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Lean construction application: A case study in Suzhou, China

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ABSTRACT: Chinese Architecture, Engineering, Construction (AEC) industry is under the reform resulting from the large amount of waste production, huge energy consumption and severe environmental pollution. Aiming to maximize the project value while reducing the waste and cost, lean thinking is referred from manufacturing industry to construction since two industries have several similarities. This paper reviewed the change of lean thinking from production to construction, the differences between traditional and lean construction (LC), and the current situation of Chinese LC situation. Besides, a case study was assessed to examine how the LC management works in a practical project in China. Through the research, project schedule is divided into several hundred sub-items to assist the site supervisors to manage the construction progress. In addition, utilizing prefabrication parts and digital technology are two effective approaches to conduct the LC in the project.

1 INTRODUCTION

Chinese AEC industry has been a pillar industry since 1978, till now its scale expends to at least 20 times and its impact on the national economy is significant (He et al. 2013, Liao 2018). In 2018, for every 10,000 RMB output value increasing in the AEC industry, it brings 24,045 RMB benefits to other industries as both direct and indirect productivities (Wang 2019).

Nevertheless, some issues are exposed to its rapid development, which contributes to a large amount of waste production, huge energy consumption, and severe environmental pollution. Considering the whole life-cycle of the building, the AEC industry consumes 46.7% of total energy consumption in China annually. The construction wastes, dust, and noise account for 30% to 40%, 22% and 8% of the relevant pollution sources in the city (Yang 2016). Therefore, the public and government are aware that such the extensive but ineffective development way in the AEC industry is urgent to be reformed, to sustain the national economy and protect the environment. Accordingly, some scholars suggest that lean thinking could be applied to Chinese AEC industry to activate its sustainable development.

This paper focused on how LC was applied in a construction project in Suzhou from reviewing the transform of lean thinking to the construction industry and its current situation in China, and analyzing the implementation of it to the case study.

2 LITERATURE REVIEW

2.1 *From lean production to lean construction*

Lean production/manufacturing is derived from the automotive industry, which is primarily introduced from the principles of Toyota Production System (TPS) that obtain higher quality with few resources and respect for humanity (Salem et al. 2006, Wang & Ma 2014). The main elements of TPS are defined as just-in-time, autonomation, workforce flexibility, and creative thinking (Salem et al. 2006). A key point of lean production is to eliminate any waste from production by identifying correct and standardized processes, therefore it is necessary to optimize the workflow to add production value and improve the performance (Liu 2015). From vast numbers of research and comparisons, such the production mode, or TPS, is the most proper management approach for the modern manufacturing industry.

The success of lean production arises the interest of the public to extend its ideas to other industries. The concept of LC is raised by Lauri Koskela at International Group for Lean Construction in August 1993 first (Ballard & Howell 2003). Having put forward the LC concept and done the analysis on the application of LC, Koskela then discusses in 2000 that transformation, flow, and value (TFV) are three fundamental elements that need to be encompassed in the relevant theory to support the lean applications in construction industry (Jorgensen & Emmitt 2008, Yang, 2016). In addition, Ballard et al. (2001) define that maximizing value and minimizing waste is a universal goal and framed a new project planning system, which promotes the lean thinking to delivery from manufacturing to construction. Ballard & Howell (2003) investigate how to implement the LC to the project, and ways to apply Lean Project Delivery System (LPDS) to achieve higher productivity.

Through the continuous explorations on its field, LC has been successfully utilized in the AEC industry. For example, Tommelein (1988) introduces “pull-scheduling” to the construction project to increase the output of the material installation. Moreover, “Just-in-time” principle is used to several projects in terms of site management and construction material supply (Grasso 2005, Salem et al. 2006). Furthermore, Salem et al. (2006) conduct a case study which implemented more complete LC system to the project, including last planner, visualization, huddle meeting, first-run studies, five S’s (Sort, Straighten, Standardize, Shine, and Sustain) and fail-safe for quality, and they obtain the active responses from the construction personnel.

