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ROBOTIZED LEAN ASSEMBLY IN THE BUILDING INDUSTRY

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ABSTRACT

The construction is probably one of the oldest industries that exist nowadays. The processes and techniques used today are basically the same since ancient times. The main difference is the level of mechanization used in the tasks execution and materials used. What seems obvious is the fact that building industry has continuously evolved towards mechanization. This evolution has experimented an enhancement in the last few years. Robotization and automation of the building processes start to be applied not only off site but on site. In this way, using concepts as DFMA and Lean Assembly, products can be developed for their assembly by robotics systems on site. In order to apply these concepts one product has been selected (the Service Core). This paper presents the starting point of the automatization process: the analysis of the traditional assembly of the module.
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KEYWORDS

Robotics, Lean construction, Building industrialisation, Service core

1. INSTRODUCTION

Along the history, there have been many attempts of automate and robotize the building industry. The developments try to carry the automated and robotised systems, already applied in the prefabrication of constructive elements, into the environment of construction site.

The construction industry has very remote origins. Due to this, the techniques currently applied in construction do not possess the level of industrialisation that has similar techniques that are carried out in other industrial sectors. The application of industrialised processes has been delayed and obstructed by the consideration of construction as a traditional industry, giving preference to techniques, processes, and traditionally used materials.

Although in recent years the production of housing has been increased, the construction industry continues to lag behind other types of industries in technological adoption and integration. Other industries have adopted energetic organisational strategies to reduce production costs and improve productivity and the quality of the product (for example, Computer Integrated Manufacturing (CIM) and Flexible Manufacturing Systems in automotive industry). The housing industry needs a change in the system of fabrication in order to achieve similar benefits and share them with the end user.

There is a series of means and industrialisation methods that have been successfully applied in other types of industries such as:

•Resource planning systems (ERP).

•Object-oriented CAD design systems.

•Just – In – Time production (JIT).

•Design oriented towards fabrication and assembly (DFMAss).

• Design of prototypes and tool analysis.

These strategies represent a first step in the process of industrialisation of construction and in the utilisation of integrated systems to achieve a product with proven performance and functioning.

One important aspect is to bear in mind the singularity of a construction project. This means that the tasks and the form of carrying them out may vary significantly between two different construction sites. In this way, the automation of processes and activities becomes complicated. Automation is restricted to specific processes within a larger activity or to processes in which the production volume is very large.

2. PAPER STRUCTURE ASSEMBLY AND MANUFACTURING IMPROVEMENT BASIS

2.1. Lean

Lean manufacturing or lean production, which is often known simply as "Lean", is the optimal way of producing goods through the removal of waste and implementing flow, as oppose to batch and queue. Lean manufacturing is a generic process management philosophy derived mostly from the Toyota Production System (TPS).[1]

2.2. DFMA

In very general terms, DFMA is a set of methodologies and principles that guide the proactive product design to optimize all the activities related with the manufacturing market (manufacture, assembly, tests, supplying, service, etc.) DFMA consists of complementary methodologies:

• DFA: Design for Assembly

• DFM: Design for Manufacturing

Important goals for a company are the reduction of costs and the time until the commercialization. The design of new products should be analyzed in order to optimize time and prototyping. As well, it's necessary to search for the factors that have influence in the cost of the final product. Nevertheless, these aspects are usually ignored, simply because the lack of a method to understand and to manage them. DFMA helps the designer to analyze and understand the costs originated by the decisions taken in the development of the product [2].

3. BUILDING INDUSTRIALIZATION

3.1. Automatization and robotization in construction

Currently, there is a low degree of automation in the construction processes due to diverse reasons. Theprincipal reason is the just mentioned traditional nature of the construction industry which slows down and impedes the advance and implantation of automated systems for carrying out these activities.

Besides, the 'site production' differentiates construction from other 'fixed position manufacturing' industries like shipbuilding or airplane building. The relative uniqueness of the buildings and no standardization of their parts is another important issue.

We have to keep in mind the singularity of each construction project, also considering the same final product, for example a skyscraper that is been built in different places. This means that the tasks and the form of carrying them out may vary significantly between two different construction sites. This rootedness-in-place brings with it uncertainty and differentiation. Carrying out the same activity in different construction sites depends on various factors that have influence on its possible automation. These factors are:

• A wide range of materials employed. The difference of the materials employed in the execution of an identical process. This implies the use of tools adequate for each material.

