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PREFABRICATION & MODULARIZATION AS A PART OF LEAN CONSTRUCTION – STATUS QUO IN GERMANY

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ABSTRACT

A possible innovative approach to unify construction processes and align it with the industrial mass production, is the integration of industrial prefabrication and modularization in construction.[2] The higher the numbers of identical components, the lower are production costs, which can be a significant competitive advantage. When applying that approach a building gets assembled on site using prefabricated parts and modules are assembled. Especially the use of prefabricated components in the field of technical building equipment still has great potential. For example plumbing units can be delivered and installed on the site already fully equipped. An application in the construction industry, for example, pre-installed ceiling modules (ventilation ducts, cables, pipes, etc.) takes place in Germany but still marginal. Connecting the individual modules is often a problem, but solutions already exist using simple connections. With this innovative production strategy waste during construction process can be reduced. By the associated reduction of individual production steps on site quality can be improved, costs can be reduced and safety for the workers can be increased. The current state of implementing prefabrication and modularization in Germany will be illustrated using examples.

KEYWORDS

Continuous improvement, manufacturing, customization, logistics, standardization.

INTRODUCTION

The leading idea of lean is: "Go to the site of action (Gemba), beware of the real things (Gembutsu), search for waste (Muda) and lead continuous improvement (Kaizen)" (Wilbert, 2009). Dating from the Japanese word "kaizen" literally means "change" or "change for the better" and stands for an ongoing and overall optimization in stages (Schmelzer and Sesselmann, 2008).

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2 The meaning of prefabrication in this paper is the use of stationary prefabricated components. These components have to be only final assembled on site. IGLC Championship defines this as prefabrication and assembly (Court et. al. 2006). The term modularization is used in this paper to describe a systematic partition of a ground plan in equal segments. Modularization should not be confused with the term modularity.

This key principle of the Lean concept applies across all lean disciplines. Kaizen is the basis for Lean Production, Lean Management and Lean Construction. A capital-intensive innovation can cause a sudden break or big changes. In the continuous improvement process, however, is trying to reach a positive change within the company through many small steps. Through a combination of innovation and continuous improvement achieved standards can be secured and new standards can be developed. Thus create competitive benefits of great importance (Kirsch, 2008).

PREFABRICATION AND MODULARIZATION IN LEAN CONSTRUCTION

LITERATURE REVIEW

Continuous improvement can be achieved by various measures. In the construction industry innovative project forms were developed, such as the Last Planner System (LPS) and Lean Project Delivery System (LPDS). The aim of this lean construction tools is to structure the manufacturing processes at the site to ensure a steady flow of information and resources and to avoid waste of resources (Ballard, 2000). This goal is achieved by a collaborative working of all stakeholders at an early stage. Builders, architects, engineers, contractors and suppliers are integrated from the beginning in the planning and can usefully bring in their Know How like that contributing to a positive course of the project at an early stage of the project. The use of simulations helps to optimize production planning processes (Berner, et. al., 2013). As a result, costs are reduced, deadlines are met due to mutual commitments and qualities are planned according to the customer.

However, it is necessary to examine further optimization opportunities to live the Kaizen principle. Especially in the construction industry, there is great potential to improve manufacturing processes and eliminate waste. Material buffer and buffer time can be eliminated by optimizing logistics. An optimized logistics concept contains to a large extent prefabricated components. These can be supplied to and installed on the site just-in-time. It is possible to use the advantages of a stationary production thus reducing working time on construction site. Furthermore the quality and safety at work, is increased by the processing of prefabricated components. Costs can be reduced because many of the same components can be prefabricated in series and not every component needs to be built on its own. The basis for this is that a pattern is used for a building floor plan. It is important that the individual character of each building is not lost. However, it is possible to assign 80% of a building floor plan to an algorithm thus using many of the same components. This modular concept can help to reduce the complexity (Hovestadt, 2014).

Another important point in the context of continuous improvement is the standardization[3] of building products. In the construction industry, there are many manufacturers that produce similar components. However, the components usually have different dimensions and have to be individually adapted to the building.

[3] Standardization: The meaning of the term standardization differs from prefabrication or modularity. International standardization of components (dimensions, connectors etc.) is the basis for a wide use of prefabricated products. An early integration of prefabricated products in the design process requires components standards that fulfill a multivendor-capability.