2.2 *From traditional construction to lean construction*

In general, traditional construction only concentrates on the organizational structuring and division of the work to be finished, which cause a series of disadvantages such as blocked information sharing, high rework rate, low quality of the project and uncontrolled construction schedule. Moreover, traditional construction is blamed to a huge amount of construction wastes from steel and cement used, extravagant energy usage and water pollution, and inefficient labor arrangement (Tam & Le 2019). From the research conducted by Wang & Ma (2014), the construction sites exist a lot of invalid or repeated works that increase the labor and time costs, which could be avoided with scientific management method. As a result, the client and the manager are no longer satisfied with the traditional construction method since the unnecessary waste and additional cost are harmful to the project and society.

LC differs from the traditional construction in regards to the goals, the structure of the phases, the relationship between phases, and the participants (Ballard & Howell 2003). LC management carries out dynamic management of complex construction processes by quantitative analysis. Table 1 summarizes the differences between traditional and lean construction from extensive literature review (Yang 2016, Wang & Ma 2014, Liao 2018, He et al. 2013, Su et al. 2018, Tam & Le 2019, Yang 2017, Salem et al. 2006).

Further, according to Su et al. (2018), their project benefits from the LC method, presenting as 112 days completion ahead of schedule, 18.6% saving of labor number, and 2% material waste reduction to traditional construction approach. Compared to the traditional ways, the advantages of the application of LC are tangible.

Table 1. Differences between traditional and lean construction.

	Traditional construction	Lean construction
Goal	Defined in contract	Maximizing value and minimizing waste
Management method	Static	Dynamic
Integration level	Low integration	Integrated project delivery
Project quality	Low	High
Project organization	Massy	Precise
Construction material	High waste	Low storage and waste
Group cooperation	Low	High
Information sharing	Low	High

2.3 *Lean construction in China*

LC is introduced in the world in 1993, while Chinese construction enterprises start to apply it to their projects in 2005. So far, only a few companies would like to implement LC, mainly due to lack of comprehensive ability to carry out new mode, the willing to change and insufficient theory support (Liao 2018). In addition, it is difficult to follow the experiences concluded by developed countries, as the applications of LC in China is not large-scale and under the initial period.

However, Chinese construction projects which implement LC method gain considerable benefits. Liao (2018) evaluates four construction enterprises, all of them show the positive results in several aspects, which are the strengthened sense of responsibility for the job, the increased profit, the earlier schedule completion, the reduced waste, and the increased customer satisfaction. Other scholars are investigating the supplementation of other advanced technology and methods to LC. For instance, Zhu & Tan (2015) try to define a cost control system for LC in China based using WSR analysis approach. Several researchers combine the ideas of green building and/or industrialized building with LC, to reduce the waste and cost in its original (Yang 2016, Yang 2017, Jiang et al. 2018).

Now the Chinese government is adjusting the structure of the AEC industry and its development pattern, the construction quality becomes the main target and LC is concentrated on. The government of Jiangsu Province also puts forward that LC, digital technology, green building and prefabrication construction are main directions to promote the sustainable construction in China (Jiang et al. 2018, Yang 2017). With the support of the government, the gap between China and developed countries in the field of LC will be filled soon.

3 METHODLOGY

The research objectives are achieved through the investigation of a construction project in Suzhou (China) with the applications of LC and corresponding management, prefabrication, BIM and digital inspection approach. Case study is carried out from mid-June of 2019 to mid-July 2019. During the period, the authors are allowed to visit the construction site, participate in the meetings, have access to the design drawings and BIM model, and assist to organize the relevant document files. The observations are recorded and the typical information related to LC are summarized. In addition, a brief interview to the stakeholders is conducted to inquire their experiences and learnings from the LC.

