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PREFABRICATED BUILDING SYSTEMS: EVALUATION OF THE CONSTRUCTION PRACTITIONERS' PERCEPTION ON THE ENVIRONMENTAL AND ECONOMIC BENEFITS

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Abstract

This paper focus on how prefabricated building systems can allow the implementation of deconstruction strategies. Prefabricated mechanically fixed components, in comparison with conventional concrete and brick in situ construction, can be more easily separated during demolition, allowing its reuse, and even if this is not possible, at least allowing the recycling or the energetic recovery. It is very important that construction practitioners understand the benefits of the prefabrication. As a way to evaluate the current Portuguese status in prefabrication, a survey was conducted within contractors, consulters and designers. The issues discussed were: construction methods comparison, and prefabrication characterization and potentialities. A discussion on the results of this survey is presented in this paper.

Key words: benefits, deconstruction, prefabricated, survey, waste

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1. Introduction

The problem of the greenhouse gas emissions in construction has alarmed people around the world, with or without straight convictions in the subject. According to the United Nations Environment Programme (UNEP, 2007), it is appointed that 30-40% of global greenhouse gas emission are due to the buildings and construction activities, and includes areas like production of construction materials, maintenance and demolition, as well as the use phase. This paper focus mainly on the construction phase, as the energetic optimization in the use phase is already widely discussed and analysed, due to much more developed and compulsory building regulations. Assuming that no action is taken to reduce greenhouse emissions, computer models of the earth climate indicate that global average surface temperatures will rise by 1.5-4.5ºC over the next 100 years (USAID, 2014).

The climate affects directly the durability of building materials through some parameters (Berge, 2009):

- Solar radiation;
- Temperature;
- Air pressure;
- Humidity;
- Wind and rainfall;
- Chemicals.

The threat of climate change is real, and it will influence the lifespan of the building materials. The environmental factors influence 80-90% of all cases of cancer (Berge, 2009). Nowadays construction is worried about the high levels of CO_2 produced; leading it to choose more environmentally friendly approaches. It consists in adapting buildings for a

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better use of the natural resources, by choosing more natural materials, prefer the reuse and refurbishing of existing buildings rather than demolishing and construct new ones, promoting the correct orientation of windows, allowing the possibility to collect more energy in a passive way, among other strategies (Ciocan et al., 2017).

Fig. 1 shows the generation of waste by economic activity in EU-15. Construction is by far the sector which generates more waste. Even if the majority of wastes from construction are non-hazardous (more than 98%) the quantity (with consequent needs of separation, loading, soil protection, landfilling) and the impacts associated with the transport to the final destination of building waste are a significant problem. One of the biggest challenges that construction is facing nowadays, is that the buildings are almost only programmed for its useful life, without any concern about the end of life scenarios.

In this scope it is also important to note that the EU pushes their members to implement the hierarchical principle, which aims to prevent negative environmental impacts caused by waste (Bartolacci et al., 2017) and to promove the circular construction. Circular economy is connected both to improve manufacturing technologies and also educate people towards responsible consumption and waste reduction (Rizzo et al., 2017)

As shown in Fig. 2, the construction waste generation per-capita increased in almost every country from the *European Union of 15* from 2004 to 2008, but in the last period analysed (2008-2010) there is a tendency for a decrease or at least stagnation. In USA, about 60% of C&D materials end up in landfills (US EPA, 2008).

Portuguese construction sector generated 172 million tons of wastes between 2004 and 2009. In 2009, the industrial production decreased almost 25% in relation to 2008, mainly due to a strong decrease from the Building Industry (INE, 2010). In spite of this, an increase on the wastes generated by extractive industries can be seen, in result from the research and exploration of stone quarrying and mining as well as of cement industries (Couto and Mendonça, 2011). The increase in exports can in part explain this phenomenon.

Sustainable building construction, as well as in other areas of industry, should rely on four strategies: reducing, reusing, recycling and recovery (energy). All those concerns have been neglected in South European building construction activities, and particularly in Portugal. The first strategy, reduction, is usually implemented in a limited way.

Preconception about innovation on materials and construction methods leads to focus the attention on the reduction of the building environmental impacts in the production of the traditional materials for building in a conventional way (Mendonça, 2005).

Housing constructions in South European climates are generally heavyweight and not relying on lightweight prefabrication. Brick is the most common material used in the exterior envelope, dividing walls and slabs; concrete is predominant in the structure, in order to achieve thermal inertia, acoustic insulation and structural resistance.

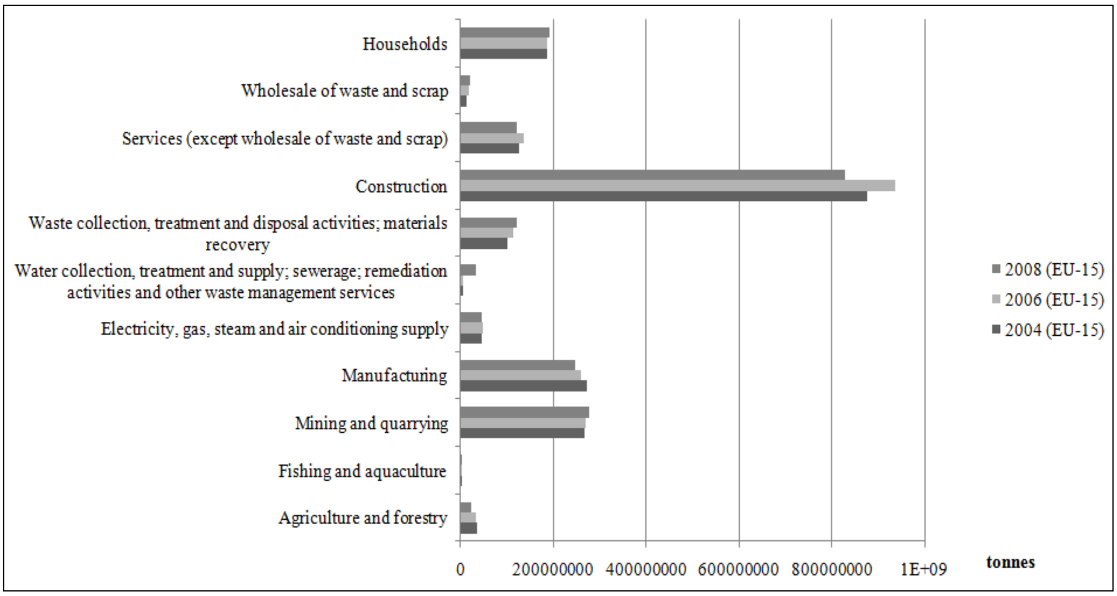


Fig. 1. Generation of waste by economic activity in European Union (15 countries) (Eurostat, 2011)