• The processes that form a constructive activity are related to the type of material and the tools used. In this way, the process flow may vary for the same activity if one of these two elements varies.

• The complexity and singularity of the processes depends on the productive system.

• The environment in which a construction site is carried out influences greatly the work system and the methods to be used. It means that the environment is highly unstructured.

• The complexity of the installations for automation due the very low level of standardization and chain supply planning.

• The cost benefit of automation of small batch production and high diversity are not clear. The automation machinery cost is very high.

One differentiation must be made between automation of construction and automation of the different activities within a construction site. Automation of only one activity implies a reductionin the size of the final product and less complexity in the executing processes, without the necessity of using large systems. Automation of tasks may be included within a larger system or be carried out by only one machine. In this case, these machines areconsidered construction robots [3].

Automation of construction processes has various advantages that help the search and implementation of these systems. Some of these advantages are:

• Less dependency on direct labour. The activity ceases to be directly linked with the operator, avoiding problems related to quality and the repetitiveness of work carried out. Costs may also be reduced by reducing labour, since fewer operators are needed for the automated system, although these present greater qualification.

• Increases in productivity. Automation of the activities increases the speed of production. It is

also increased by disengaging the operation of the limitations of the human factor.

• Increase in work safety. The automated systems may carry out their work in environments and zones of danger for humans, making it possible to reduce labour accidents.

• Increase in quality. The quality of the operations increases with the automated systems since they are typically carried out with less variability than human workers.

• Competitive advantages by reducing costs. The reduction in cost of human labour and the decrease in material loss, among other factors, reduce the cost of the operation.

• Greater control over the productive process. Each stage of the process is controlled in order to verify the correct functioning of the system and the result of each one. In this way, problems may be detected and isolated in an easier way. The automation is also supported by an integrated information system that provides data interchange between the actors involved along theconstruction process.

• Greater control over the final result of the process. Controlling the result of each step of the aforementioned process, the final result may be controlled in a more efficient way.

The success of automation in construction will depend on the examination and the understanding of the economic, technical, and organisational implications.

Within the automation of construction, the field of construction robotization is integrated. This concept refers to the introduction of robots as part of the automated system or forming the complete automatic system [4].

The main obstacle for the introduction of robotics within the world of construction is the variability of the processes and the variable conditions of the construction environment. Bearing this in mind, the use of robots in construction is far away diverting from programming, from the sequence of fixed tasks, and moving towards a new form of robot usage, adaptable, that may successfully carry out a variable task. In this way, the implantation of robots within the constructive system in construction site may be used as an ideal scenario to test and to verify the development of robotics.

Another issue is the limited payload of the existing robot technology. While the manufacturing industry manipulates light or medium weight pieces, construction industry manage heavy loads and tools.

On the other hand, the relationship payload vs. position accuracy is another related factor. The increasing of the payload leads to decrease the position accuracy in the tip of the robots. Given that the use of robots falls within the framework of the field of automation, it shares the advantages and inconveniences previously described.

The most significant differences with respect to classical electro-mechanical automation (based onPLCs without the use of robots) are:

• Increase in flexibility. This aspect is incremented by a mobility enlargement, whether it is in the manipulation of materials or in the robot itself. Flexibility is also increased in automatic systems with the possibility of carrying out different types of tasks due to the incorporation to the robots of interchangeable tool systems. Lastly, the possibility of re-programming of activities to be carried out by a robot contributes to this increase in flexibility.

• Increase in complexity. A robot-based system is more sophisticated than a classical automated system. The fact that a robot is a dynamic system makes the hardware elements for their supervision and control more complex. Furthermore, the programming of the robot systems requires a greater degree of detail. More specialized operators needed.

• Robots may carry out more complex manipulation and processing tasks than classical systems. Another way of seeing the advantage of a robot system is by carrying out manipulation tasks so that only one machine may carry out the same task that would otherwise need to be carried out by an ensemble of machines.

3.2. Comparison with the automotive industry

The automotive industry is characterised by the existence of an assembly plant where all of the components that have been manufactured at other factories are assembled after being transported to the assembly plant. By means of an assembly line, the different components are assembled sequentially until finally forming the finished automobile.