4 CASE STUDY

4.1 *Project information*

A case that BOSCH Suzhou parking house project is researched and evaluated as it applies to LC management throughout the project. The parking house is six-storey occupying 31,349.47 m^2, which is planned to complete in 400 calendar days. To carry out the LC, a temporary group is set to manage and solve the issues occurring on the construction site. The group includes different

stakeholders, which are representative from the client, the design institute, the consultant company, the site supervision company, the contractor and subcontractors.

4.2 *Lean construction approach*

Before the project starts, a master schedule has been determined from the tendering, design and construction to handover. The detailed schedule is updated weekly based on the design alteration and construction progress. With the aid of the Gantt chart, the master schedule is refined as more than 600 project sub-items. In that case, last planner system is implemented to pull the schedule, and the project managers can track the updated tasks to be completed by look-ahead schedule. Combined with the daily huddle meetings, weekly work plan and post-it notes on walls, all construction stakeholders and personnel are familiar with the project progress, so that participate in controlling the construction schedule and improving the construction quality. Figure 1 shows examples of the applications of LC management in the project.

Figure 1. Examples of lean construction management application.

The prefabrication rate in this project is approximately 50%, which is beneficial to maximize the project value and minimize the waste. Compared to cast in situ, prefabrication is superior to time consumption, quality control, waste reduction, and on-site material storage. According to the feedback from the site manager and supervisor, the standardized prefabricated parts used in the project diminish the rework, enlarge the available interior space, and save the construction time. The rest cast in situ parts follow five S's principle of LC. Moreover, the application of the modular construction method promotes the efficiency of the construction process, to achieve the optimized resource distribution. Such an approach requires that the staff focus particularly on the tasks assigned, accordingly to cut down the personnel waste and add the project value.

In addition, Building Information Modelling (BIM) is implemented to the construction management in this project. Through 3D visualization, construction process simulation and clash detection, see Figure 2, it is effective to find out unreasonable issues during design and construction period so that to guide the construction activities. Meanwhile, the construction simulation is referred to, assisting to master the detailed schedule and adjust the next assignments.

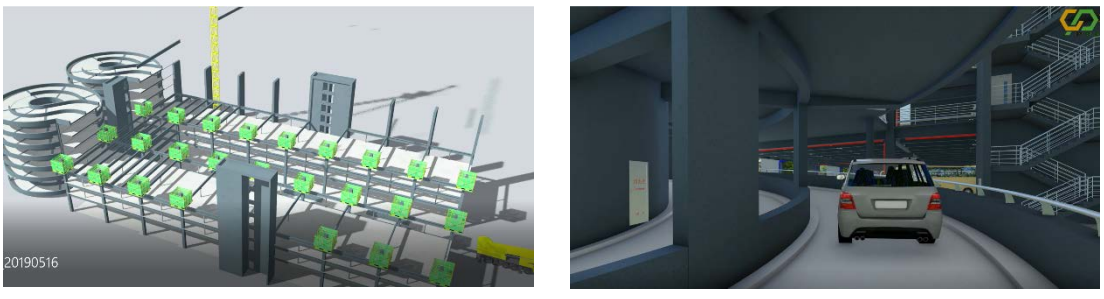

Figure 2. BIM applications in lean construction management.

Regarding the inspection and acceptance of the construction tasks, a new checking procedure is applied, see Figure 3. Once site supervisors detect the undesirable on-site issues, they record it

in Aconex Field platform to inform the contractors and track the subsequent solution. The contractors can follow the details given such as the issue type, the location, the issue description, and due date. They will respond to the supervisors through the mobile phone anytime when they rectify the issues on site, instead of submitting a paper report, which avoids the checking omission, shortens the response time and raises the management level.