Table 1. Wastes generated by the construction sector in Portugal between 2004 and 2009

Year	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***
Construction sector (tons)	2 625 930	5 212 520	3 607 232	5 674 248	8 148 290	3 152 098
Total (tons)	24 689 088	31 096 302	31 155 301	30 240 562	31 591 727	23 659 876
% share	10.6	16.8	11.6	18.8	25,8	13.3

Source: INE, 2010

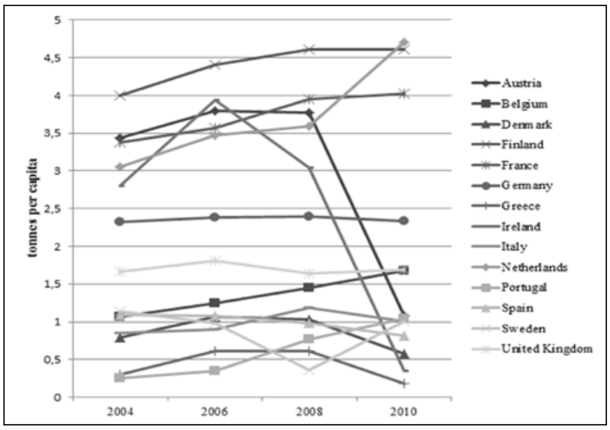


Fig. 2. Construction waste generation per capita in EU-15 (except Luxembourg)

The use of vernacular solutions, as earth, wood or stone, with intensive labour locally available, can allow to reducing the environmental impacts, but these solutions are not the most adequate to high density urban areas, in comparison to the prefabricated building systems. In these areas, the increase of the global mass of the building implies problems such as: higher cost of the structural system due to an increased weight; higher cost of soil per useful area due to thicker walls, difficulty to achieve contemporary building performance standards. The use of optimized solutions in terms of weight, even when associating conventional heavyweight systems with lightweight prefabricated ones, has proved to be more sustainable and at least equally efficient in relation to heavyweight conventional systems, in terms of functional performance in the context of a temperate climate (Mendonça, 2005).

2. Design for disassembly: a premise for a sustainable future

The Industrial Revolution was the biggest propeller of the world economic growth, with important changes relative to productions methods, until that time based on manual labour and draft-animals. The machine-based production resulted in time savings, and, for housing, it enabled the construction of densely populated cities, with infrastructures allowing the improvement of life conditions in terms of sanitation and communications.

However, the economic growth that arisen with the Industrial Revolution, also brought some problems, concerning the extinction of non-renewable resources and the pollution increasing, which are now emergent concerns.

The availability of non-renewable resources has suffered some changes since Industrial Revolution, and, nowadays, some materials are facing the risk of exhaustion. The industry of materials' extraction takes advantage in extracting large quantities of material; therefore it is necessary to limit the quantities and the types of materials to extract, with more severe legislation and with the design of more efficient buildings in terms of the materials used. Apart from the use of more renewable resources, the reduction of the materials used in buildings is also important. It is pointed out that mining or harvesting of materials are directly responsible for today's problems related to air pollution, loss of biodiversity, and soil and water contamination. This implies the increase of reuse and rehabilitation as preferable strategies, instead of new construction.

2.1. Closing the loop on materials' lifecycle

The concept of product, in this specific case the building, comes in a hierarchy process, where the basic step is made by the material. The material acquires a function, and then it becomes part of a component; finally the components are grouped, in order to establish a module or a sub-assembly. A building is composed of various building components, forming systems (structure, facades, fittings, partitions, furniture, etc.). The structural system has to last the entire lifetime of the building, while interior partitions are often rearranged in short periods of time, for functional or more futile reasons (Couto and Mendonça, 2011). Brand (1995) proposed the concept of hierarchical building layers (Fig. 3) to illustrate this principle. Those presented with thicker lines in Figure 3 are the most difficult to rearrange, so it should be the most durable. The thinner lines represent the layers that should be easier to rearrange or substitute in the building lifetime.

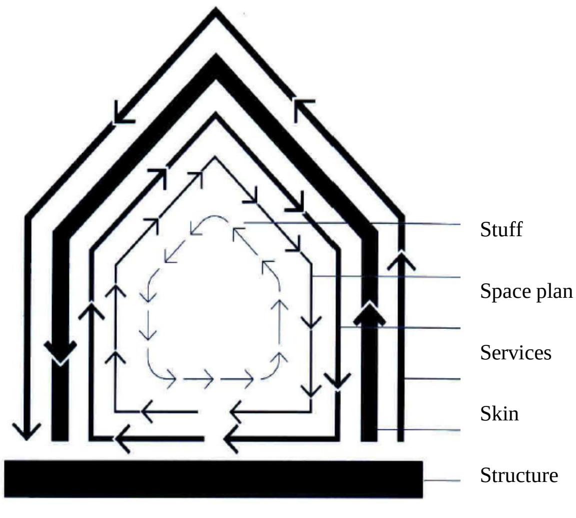


Fig. 3. Shearing layers of change (adapted from Brand, 1995)

The main goal is to integrate the components and materials in a new construction process, instead of its elimination on a landfill. The lifecycle analysis – LCA – should include the raw materials and energy requirements throughout the lifecycle but also the quantifications and identification of the waste generated. LCA method can be constituted by the following components (adapted from El-Hagar, 2007):

- Definition of objectives
- Scoping;
- Compiling quantitative data on direct and indirect materials/energy inputs and waste emissions;
- Impact assessment;
- Improvement assessment;
- Data interpretation

The common end-of-life scenario, the landfill (Fig. 4), has to change and give place to recycle or re-use. By closing more the loop of the lifecycle of materials, their embodied energy, which includes its extraction, manufacture and transport till the factory, is preserved and their use is improved. Thus, the traditional open cycle (extraction-manufacturing-waste) is changed and is assumed as a closed cycle (recycle-manufacturing-use-recycle) (Fig. 5). To make this assumption possible, and turn waste material to renewable, the same quality existent on the resource should be attributed to the waste that is intended to be recovered.