In the present day, the components reach the factory with a minimum time in advance and do not require prior storage. The Just-in-Time strategy was developed by manufacturing industry in order to reduced time, cost and space of warehouses. Furthermore, on the assembly line, different models of the brand with different degrees of personalisation are assembled, since it is habitual to manufacture cars according to the specific order (colour and different options) of the purchaser.

With this system, a mass production of "on time" automobiles is obtained, according to specific order. This order is defined by the manufacturer and end-user (the person who order the car). The strategy of the assigning and defining the order of manufacturing is focusing in the optimization of all the production process.

The automotive production is a mass production industry but at the same time is a small sized production due the high variety (hundreds) of the different products, with a great mobile value, making it easily transportable to its final destination. The balance between the high productivity and flexibility is the key issue of automotive industry. In the traditional construction of buildings, the scheme has some similarities with automotive industry and some notable differences as well.

The similarities are that the buildings are constructed with manufactured materials and components, mostly in places and factories that are outside of the construction site and which are transported to the construction site to be placed there. Sometimes the distance (and cost) of this transportation is very high.

The differences begin in that the construction site is a true assembly plant, unique for each building, that is to say, an assembly plant that produces one single product, the building. This means that for each building it has been necessary to install a new assembly plant, which at the end of construction was disassembled or sometimes destroyed. The cause of this is that the product produced is large in size and fixed (it is not mobile) and furthermore, in proportion to its size, of lesser value than the automobile, i.e. low value added.

4. CASE STUDY

In order to apply the Lean assembly and DFMA concepts, there has been selected a product with three main characteristics:

• Medium/high level of complexity.

• Use of different materials

• Different type of tasks (assembly, machining)

4.1. The Service Core

Service Core consists on a metallic frame to which all the necessary services for the operation of bathrooms, utility areas, or even kitchens go fixed (Figure 1). The service core essentially contains much of the equipment that would otherwise be field-installed in a house, such as plumbing lines, HVAC ducts, and fixtures. The efficiency of the production of this type of system to make the facilities of the services in a house has been proved, especially in multi-storey housing. The production of this system includes the preparation of raw materials received at the site in order to fit them into the particular design and the assembly of the generated parts with other prefabricated elements.

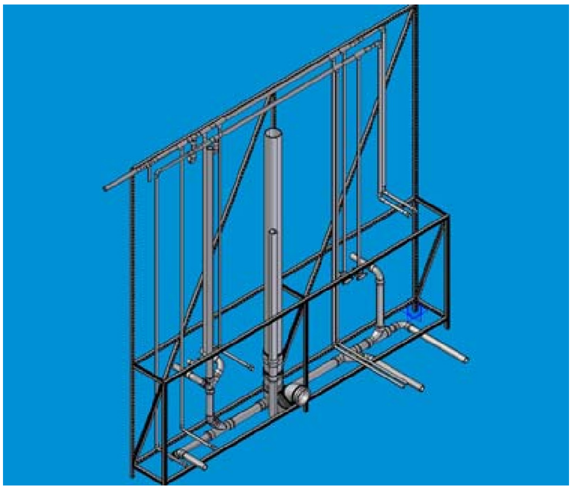

Figure 1. Service Core model

The parts that integrate the Service Core are made with diverse kind of materials. The use of so different materials as the steel for the frame or the PEX (crosslinked Poliethylene) for the sanitary water facilities implies that different types of tools must be used in the preparation and assembly processes. Furthermore, the joining methods are different.

4.2. Traditional manufacturing

The assembled prototype module has three substructures: the frame, the sanitary water installation and drainage.

The frame structure is the stand for the installations. Its design is made taking into account the size of the final location and but not the sub-structures that will be assembled on it. This means that the frame is more like an all-purpose metallic structure. Later, the sub-structures are assembled on it and adaptations are made if necessary.

Usually the frame is assembled on a factory and transported to the site. Transport costs are bigger in this case than transport raw material. The sanitary water and drainage installations have two main components: pipes and connectors. The systems are made following two main design criteria over other less restrictive factors. The first one is the location of the water inlets and outlets. The position of the connections with the fittings is set in the architectural design. Usually, the design of the path of the installation is made on site. The second one is the water conditions (pressure, flow). These design premises fix the diameter of the pipes to be used.