Standardization, as it exists, for example, in the automotive industry, isn't common yet in the German construction industry. Attempts at standardization have been made, but there was always a contradiction between maximum standardization and flexibility. This restricts creativity why architects often oppose standardized products. But standardization should ensure optimal implementation and contribute to compatibility. Therefore, the focus of standardization is currently at the interfaces between components and not at the individual components per se (Gibb, 1999).

The construction industry is not yet focussing on standardizing systems and products. The focus currently lies on systematically optimizing the organization and processes. Goal must be to effectively utilize the advantages of standard products or components in the early planning process (Aapaoja and Haapasalo, 2014). In this area, there is much to be done to standardize products to appropriate standards and regulations. On this basis, a building can be planned considering the components that will be used and thus ensuring execution-orienting. By defined standards the quality of individual components can be increased (Groenmeyer, 2012).

To use the great advantage of prefabrication in construction projects, a change of thinking in the construction industry is necessary. You may have to move the focus from an individual project execution dealing with unique objects towards a standardized process like in the stationary industry. Therefore, the standardization of products and processes are an essential and maybe even the most important factor to be considered when it comes to optimal prefabrication (Ballard and Arbulu, 2004).

INTEGRATION OF PREFABRICATION/MODULARIZATION IN LAST PLANNER SYSTEM

The Last Planner System is meant as a method of scheduling and production in the planning and in the execution phase. The LPS requires a partnership of the people involved in the project (Last Planner). This can ensure that the required manufacturing process is understood and comprehended by all before starting work. The planning of manufacturing processes in accordance with the LPS forces the supervisor to plan and prepare for the work. It is elementary that they are aware of need of the following trades. Critical points between the individual trades can be addressed in regular meetings during the design phase in order to avoid obstruction on site. Previewing planning guarantees that the necessary information and resources for the implementation of the processes are available on time. Thus, the work can be done according to the joint planning. This reduces waste by faults, reduces costs and gives certainty in meeting deadlines (Gehbauer, 2011).

It is clear that prefabrication is not part of LPS. However the benefits of prefabricated components can be optimally integrated in the LPS. It is particularly useful during the execution phase, to draw on the expertise of the contractors. In this case, not only to the statements regarding the scheduling but also the know-how regarding construction is used systematically. The contractors usually have the best knowledge about the availability of prefabricated products including knowledge about dimensions or other parameters that should be considered in the planning. That fact is the basis for the matching algorithm that needs to be found in order to modularize a building. The objective here is to break down the plan into as many equal areas in which the same prefabricated construction products can be installed.

Applying this modular concept and including mass-produced components, the cost can be reduced by up to 20% (Hovestadt, 2014).

INTEGRATION OF PREFABRICATION / MODULARIZATION IN LEAN PROJECT DELIVERY SYSTEM

The Lean Project Delivery System intends to integrate the executing companies already during planning. The different project phases (design, construction and operation) are looked at integrally in LPDS (Sonntag and Hickethier, 2010). The LPDS is a lean technique that integrates various phases in order to facilitate the design and implementation of construction projects. It is based on close collaboration between the members of the project team. The parties are bound by a code of conduct which does not focus primarily on project success of individuals, but to realize success of the overall process. The LPDS provides a tool to cope with the normal problems occurring on site, such as cost overruns, time delays or poor quality. Furthermore, it contributes to the optimization of the entire design and construction process (Forbes and Ahmed, 2011).

The LPDS integrates the three components of the TVF-theory (transformation, value and flow) and implements them by structuring and control. This contributes to an improvement. The LPDS intends to organize the work on the site so that the three basic objectives can best be implemented:

- Deliver the product,
- Maximize the value,
- Reduce waste.

In contrast to traditional projects, which are divided into different phases (planning, procurement and construction) and are processed separately by a different group of people, the companies involved are already integrated into the decision-making processes during planning implementing LPDS (Ballard, et. al., 2002). Important factors are early procurement decisions. These are required that the suppliers are able to integrate their prefabricated solutions into the early design process. Early selection and early procurement are necessary to do the design around the prefabricated products. This is often called the „Alternative Procurement". All parties are required much earlier in the process (Mawdeslay and Long, 2002).