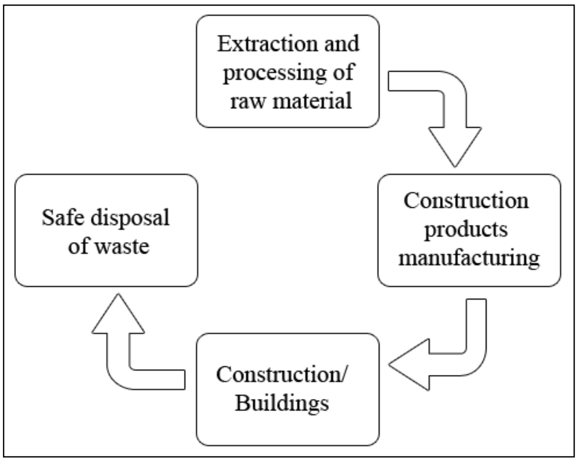


Fig. 4. Open cycle construction concept

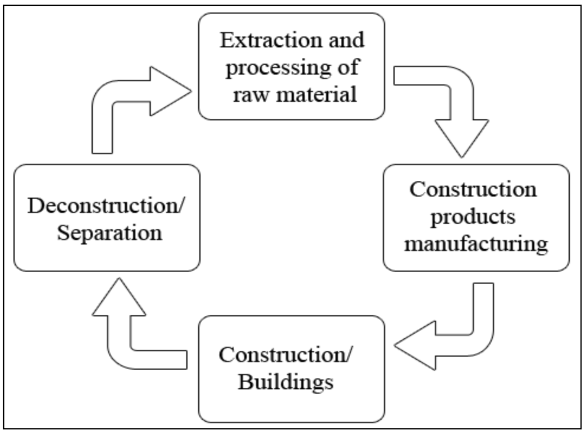


Fig. 5. Closed cycle construction concept

2.2. Deconstruction advantages

Deconstruction effectiveness relies on the building's component easy disassembly and allows closing more the loop of the building lifecycle, when it becomes obsolete, or simply no longer needed as it is. Disassembling the building components, instead of its traditional demolition, allows recovering all or some materials to posterior reuse or recycling. A measurable way to better understand the contribution of deconstruction into the materials lifecycle are the waste rates. The waste is by far one of the most impactful consequences of deconstruction (Rios et al., 2015).

Deconstruction represents today a site waste reduction of about 50% to 70% (Browning et al., 2006), even if in the south European countries the scenario can be less favourable due to cultural and educational factors that the recent economic crisis accentuated.

The deconstruction process has to correlate two fundamental characteristics: flexibility and connections. The conventional buildings are not prepared for dismantling, because they were conceived to be built as one single structure, with dependent relationship between the parts that integrate them. Designing buildings by different and independent layers (Brand, 1994), increases the opportunity for recovering the material, due to their flexibility and consequent easier dismantle. An important issue related with the building layers is that the less durable ones should not compromise the most durable. In general, the structure is the most permanent layer, that's why in the Brand model it appears with a thicker line, the lesser thick lines in general correspond to layers that can be more often substituted and adaptable. Relatively to connections, the success of the deconstruction is also due to the type of the connection: a mechanical connection, through nails, screws, rivets or bolts is preferred to adhesive joints and welding.

During recent decades several studies were carried out around the world in order to find forms to overcome barriers and to promote the deconstruction. Issues as the methodologies to implement a conscious deconstruction, with quality, considering all safety aspects, and to give minimum hazard to the environment and to the people and not to waste our sources, were developed. The importance of all the works should be done by planning also has received much attention (Arioglu and Anbanuz, 2005). One important stage in the deconstruction process is related to the design process. It is pointed that 33% of on-site waste is due to architect's failure during design stages (Osmani, 2008). Couto and Couto (2009) proposed some measures, namely:

- Designing with standard sizes, using modular and prefabricated construction, minimal earthworks;
- Incorporating recyclable, recycled and reusable products in construction
- Designing for dismantling or deconstruction. Some of the principles include: the disentanglement of systems, materials bolted together instead of glued, built-in tie-offs and connection points for workers and machinery, no hazardous materials and highly recyclable materials;

- Considering renovating or refurbishing an existing building, rather than demolishing and rebuilding;
- Coordination between designers and construction companies should be attended in the definition of materials and construction products;
- Promoting adequate communication among owners, project designers and contractors. Lack of communication is often the cause of partial demolition and removal of applied material, contributing towards needless output of debris;
- Packing conditions should be discussed with suppliers to reduce the number of packs and the amount of packaging materials, especially those not possible to reuse or difficult to recycle.

The public acceptation is a growing process, only consolidated with detailed studies proving its advantage in relation to traditional demolition. In fact, when the people face the possibility of using recovered material instead of new one, they choose the new material because they think that these can assure better structural stability (US EPA, 2008).

The major problems around the deconstruction process are the economic cost and the requested time spent, which is higher than demolition. On the other side there are some studies that prove its cost-competitiveness, if the recovered materials have a high market value that could surface the increased labour costs (US EPA, 2008).

With more research studies carried out, improving the used techniques, normalization and legislation, deconstruction could be the rule for a near future.