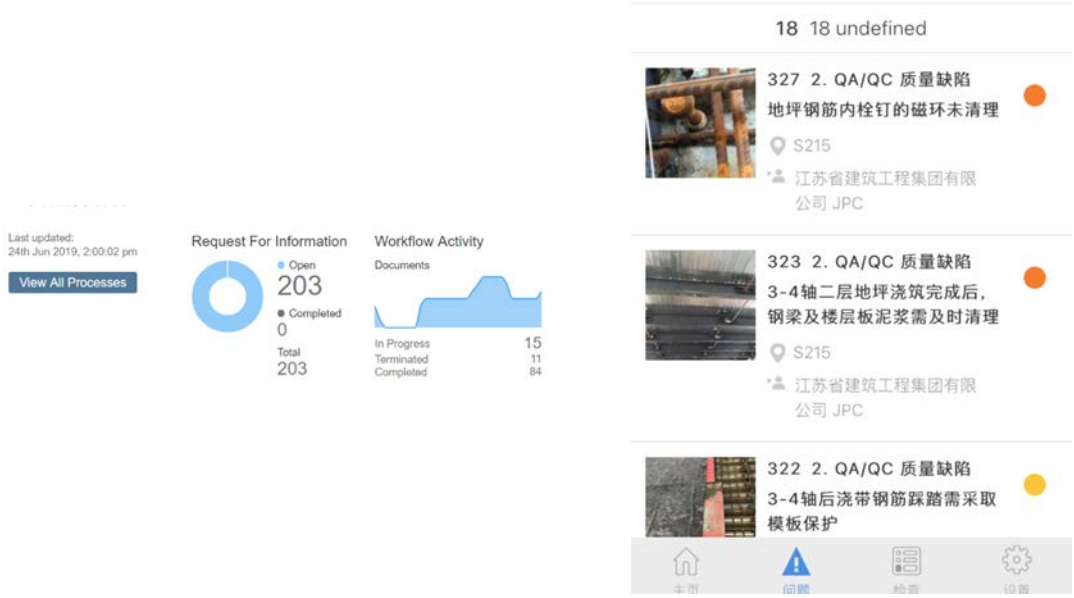

Figure 3. Inspection and acceptance by Aconex Field.

5 FINDINGS

It is observed that with the application of LC management, the schedule is followed fundamentally, when the quality of the project and safety of the staff are provided as well. Prefabricated elements used in the project reduce the on-site waste and risks while accelerates the construction progress. Further, implementations of digital technology/tool that BIM and Aconex Field are advanced for a construction project since the construction staff are accustomed to use paper-based drawing and report in the traditional projects. The 3D visualization, the construction process simulation, the clash detection, the in-time inspection and acceptance by digital technology/tool allow the project to be in control of the management group well.

Based on the responses from the management group, not all the construction sites use the same management method as that applied to the BOSCH parking house. In China, LC management is still at the preliminary stage, therefore it is difficult to follow the specific management approach to conduct the LC. However, this construction project combines LC and corresponding management approach, prefabrication, BIM, and digital inspection tool in it, giving a good example to Chinese AEC industry for LC development. Due to the concept of 'lean' comes from the manufacturing industry, the current LC management refers to its main elements and principles to guide the on-site construction activities. Such a management approach is improved according to the benefits and lessons obtained from the previous implementations, to form a standard method gradually.

To accelerate the project value while reducing the waste and cost, it is a suitable way to combine LC with the prefabricated construction method and digital technology such as BIM. Both the case study and previous experiences from managers have indicated that they have positive effects on the project progress and performance, and wastes in terms of the personnel, the material, and the equipment. China is now developing the building industrialization and informalization, hence, the LC with implementation of prefabricated construction method and digital technology will be a tendency in the Chinese AEC industry.

6 CONCLUSIONS

Aiming to maximize the project value while reducing the waste and cost, lean thinking is referred from the manufacturing industry to construction since two industries have several similarities. LC brings advantages to the project value by reduced wastes, controlled construction progress, proper labor number, and just-in-time material preparation. Through the investigation of a construction project using LC method, several findings are summarized. All the construction staff is involved and responsible to improve the project performance, when supervisors are capable to manage the construction progress efficiently. Utilizing prefabrication elements and digital technology are effective to conduct LC in the project.

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