The LPDS is particularly suitable to take the advantage of prefabricated components to be integrated into the planning process. Thus takes place at an early stage of an execution-oriented planning. If not only executing companies but also substantial suppliers are involved in the project team, who's Know How can be included into the planning. The supplier knows your product best. They can make the planning requirements and know which parameters must be fulfilled that their prefabricated products can be used. Furthermore, suppliers can suggest on how a plan has to be slightly modified (modularized) so that a maximum number of same construction products can be produced. The number of same products lowers production costs and hence the construction costs. This effect is due to the fact that machinery and tools of the production are used more efficiently therefore causing lower unit costs. Furthermore, fewer steps in the production are necessary to setup the machines for new components.

As described, uniform standards for construction hardly exist, it is still necessary to manufacture components individually for each building. However aim is that for each building as many equal parts as possible are used. For this purpose, an individual planning by including executing companies, suppliers and manufacturers is elementary. The LPDS provides an ideal platform for this.

PREFABRICATION AND MODULARIZATION IN GERMANY – A STATUS QUO

BACKGROUND

Certain buildings are built modularized in Germany for many years. Examples of modularized constructions are halls, parking garages or simple hotels and office buildings that are assembled and prepared using special modular system. In this case, there are hardly creative possibilities, as a given raster is compulsory.

Also prefabricated components, which are stationary constructed and installed at the construction site, are also already in use for many years. Especially when it comes to prefabricated houses, prefabricated parts only have to be assembled on site. Prefabricated components are also increasingly used at traditional high building projects. The most common examples are:

- Reinforcement cages,
- Lattice girder plates as semi-finished parts,
- Prefabricated stairs,
- Facade systems,
- Room units systems,
- Wall elements,
- Plumbing units.

Figure 1: Example of prefabricated plumbing cells and stationary production in a hall (Sanika GmbH, Via Primo Maggio 22, 38089 Storo (TN), Italy)

However, this understanding of modularized construction and the examples of prefabrication mentioned above are not further considered. Derived from the example of a plumbing cell, it is intended to demonstrate what opportunities may arise in the prefabrication in the field of technical building equipment. Basis is the classification of an individual, complex building plan into as many equal areas as possible (modularization). Plumbing cells are often prefabricated in the field of technical building equipment. Hence they can be made in a production hall regardless of the weather, dirt and cramped conditions. These bathrooms are turnkey pre-assembled and only have to be put on the construction site with a crane ready to be installed. This usually happens already once the carcass has been erected. During the finishing the plumbing cells must only be connected to the power supply and connected to the pipe network. Ideal fields of application are buildings with high repetitions in terms of room concepts. Explicitly these are hotels, nursing homes, hospitals, residential complexes and correctional facilities.

Especially the technique for connecting the plumbing cells with the pipe network and the electrical wiring has improved significantly over the years. While in the past still complicated soldering took place, one can work with easily and quickly connectable pressing-joints today. This technological progress should be exploited for further pre-assembled modules to take into account in the planning and implementation at the site.

MODULARIZATION OF COMPLEX BUILDING STRUCTURES

As already described, the modularization of a building is essential for the optimal use of prefabricated construction. A complex floor plan can be analysed with the help of computer programs.