2.3. Waste management

As well as in the building design, the approaches for waste management that must be considered and evaluated in its advantages and disadvantages are: reducing, reusing, recycling and recovery. The two more desirable alternatives are reducing and reusing. Reducing can be applied to the raw materials at the source, for example by using less unnecessary packaging products, and using fewer toxic products. This will conserve natural resources for other uses. Reuse represents the most sustainable form of waste management, in which the product in the end of its lifecycle is introduced in a new one, without transformation.

These two principles are best applied with some programs like the "Pay-As-You-Throw", developed by US EPA, where users are charged a rate based on how much waste they present for collection to the municipality or local authority. Recycling is the worst option when it concerns to waste management: the techniques used on it requires some investment, and thus it becomes a less desirable option, especially in what respects to recycled products that can't be profitable. One advantage in this process is the possibility of creating jobs, much more than when using wastes for landfilling. Recovery verses on the burn of waste to produce energy directly (El-Hagar, 2007).

There are several costs relative to waste management, such as (Cheremisinoff, 2003):

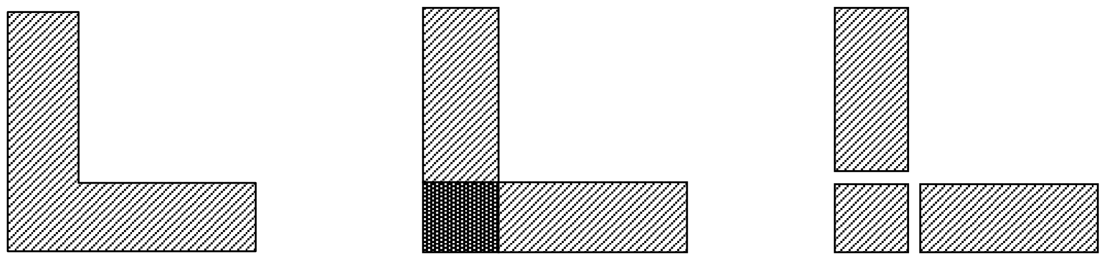
- Usual and normal costs;
- Hidden and indirect costs;
- Future and long-term liability costs;
- Less tangible costs.

Usual and normal costs are direct costs, predicted since the beginning, that include equipment cost, cost of operating the equipment, site preparation and the tipping fees for the transport and disposal. Hidden and indirect costs do embrace expenses associated with monitoring, instrumentation/ equipment maintenance and insurance premium to cover situations such as fire, explosion, and environmental damages that might occur. Future and long-term liability costs are uncertain, just because they are based in future scenarios: possible medical claims from personal injury and chronic health risks for workers, which can raise the company premiums for medical coverage, and also the off-site damages and remediation. Less tangible costs depend on the success of the project and including: negative consumer and investor response, mergers, acquisitions, joint ventures halted because of high risks from poor environmental and consequence raise premiums and drop coverage from the insurance companies (Cheremisinoff, 2003).

3. Prefab technology

Portuguese conventional contemporary buildings are characterized by having components that are permanently fixed, forming inseparable units. This causes components with shorter useful life to sometimes condition the durability of components with longer durability. A basic principle for the efficient reuse of building components is the differentiation between these. Fig. 6 presents different connection types between wall and structure: (a) the common situation in the buildings made in stone masonry nowadays; (b) the common situation in the buildings made with hollow brick masonry walls and reinforced concrete structure nowadays; and (c) the situation in separate systems, whose materials can be of the same quality or not, but with ease separation, common till 100 years ago.

Easily dismantling building systems generally comprise components prepared to be loose fitted together during assembly. These are commonly known as prefabricated and present, among other advantages, the fact of being easily transported. In areas that present difficult access to large transport vehicles, these can be more feasible economically than the conventional heavyweight systems. Prefabricated systems start to be common in Portugal, mainly for building single family houses, and marketed by companies that are normally responsible for their design and construction. The most common material used is timber, although steel framing and precasted concrete are also common (Couto and Mendonça, 2011).



a) Similar quality and permanent connection

b) Structure of better quality and permanent connection

c) Similar or different quality, but easy separation

Fig. 6. Connections between structural and wall systems. Adapted from Berge (2000)

The prefabricated techniques have been developed in response to a social demand: the construction of shelters in World Wars' periods, requested to lodge in short time the millions of homeless people. Thereafter, these solutions are still being called to be used in natural disasters, aggravated with the climate change. This situation, and the applied substandard quality in those solutions, gives them a bad image (Blauvelt, 2007).

Nowadays, and especially in the less developed countries, the community still resist to adopt these solutions, but they are gradually changing their minds, due to access to more information and to new materials and technologies that are increasingly related with success cases.

Prefabricated buildings can consist in two different types (Staib et al., 2008): closed systems and open systems (Fig. 7).

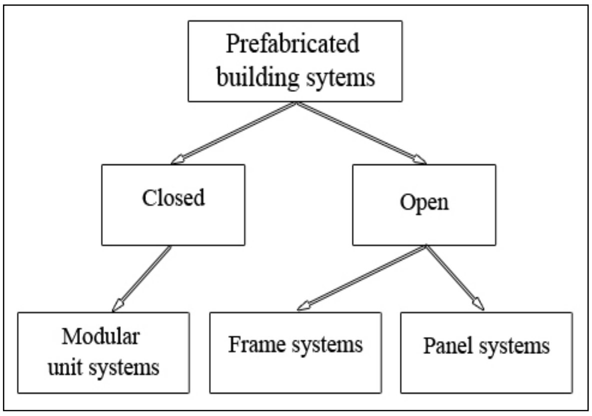


Fig. 7. Different systems of prefabricated building

In a closed system, generally produced by a single manufacturer, there is a modular unit in which all components are linked together, without the possibility to be exchanged or extended (Staib et al., 2008). The modular home is produced in the factory, ready to be placed on the construction-site. It consists in a module, which can be connected with other ones, resulting in a series of modules. Most units have already the paint and finishes (Blauvelt, 2007). These building systems are mostly applied to construction where the time is the decisive element, but still presenting competitive cost (Staib et al., 2008).

