there are different systems at each stage of the life cycle of the building (Table 7).

Stage	Benefits in relation to conventional construction	Mod.	Unit	Prefabricated system			
				Integral modules		By components	
				Heavy	Lightweight	Heavy	Lightweight
A1-3 Product stage	Reduction of resources consumed	A1-3	(kg/m^2)		X		X
	Reduction of waste		(kg/m^2)		X		X
	Reduction of process		(MJ/m^2)				
A4-5 Construction process	Ease of transport	A4	(kgCO2-eq/m^2)		X	X	X
	Reduction of process on-site	A5	(MJ/m^2)	X	X	X	X
	Reduction of waste	A5	(kg/m^2)	X	X	X	X
B1-7 Use stage	Better acoustic performance	B1		X		X	
	Better fire resistance	B1		X		X	
	Ease of repair and replacement	B3-4			X	X	X
	Ease of refurbishment	B5			X		X
	Thermal inertia	B6		X		X	
C1-4 End of life stage	Recycling of materials	C3	(kg/m^2)		X	X	X
	Re-use of the product materials	C3			X	X	X
	Reduction of waste	C4			X		X

Table 7 "Environmental benefits of different prefabricated systems".
Source: Own elaboration.

5.- Conclusions

In this paper, there have been compared t and how both are confronted by the distinction in the different stages used in Life Cycle Assessment. Although nowadays the prefabrication is considered as the unique way of optimization of resources and reduce environmental impact, it has become clear as this is neither homogeneous nor their design or in their processes. Therefore, this article has deepened in distinguishing the different systems of prefabrication to find the benefits that each brings, and defining the challenges they face.

It has highlighted how today we still find lack of criteria for assigning materials and processes at different stages of life cycle assessment in the different systems of prefabrication. This has led to the use of simplified LCA methods, where comparisons under reference systems are exclusively to items or reduced work processes.

It has emphasized the need to take into account different factors from consumed resources and work processes to conduct to a comprehensive and comparable study between different systems of prefabrication, such as associated infrastructure, transportation, weight, compliance with the habitability requirements, fire resistance, the influence of the type of union, etc.

The importance of dimensional and modular coordination throughout the lifecycle of the building is evident. There is a responsibility from design both the efficiency of the work, of waste generated, as well as manufacturing time, work and service life of materials and products, which directly affects the economic and environmental

It is justified how the development of lightweight components in prefabricated systems has greater advantages in the global lifecycle of the building than an integral prefabrication. This is mainly due to its viability in the development of regional markets, greater reliability in transport due to its high efficiency, efficiency in construction processes, its viability in dry construction, allowing the replacement, revaluation and selective recovery materials and products, etc. However, in the use stage it is found as acoustic comfort or fire resistance mark limitations that must be determined properly in the design and how the lack of inertia must be taken into account climatic adaptation strategies (Table 7).

Therefore, in the current context where the optimized management of natural resources becomes essential factors for the development of building systems, have an overview of prefabrication and life cycle assessment. It could open the door to a renewed industrialization; it will enable to understand the condition of each of the processes associated with each system.

REFERENCES

[1] European Union. (2014). Horizon 2020 Work Programme 2014-2015. Area of “Secure, Clean and Efficient Energy”.
[2] Barrios, Á., Serrano, A. J., Lizana, F. J., & Mariñas, J. C. (2014). Architectural heritage in prefabrication. Protection and enhancement of the construction technique. In *The 4th International Conference on Heritage and Sustainable Development*. Guimarães, Portugal.
[3] Águila García, A. del. (2006). *La industrialización de la edificación de viviendas*. Tomo I y II. Sistemas y Componentes. Madrid: Mairea Libros.
[4] AENOR. UNE 41604 (1997). Construcción de edificios. Coordinación dimensional y modular. Principios y reglas (1997).
[5] AENOR. UNE-EN ISO 14040. (2006). Gestión ambiental. Análisis del ciclo de vida. Principios y marco de referencia.
[6] AENOR. UNE-EN ISO 14044. (2006). Gestión ambiental. Análisis del ciclo de vida. Requisitos y directrices.
[7] AENOR. UNE-EN 15804:2012+A1. (2014). Sostenibilidad en la construcción. Declaraciones ambientales de producto. Reglas de categoría de producto básicas para productos de construcción.
[8] AENOR. UNE-EN ISO 14025. (2010). Etiquetas y declaraciones ambientales. Declaraciones ambientales tipo III. Principios y procedimientos.
[9] Cabeza, L. F., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renewable and Sustainable Energy Reviews*, **29**, 394–416.
[10] Sartori, I., & Hestnes, A. G. (2007). Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings*, **39**(3), 249–257.
[11] Scheuer, C., Keoleian, G. A., & Reppe, P. (2003). Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. *Energy and Buildings*, **35**, 1049–1064.
[12] Kofoworola, O. F., & Gheewala, S. H. (2009). Life cycle energy assessment of a typical office building in Thailand. *Energy and Buildings*, **41**(10), 1076–1083.
[13] AEN/CTN198. UNE EN 15978. (2012). Sostenibilidad en la construcción. Evaluación del comportamiento ambiental de los edificios. Métodos de Cálculo.
[14] García, A. (2010). Análisis del ciclo de vida (ACV) de edificios. Propuesta metodológica para la elaboración de Declaraciones Ambientales de Viviendas en Andalucía. Tesis. Universidad de Sevilla.
[15] Barrios, Á., & Lizana, F. J. (2013). Strategies for responsible consumption of buildings products. In *The 1st International Congress on Sustainable Construction and Eco-efficient Solutions* (pp. 243–256). Seville.
[16] López-Mesa, B., Pitarch, Á., Tomás, A., & Gallego, T. (2009). Comparison of environmental impacts of building structures with in situ cast floors and with precast concrete floors. Building and Environment, **44**, 699–712.
[17] Cole, R. J. (1999). Energy and greenhouse gas emissions associated with the construction of alternative structural systems. *Building and Environment*, **34**, 335–348.
[18] Lu, W., & Yuan, H. (2013). Investigating waste reduction potential in the upstream processes of offshore prefabrication construction. *Renewable and Sustainable Energy Reviews*, **28**, 804–811.
[19] Aye, L., Ngo, T., Crawford, R. H., Gammampila, R., & Mendis, P. (2012). Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules. *Energy and Buildings*, **47**, 159–168.

[20] Wadel, G., Avellaneda, J., & Cuchí, A. (2010). La sostenibilidad en la arquitectura industrializada: cerrando el ciclo de los materiales. *Informes de La Construcción*, **62**(517), 37–51.

[21] Clough, R. H., & Orden, R. G. (1993). *Building Design using Cold Formed Steel Sections: Acoustic Insulation* (SCI Publication 128). Ascot, United Kingdom: The Steel Construction Institute.

[22] Pons, O., & Wadel, G. (2011). Environmental impacts of prefabricated school buildings in Catalonia. *Habitat International*, **35**(4), 553–563.