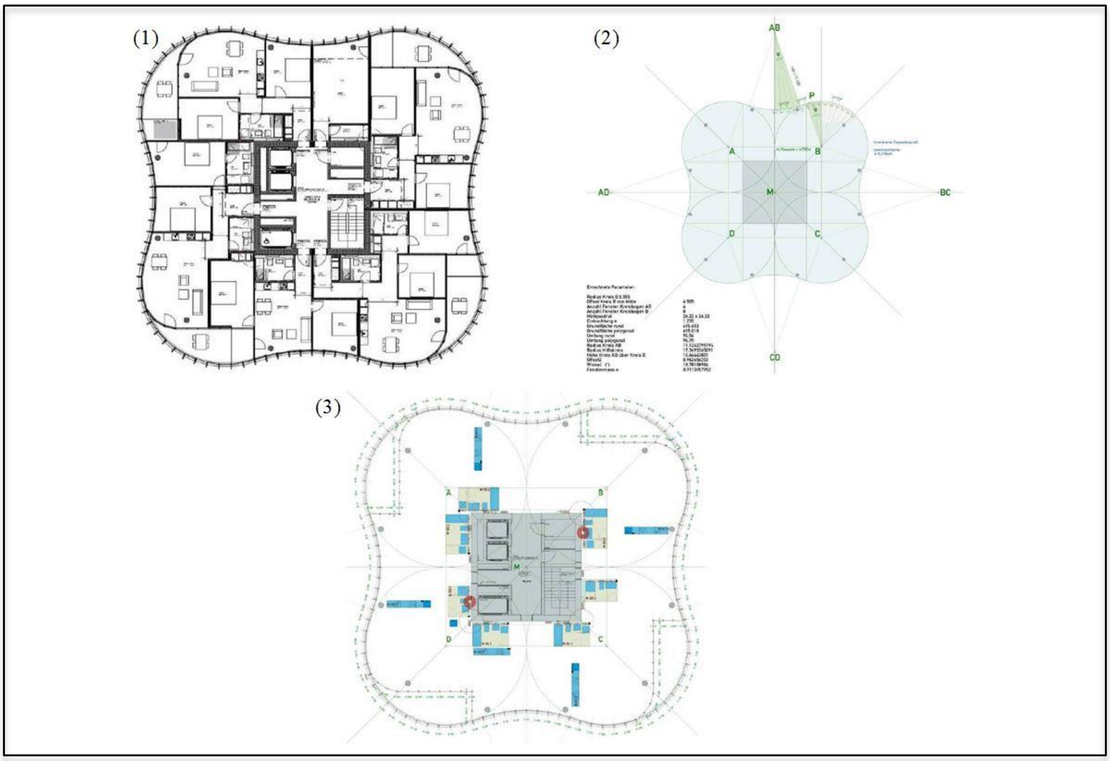

Figure 2: Example for modularization building plan with planning basis (1), project coordinate system (2) and module technology plan (3) (Figure p. 26, 28 and 32 in Hovestadt 2014, Digitales Bauen GmbH, Germany)

Using these data analysis suitable algorithms can be recognized and implemented. The floor plan can be described with a project coordinate system and in this as many equal areas will be presented and created by small changes in the design. This area plans and based on the technology module plans represent the operational area by pre-built series components. Furthermore, the complexity can be reduced in a design and on site-solutions are minimized by this modular construction. A reduced complexity is achieved, less individual solutions are necessary. These details don't have to be individually planned during execution planning and realized on site. This results in more repeats, resulting in higher quality, lower costs and greater adherence to deadlines. Another advantage is that the architectural quality is maintained.

WAYS OF PREFABRICATED CONSTRUCTION PRODUCTS IN TECHNICAL BUILDING EQUIPMENT

The use of prefabricated components is limited in the field of technical building equipment in Germany usually only on Plumbing cells are used. In addition to the time and cost savings, the execution quality can be significantly increased. Just disciplines, which are frequently applied in problems during the design should, as far as possible be industrially prefabricated. These are the disciplines ventilation, heating / plumbing and electrical. Problems occur when the planning does not coincide exactly with reality. Therefore collisions occur often when it comes to the installation of ventilation ducts, pipes and electrical wiring on site. Thus requires improvisation on site. Another critical point is fire protection measures. The most common errors occur here during execution for cable and pipe seals. These are prepared either incorrectly or lose by subsequent line guides their approval. This is precisely this potential of errors that can be avoided by the use of stationary prefabricated components. Goal is to deliver as much as possible prefabricated on the site, so only a final assembly takes place. That means, that the principle of stationary industrial production adapted to the construction industry.

Figure 3: Example for prefabricated ceiling module stationary and installation at construction site (Figure p. 24 und 25 in N. U. 2013, USA)

Reality differs greatly from that vision. However, the technical progress offers many new opportunities. The planning using Building Information Modelling (BIM) lays the foundation for this. Building models can be designed and the structural sequence is also shown. The building model, which is optimized under modularized aspects, sets the parameters for the industrial prefabrication. It will be possible to deliver entire ceiling modules, which are pre-installed with ventilation ducts, pipelines and power lines can already be delivered to the site and they only need to be installed and connected to each other there. This is an exception in Germany. So far the majority still is assembled on the building site in pieces.