In an open system there are two possibilities: frame system or panel system. The frame system is the one that approaches the traditional construction, because it also uses column and beam elements. The beams carry the loads from the floor slabs and roof, that are than transmitted to the columns and finally to the foundation. The junctions in all load-bearing and bracing elements need to be connected with precision during the design phase. The panel system doesn't use columns and beams, the transverse walls supports the floor slabs above, that must be constructed continuously across a number of fields. The external wall elements must be light, in order to ensure its easy transport and assembly. A better control over waste, cost and quality of materials is allowed (Kaufmann, 2009). These open systems offers the possibility of integrating materials from several different manufactures, as well as they combine various prefabricated building parts (Staib et al., 2008).

The cliché "time is money" is more present than ever in developed countries. The prefab solutions do bring the possibility to reduce the time of construction: the on-site construction work is less time consuming due to the preassembled sections, and so there are fewer tasks to perform. This also leads to less detrimental impacts on the surroundings in form of noise and dust, commonly associated with building sites. The automation of the manufacturing process can be implemented when there is continuous significant demand, contributing to save labour costs and reduce final price. Thereafter, there is a productivity increase, with a best schedule of the construction, which is less propitious to delays and based on repetitive processes. The costs are reduced with a less time spending in construction, avoiding the shuttering and scaffolding, and also reducing the construction waste (Tam, 2006). For workers it is a safer context to work, with less worker accidents due to a more clean and reliable construction system (Smith, 2011). The manufacturing off-site also provides a better environment protection, and the weather conditions are not a problem relatively to construction schedule (Adlakha and Puri, 2003).

It can also be some disadvantages like the transport of the sections, in case of being large ones. Lightweight prefabricated systems, on the other hand, don't usually have this problem, because its transport is easy and with fewer restrictions – the economically competitive distance can be larger. Other problem is related to the needs of reinforcement to take care of handling and stresses. At the same time, an extra care is required to make air tight solutions (Adlakha and Puri, 2003). In terms of thermal comfort, there will be disadvantages especially in temperate climates, with too much daily fluctuations and hot temperatures in the summer (Martín et al., 2009).

There are some direct advantages in the use of prefabricated solutions, with lower specific weight, which can be summarized as follows (Mendonça et al., 2011):

- Embodied energy of the materials: taking advantage of the lower incorporated energy of wood, for example;
- Cost of the transport of materials to the construction site: reducing the cost of transport by using lightweight materials;
- Waste produced from construction: prefabrication enables a reduction of the waste produced in traditional construction;
- Construction time schedule: by using methods that avoid shuttering, shoring and scaffolding, the construction takes less time to perform;
- Construction areas: there can be an easier increase in the total area of the construction if needed, because other modules may be added to the construction after it is finished.

4. Survey findings

4.1. Survey objectives and conducting

The main aim of this survey was to evaluate the current Portuguese status in prefabrication and to collect the construction practitioners' perception on benefits and potentialities of the prefabrication. This study is part of a study performed by authors at University of Minho, Portugal, on the characterization of Portuguese construction methods and defining the guidelines to improve the use of industrialized construction. Thus, the survey questionnaire was structured in three sections. First section consisted on general characterization of the respondents. Section 2 was designed for companies to compare prefabrication with conventional construction methods concerning the costs of construction and the waste production, and to classify aspects usually considered for the selection of the construction processes. Furthermore, companies were asked to identify the most common construction methods for each type of project developed. In section 3, it was intended that respondents characterize prefabrication regarding its advantages and barriers considered most important and, also, regarding the ability it offers of reducing waste according to the diverse types of projects. For the development of the survey, an online platform was used.

The implementation was carried out in northern Portugal, initially with 70 contractors and architecture and engineering companies, through email. Selection criteria considered included geographic location (Northern Portugal), experience and curriculum with projects based on prefabrication, and recognition by the current adoption of sustainable practices and environmental certification. To obtain these data were consulted the websites of the Portuguese association of contractors and of the Portuguese association of designers and consultants where is possible to consult the constructions performed in recent years as well as their constructive methods and intervenients. The participation was low, even after insistence, and 11 responses were obtained. Subsequently, a new approach to a much more restricted set of companies was carried out; therefore, ten companies were contacted by telephone in order to obtain the contact of the best qualified person to participate in the survey. A link was sent to the contacts obtained, and three more timely responses were received. Finally, surveys were personally delivered to companies belonging to the author's area of residence, and four more responses were attained. As resulted, a set of 70 of companies were contacted, from which 13 construction companies and 5 design companies or consultants accepted to answer, corresponding to a participation rate of 26%. Participating companies, which selected their own representative responders, were asked to choose experienced, competent collaborators. The companies' sizes were heterogeneous, comprising big and small. The distribution of the respondents by activity, number of employees and experience (years) is presented in Table 2, Table 3 and Table 4, respectively.

Table 2. Respondents´ distribution by activity

Respondents´ activity	
Contractor company	13
Engineering company	3
Architecture company	1
Consultant (architecture and engineering)	1
Total	18

Table 3. Respondents´ distribution by number of employees

Employees	
Micro-companies (employees < 10)	7
Small-companies (10 < employees < 50)	3
Medium-companies (50 < employees < 250)	4
Big-companies (> 250 employees)	4

Table 4. Respondents´ distribution by experience

Experience (years)	
< 5	5
5 < years < 10	1
10 < years < 15	3
15 < years < 20	3
> 20	6

The percentage of responses obtained (26%) is due to the fact that companies are undergoing a period of economic and financial contraction, with a corresponding effect in the dismissal of part of their employees and consequent workload of others, which decrease the availability of time to more actively participate in this sort of studies. Currently, companies are forced to engage only in activities that bring them quick and direct benefits. Hence, and taking other surveys recently carried out as an example, the response rate attained configures a participation that may be considered normal and resulting from a significant effort undertaken in the stage of the survey implementation.