The installations are also attached to the frame. If there is not possibility of attachment in some place of the frame, other metallic shape can be added to support the installation. This modification on the structure of the frame is because of the generic design of the frame and after adaptation of the installation assembled on it.

The main differences between the two installations are the materials and the way to be assembled: press fitting in the case of the sanitary water installation, and gluing for the drainage.

Taking in account these considerations and constraints the time spent in the assembly of each substructure of the Service Core is (Figure 2):

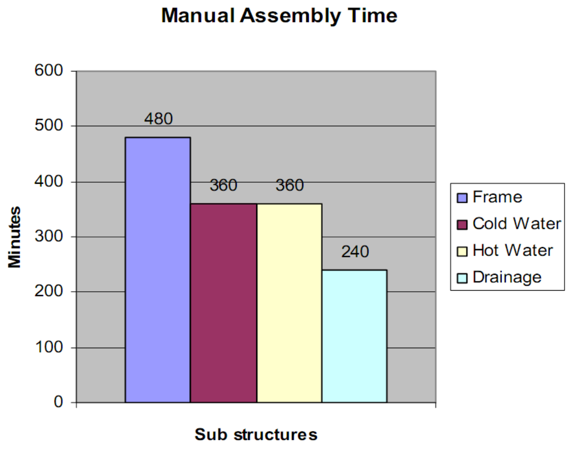

Figure 2. Assembly time

4.3. Time analysis

From the graphic above, the frame assembly time on factory was 8 hours. Once the frame was on the site, the overall assembly time of the installations was 20 hours. Taking in account that one working day is 8 hours long the Service Core construction took 3.5 days (Figure 3).

This time was dedicated to the prototype assembly. When several modules must be constructed, the time spent in the assembly of each one starts to going down. Reductions between 30% and 50% of time can be achieved. In the best case, we can obtain 19 hours of assembly time (≈2.4 days). The time reduction in hours is the 50% but in working days the reduction is about 32%.

4.4. Quality analysis

Other important issue is the quality of the final Service Core. The manual process depends on the skills of the people in charge of the assembly. There are aspects directly related with this issue but some defects or low quality finishing are derived from the on site adaptation of the substructures. Some faults that decrease the quality are described below:

• Bad junctions: the finishing of the welded junctions is poor and there are defects caused by bad welding or finishing operations.

Figure 3. Add on to the frame

• Need of more frame support: some metallic supports must be added to the frame in order to support the installations. This issue is caused by the adaptation on site of the installation to the frame.

• Complex adaptation: the location of the outlets and inlets sometimes makes difficult and complex the assembly of pipes and connectors (Figure 4).

• Misalignments: derived from the previous problem, there are misalignments in the pipe's path. This makes difficult the attachment of the pipe to the frame.

Figure 4. Complexity on installations

5. CONCLUSIONS

Leave the header and footer empty. Once the Service Core prototype was made to validate the concept, the analysis of the traditional work shows the wastes that fit with five of the Lean principles. There is a main waste of time (waiting) due to the lack of materials and breaks during the work. In addition, changes in the original design during assembly cause problems with the material resources (inventory), having influence in the assembly time. The last factor that can affect time waste is the logistics in the assembly process (motion); that means, the time used to transport materials from the warehouse to the assembly area by the worker. Related with quality, low degree of labour and bad assembly techniques cause the necessity of rework (over processing) and low quality results (defects).

The Design For Manufacturing and Assembly should be the tool used to avoid all the wastes mentioned before. The study of the traditional assembly process helps to identify the problems to solve. Automation and robotization are the means to obtain the required levels of quality and time savings. The combination of these new techniques can improve the traditional building industry, moving the knowledge from more productive industry sectors to the site.

REFERENCES

[1] Howell, G.A. (1999). What is Lean Construction?, Proceedings of the International Group of Lean Construction 7th Annual Conference, Berkeley, USA.

[2] Van Vliet, J.W.; Van Luttervelt, C.Ass Kals, H.J.J. (1999) State-Of-The-Art Report On Design ForManufacturing. Proceedings of the 1999 ASME Design Engineering Technical Conferences, Las Vegas, Nevada.

[3] C. Balaguer (2000), Open issues and future possibilities in the EU construction automation *IAARC Int. Symp. Robotics and Automation (ISARC'00)*, Taipei, Taiwan, pp. K21-32.