The technical requirements are e.g. created by BIM and other programs used for modularization. A stationary production is no problem. One difficulty still has to be eliminated in order to realize prefabrication as mentioned above. That raises the question of the optimal connection technology of these modules. Modern pipes use innovative pressing techniques that replace soldering or welding. With the ventilation ducts the question arises how the ducts can be connected simultaneously while fire protection is guaranteed. Ventilation ducts extend in case of fire and must therefore be provided with fire-resistant joint systems. If possible, this should already been made during prefabrication. Otherwise, it must be done on site and that increases the risk of errors.

There is a big gap to close considering the connection of the electrical wiring. Usually, the cable must be connected to each other by hand individually, which means a lot of effort and thus causes unnecessary costs. Here, it is suitable to develop plug connection systems and further develop existing systems. The target here is to define a common standard that applies across all products and can be used everywhere. The automotive industry has shown us this. As an example of the international ISO 10487 (International Standardizing Organization) standard connector can be called for car radios. Regardless of which radio is installed in the car, it has to be exclusively connected to a plug having to connect properly with each other without any single cable. Comparable standards are important for the construction industry as well and can be optimally implemented especially in the prefabrication of modules. Connectors for construction equipment are already made standardized. It's obvious that it would be beneficial for the manufactures to develop and define compulsory standards for connectors. A lot of research in the field of connectivity and modularising mechanical and electrical services is already done by the Loughborough University, UK (Court, et. al., 2006). It is recommended to implement these research results in the construction practice, particularly in Germany

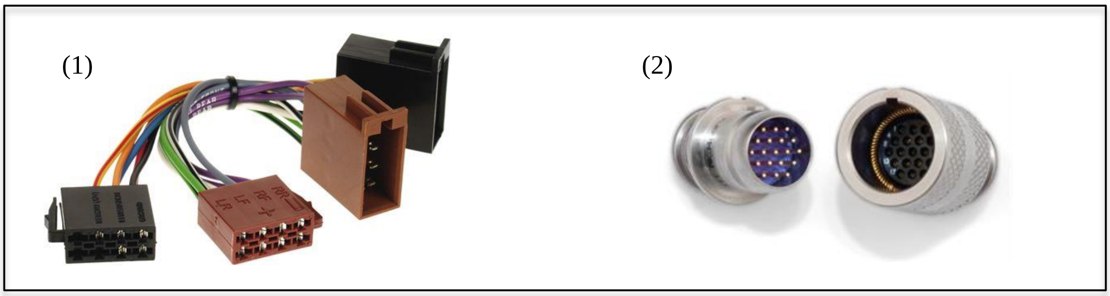

Figure 4: Standardized connection according to ISO 10487 (1), Connector construction equipment (ITT Corporation, 100 New Wood Road, Watertown, CT 06795, USA)

CONCLUSION

Modularization and prefabrication can be used alongside many other tools of Lean Construction in order to the objective of continuous improvement. For the application of LPS and LPDS the know-how of manufacturers, suppliers, and construction companies can be shared regarding by available on the market components and products in the planning. Thus, optimal use of prefabricated parts is oriented towards a possible execution. A benchmarking by the Loughborough University, UK shows the effectiveness of the use of prefabricated components (Mawdeslay and Long, 2002). A high degree of serial prefabrication has a number of advantages for a construction project (Pasquire, et al., 2004; Luo, et al., 2005):

- Reduced construction time and saving costs,
- Cost savings as many of the same components that can be produced in series,
- Improved site logistics, as Just-In-Time deliveries may be made attuned to the construction process,
- Reducing the frequency of errors in the execution, being at the construction site for the most part only at the final assembly,
- Improved safety as less work has to be done in harsh conditions at the construction site.

Prefabricated components can be used in the construction industry to a greater extent. There is still a significant need for standardization. To achieve this goal it is necessary that manufacturers develop standards together with construction companies, research institutions and clients. Those standards should be compulsory. Using these standards, the site fabrication can get closer to the already optimized production in the stationary industry. A successful adaptation can increase the productivity in the construction industry (Teichholz, 2013). Construction companies will be enabled to generate adequate return on investments comparable to other business sectors.

Additionally to the research field described in this paper it is important to execute further research. Areas with great potential have been discussed in the IGLC Arena in 2006 by the Loughborough University, UK ("Rapid manufacturing" and "Rapid Prototyping" (Pasquire, et al., 2006)). The steady technical progress in digital building and digital fabrication promotes a wider use of prefabricated components.

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