4.2. Survey findings and discussion

4.2.1. Data analysis methodology

In order to gather, quantify and rank the answers given, it was adopted the Relative Importance Index (RII) model, based on the following equation (Eq. 1):

$$\text{RII} = \frac{1\times n_1\times 2\times n_2\times 3\times n_3\times 4\times n_4\times 5\times n_5}{5\times n_t} \quad (1)$$

where $n_1,\ldots n_5$, are the number of answers given quantified by the respective weight, which ranges from 1 (less important) to 5 (very important), and n_t is the total number of answers (Doloi, 2009).

This method of analysis is widely used in studies focused on conducting surveys and is very useful when searching for a classification and ordering of answer options provided in the questionnaire.

4.2.2. Construction methods comparison

Considering the construction method adopted, the respondents assume that all the parts included in the method have a significant role, especially construction cost and the building technology used. As it was already mentioned, Portugal presents a conservative construction industry, and thus the prefabrication technology is not much explored by contractors. For that contributes also the fact of this constructive option not to be one of the main choices of the designers and not be properly considered by the owners.

To surpass the problem of low investment in new technology, it should be demonstrated to the companies the importance of being adopted the new solutions and its advantages.

Firstly, it was asked to the respondents to classify a set of aspects considered to the selection of construction method. Possible responses ranged from 1 to 5 corresponding to "little important" and "very important". As shown in Table 5, the cost is the most important aspect but there are already some environmental concerns depicted by the topic “Waste reduction”.

The proposed questions allowed respondents to add aspects considered important and which were not included in the list presented. Thus, three companies mentioned other criteria/aspects considered important in their selection of construction method. The added criteria were the "Characteristics of the developer" and "Safety", both with the rank of 5, and "Quality" with 4 values, according to the scale mentioned above.

Table 5. Constraints for selection the construction method to be adopted

Relevant aspects considered in the selection of construction method to be adopted	***Responses***	
	RII	***Ranking***
Construction cost	0.96	1
Familiarization with the technology	0.90	2
Construction time spend	0.87	3
Resources availability	0.86	4
Waste reduction	0.84	5
Deliver logistics	0.78	6
Type of construction method adopted in the local market	0.74	7

There is a very significant percentage of opinions that the prefabrication technology reduces the waste produced in comparing with traditional construction. Thus, when argued about the percentage of waste that prefabrication allows reducing in construction sites, compared with traditional construction, the majority of survey respondents believe that the reduction is between 21 to 30% of the volume approximately, as is shown in Fig. 8 (the ranges of rates of waste reduction considered in questionnaire were based on others related Portuguese studies undertaken). A value within this range allows concluding that the respondents, based on their experience, consider that prefabrication is an effective way to mitigate the impacts of the construction industry.

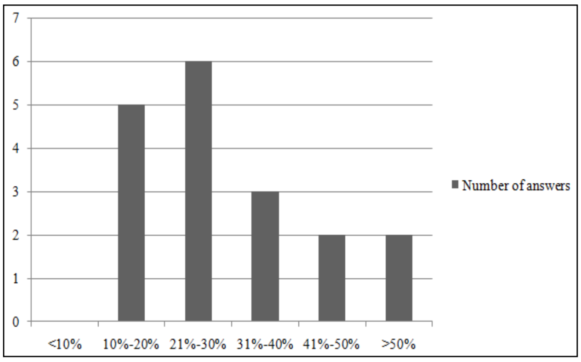


Fig. 8. Percentage of waste minimization by choosing prefabrication, instead of traditional construction

According to respondents, the construction activity responsible for producing more residues is the “finish works”, with an RII of 0.83, followed by the "packaging and protections" and "Formwork", both with an RII of 0.72, as documented in Table 6. The answer scale ranged from 1 to 5 corresponds to "Low production of waste and "A lot of waste" respectively.

The results from the analysis of the table above, shows that the waste is related to the construction method applied. When prefabrication is chosen, the activity "finish works" can be practically nil, depending on the level and quality of prefabrication, and in this case, the waste produced will not be as significant. The production of waste is also related with the last-minute changes derived from changes in owner decisions, or changes needed in the project, thereby increasing the production of waste. Whether a detailed prefabrication study is performed since the design phase, subsequent decisions will not be necessary and the need to do reworks and demolitions it will be significantly reduced.

Table 6. Different stages in the construction process and its related waste production

Different stages in the construction process and its waste produced related	***Responses***	
	RII	***Ranking***
Finish works	0.83	1
Packaging and protections	0.72	2
Formwork	0.72	2
Concreting	0.67	3
Materials' transport	0.66	4

In terms of costs per m^2 of construction, according to respondents' opinion, the prefabrication was considered more economical compared with traditional construction (Fig. 9). Seven respondents reported that is until 20% cheaper while five companies responded that it is more economical up to 10% than the traditional construction.

During the survey, participants were asked to compare the traditional construction with prefabrication in certain issues. Possible responses ranged from 1 to 5 corresponding to "very weak" and "very good", respectively. With these classifications the relative importance index (RII) were obtained for the different aspects what allowed to compare the prefabrication with traditional construction and also to establish a ranking for both construction methods. The data was organized according to Fig. 10.

Overall, the prefabrication was considered benefic against conventional construction in all aspects, except in concerning to "Life-cycle of building". These results reflect that Portuguese companies are satisfied in relation to which they apply in prefabricated buildings.

The prefabrication stood out heavily on traditional construction with regard to the "Waste reduction" construction with an RII of 0.3 between them, followed by "Maintenance facilities" with an RII of 0.13.

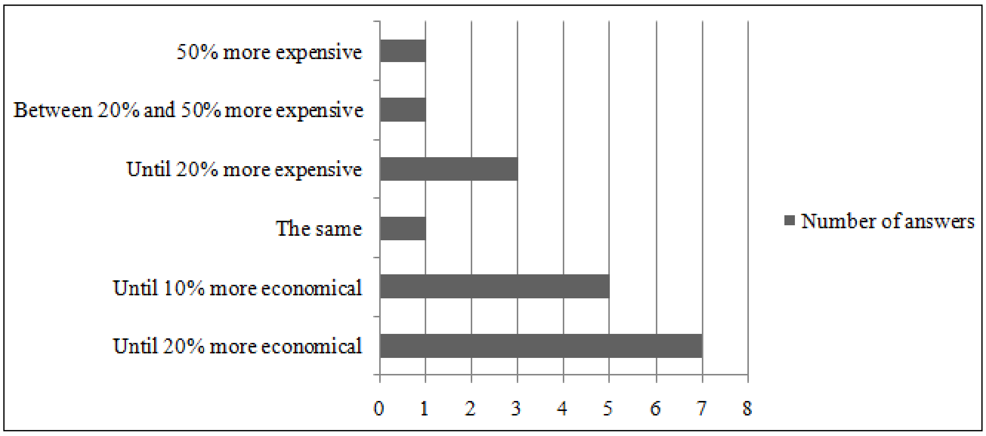


Fig. 9. Cost of construction variation per m^2 between prefabrication and traditional construction

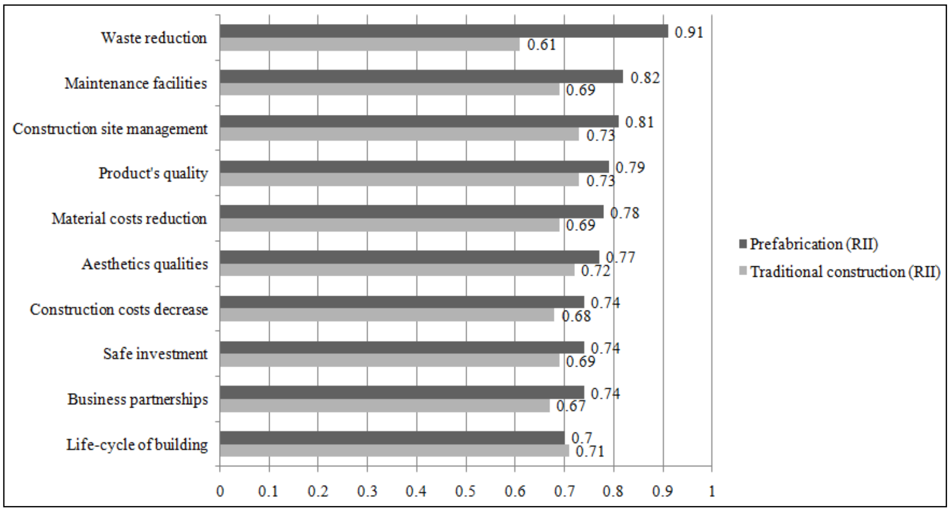


Fig. 10. Prefabrication versus traditional construction

The big difference in the characteristic of existing RII "Waste reduction" between the two methods of construction, is due to the fact that prefabrication be able to minimize waste during the various stages of construction, verifying a large reduction of waste at the end of the building. Subsequently, it was requested the participants to select the method usually used in the constructive types of projects that have been involved. The responses are organized in Table 7.

Table 7. Projects inserted in each construction method

Projects	***Traditional construction***	***Prefabrication***
Residential	15	3
School	9	9
Industry	0	18
Commerce	10	8
Hospital	8	10
Hotel	12	6
Total	54 (50%)	54 (50%)

As expected, the residential sector chooses the traditional construction. On the other hand, the industrial projects are totally based in prefabrication methods what is certainly related with the deadline limit for completion of the structure. From results it is also possible conclude that despite the problems of the prefabrication sector previously mentioned, the set of respondents selected for this study have an interesting experience with prefabrication.

It was performed the same analysis, but in this case in relation to public and private projects. The answers indicate that prefabrication is mostly used in public projects, while traditional construction is applied mostly in private projects.

The public projects are usually large and with repetitive elements, such as the housing estates, buildings where are usually repeated equal to each other. The repeatability of elements is ideal for the adoption of prefabrication and cost reduction. For example in social housing estates, the repetition of structural elements favors the use of prefabricated elements, allowing the reduction of construction period. In contrast, private projects have characteristics that change from client to client, with lower construction volumes. The results are organized in Table 8.

Table 8. Public and private projects associated with each method of construction

Projects	***Traditional construction***	***Prefabrication***
Public	5	13
Private	14	4
Total	19 (53%)	17 (47%)

4.2.3. Benefits of prefabrication

In this section it was asked the respondents to characterize today's prefabrication companies about their benefits, barriers, among others. Initially it was requested to assess the level of importance of some advantages, using a scale from 1 to 5, where (1) means "less important" and (5) "very important". The answers are presented in Table 9.

The advantages related to prefabrication are the "reduction of construction time" and the "productivity increase".

By reducing the time of construction, the companies can obtain a return on their investment more quickly. The building is set to be finished sooner, and thus faster is sold. The overall analysis indicates that users are aware of the importance behind the benefits, since all have significant levels of relative importance, for above 70%. Subsequently, respondents qualified certain barriers / obstacles to the use of prefabrication. The range of possible responses ranged from 1 to 5, where (1) corresponds to "completely disagree" and (5) corresponds to "completely agree". The data is organized in Table 10.

Table 9. Companies' assessment for the prefabrication advantages

Companies' assessment for the prefabrication advantages	***Responses***	
	RII	***Ranking***
Reduction of construction time	0.91	1
Productivity increase	0.91	1
Quality assess increase	0.90	2
Waste reduction	0.89	3
Construction easy to perform	0.89	3
Construction site management organized	0.87	4
Labour demand reduction	0.84	5
Project costs reduction	0.82	6
Material use reduction	0.82	6
Safety increase	0.80	7
Schedule of construction easy to define	0.78	8
Project time reduction (design, planning and construction phases)	0.73	9

Table 10. Companies' assessment for the prefabrication main obstacles

Companies' assessment for the prefabrication main obstacles	***Responses***	
	RII	***Ranking***
Lack of standardized components	0.77	1
Lack of skilled labour	0.74	2
Rupture with the traditional method	0.72	3
Conflict between the practices adopted	0.70	4
Lack of incentives	0.70	4
Lack of some elevation equipments	0.62	5
Cost non-competitive	0.57	6
Lack of space on the construction site	0.53	7

The "lack of standardized components" was considered the greatest barrier to the use of prefabrication. The variety of the prefabricated solutions standardized existing in the market is not enough to face the needs of users, forcing them to resort to compulsory traditional construction to achieve a solution that fit their needs.

On the other hand, the great variety of constructive elements used in most projects results in a poor demand of prefabricated construction elements which prevent these constructive options becoming an economically viable market.

Next is the "lack of skilled labor" with an RII of 0.74 and the "rupture with the traditional construction process" with an RII of 0.72, thus completing the three major barriers in accordance to Portuguese companies consulted. The lack of skilled labor is associated with a lack of familiarity with the building process, thereby preventing the expansion of prefabrication. This barrier can be overcome through training and specialization of workers and specialists involved. The lack of qualifications in this area implies buildings that are completed without quality, reflecting serious problems later.

After characterization of the benefits and barriers of prefabrication, respondents were questioned about the level of satisfaction they get when choosing the prefabrication, for certain aspects considered relevant. Possible responses ranged from 1 to 5 corresponding to "just satisfied" and "very satisfied", respectively. The data is organized according to the Table 11.

Table 11. Companies' satisfaction level when choosing prefabrication

Companies' satisfaction level when choosing prefabrication	***Responses***	
	RII	***Ranking***
Reduction of construction time	0.87	1
Reduction waste on construction	0.84	2
Product reliability	0.83	3
Production monitoring/techniques	0.81	4
Construction site management	0.77	5
Communication between the team members	0.77	5
Total cost	0.73	6
Overall satisfaction	0.72	7
Material cost	0.71	8
Project design (standardization)	0.69	9

The "reduction of construction time" and "reducing waste at work " are the aspects that leave more satisfied the companies. Another characteristic is the "product reliability" with an RII of 0.83, which indicates that the market considers the prefabricated products for the quality applied.

The "project design (standardization)" was considered the least satisfying aspect that consumers use when they want to choose prefabrication. This assessment is possibly due to the low number of standardized products that can satisfy the initial choice of the designer. Thus, the designers are dependent of the existing elements and so in many cases they have to modify the design characteristics to incorporate these elements in order to achieve the prefabrication.

Finally, participants were asked about the potential for waste reduction that prefabrication has when applied to various types of projects. On a scale of 1 to 5 with the minimal amount to "very negligible" up to "extremely significant", the result of the survey reveals that the introduction of industrial projects in prefabrication significantly reduces waste, followed immediately by hospital projects. According to respondents, the incorporation of prefabrication in residential buildings is leading to a smaller reduction of waste, as shown in Table 12.

Table 12. Prefabrication advantages associated to waste reduction in each sector of construction

Prefabrication advantages associated to waste reduction in each sector of construction	***Responses***	
	RII	***Ranking***
Industry	0.88	1
Hospital	0.87	2
Hotel	0.84	3
Commerce	0.79	4
Residential	0.77	5

5. Conclusions

The impact of construction industry on the environment is very significant. Construction site activities in urban areas cause damage to the environment, interfering in life's quality of residents, that frequently claim against dust, mud, noise, traffic delay, space intrusion, materials or waste deposition in public space, etc.. In a time where the knowledge about cleaner construction systems, techniques and materials is highly developed, the practice is in most cases not accompanying these improvements, due to several factors, but mostly associated with a conservative vision of the construction sector.

Portugal presents a conservative construction industry, and the prefabrication technology is not explored by the constructors, so it is necessary to implement awareness actions with contractors and others stockholders in order to change this paradigm and overcome barriers that hinder the expansion of prefabrication. The consult of the practitioners in order to collect their perception regarding to several important aspects that can influence the use of prefabrication as well as on its benefits, was a relevant source and an important contribute for this process.

The questionnaire results shown that the cost is the most important aspect considered for choice the construction method, but there are already some environmental concerns depicted by the importance of topic "Waste reduction". The majority of respondents think that the waste reduction in construction sites is between 21 to 30% of the volume approximately. The respondents consider that prefabrication is an effective way to mitigate the impacts of the construction industry. According to respondents, the "finish works" are responsible for most quantity of waste produced in construction sites, so if the prefabrication is chosen, the activity "finish works" can be practically nil contributing, thus, for the reduction waste produced significantly. Overall, the prefabrication was considered benefic in comparison to conventional construction in all aspects, except the durability of building, and it is possible conclude that results reflect that participants are satisfied with their experiences in prefabricated buildings. The "reduction of construction time" and "reducing waste at work " are the aspects that leave more satisfied the companies. In concerning to obstacles the "lack of standardized components" was considered the greatest barrier to the use of prefabrication.

Thus, it is possible conclude that this study was important to exemplify how prefabricated systems can contribute to the reduction of the environmental impact of buildings. Prefabrication allows a faster assembly with reduced environmental impacts on site, but also, and most relevant, the easy disassembly of buildings, promoting reuse and recycling. This concept arose as a consequence of the increase in the number of buildings that need to be demolished and the evolution of environmental consciousness. Demolition is, among the construction activities, the one that presents the most relevance in what concerns to the production of waste. Selective dismantling is still an unusual process in Portugal; as traditional demolition is yet the usual method. In addition to the general lack of awareness of the overall benefits of disassembling, there are still many barriers to implement this strategy in Portugal. The barriers include not only technical and market issues, but also socio-cultural factors as attitude of people (apathy), reluctance to accept recycled and reused materials, lack of knowledge on how to reuse, lack of standards and regulation on requirements of the materials reuse, low cost of the new materials etc.. A deconstruction effective design can be obtained by several strategies, such as: use of totally separated systems; possibility to separate the components in each system; using standardized and homogeneous materials; using mechanical fixings, using dry joints; use prefabricated lightweight materials and components. Easier, quick, and less costly handling, allow reuse to be a more widespread strategy.

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