A Critical Review of Lean Construction for Cost Reduction in Complex Projects

Leong Sing Wong [1)*] and Mohammed Elhaj Alsoufi Mohammed Ahmed [2)]

[1)] Doctor, Universiti Tenaga Nasional, Malaysia.
* Corresponding Author. E-Mail: wongls@uniten.edu.my
[2)] PhD Candidate, Universiti Tenaga Nasional, Malaysia. E-Mail: mohammedelsofi@yahoo.com

ABSTRACT

Many countries started to apply lean construction and get benefits of lean construction techniques that can reduce project cost in construction industry, particularly for complex projects. In addition, last planner lean construction techniques started to be widely used instead of current traditional planning techniques for the purpose of decreasing the variation in the processes. Importantly, reducing variation in the project processes can help improve performance and make significant cost savings. Moreover, processes should optimize predictability and facilitate team work and effective communication among participants. In the current scenario, lean construction techniques are not reviewed for complex projects. This paper aims to perform a critical review of lean construction for complex projects.

KEYWORDS: Lean construction, Project cost, Traditional planning techniques, Cost savings, Team work.

INTRODUCTION

Conventional construction project management is constantly facing problems in terms of cost, time, quality and safety. These problems are fueled by the segregation between design and construction works (Ballard, 2000). For this reason, construction industry needs a radical change rather than a step-by- step change to overcome the problems and challenges it is facing. Project management is often defined as the process of ensuring that projects are completed within a predetermined budget and duration and with the specified quality. Project managers control duration and take necessary action when progress deviates from the overall project plan (schedule) (Kerzner, 2006). Whilst this approach seems logical, it is often a cause of waste and inefficient performance as a result of applying the traditional approach. Projects are becoming more complex and the need to finish projects more quickly makes the task of controlling progress very hard. As building construction becomes more complex (level of services, information technology, building technology), the construction process becomes more demanding and the number of suppliers becomes more extensive. The need for fast track projects means that more building components are produced off-site and on-site, followed by construction activities (site-based assembling activities). As the number of overlapping activities becomes significant, the effect of delay (or slower than anticipated production rate) in one activity is likely to result in others being slowed down or suspended (waste). This is a problem that is well understood and addressed in the manufacturing industry, where physical or time buffers are placed between activities with variable production rates. Alternatively, “planning buffers” could be introduced where short-term plans allocate work only to activities of the necessary

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resources, which are already available (Ballard, 2000). In addition, planning buffers cannot cope with the complexity of projects (it is difficult to match actual progress with the initial plan) in traditional planning systems. It creates adversarial relationships between design (engineering), procurement (material supplies, prefabrication of components or off-site assembly) and assembly on site, in addition to that emphasis on control affects human factors and the morale of workers (Ballard and Howel, 1997).

Lean thinking is a matter of developing requirements to meet global challenges by minimizing waste, fastening the iteration operation and innovating through various production processes to ensure continuous improvement. There are many advantages for adopting lean construction. Firstly, reducing variation in the project processes will improve performance and make significant cost savings. Moreover, processes should optimize predictability and facilitate team work and effective communication among the stakeholders (Li et al., 2017). Mahrani et al. (2012) stated that lean thinking has attained great success in reducing waste in manufacturing industry with a rate of 12%, while the rate of waste in construction industry is 57% due to the various differences between the two industries. Ballard and Howell (1997) stated that manufacturing industry has controlled production environment and customization achieved by modularization and assembly, while the environment in construction industry is uncontrolled, in addition to that every project is unique and is uniquely customized to suit one specific need. Abd Jamil et al. (2016) opined that there is a need for a high level of integration between design and manufacturing, while design and production are treated as separate processes in construction industry. Abd Shakur et al. (2016) provided a supporting statement that manufacturing industry is distinguished by the capacity to realize continuous improvement. By comparison, construction industry has low capacity of innovation and continuous improvement. Therefore, in general, construction industry is less impacted by 'lean' production thinking than what may be found in the manufacturing sector according to fixed position production (on-site production). The characteristics of construction industry above will end up the project that is unable to meet the customer objectives in terms of time, cost and quality.

According to lean construction, value can be maximized by focusing on the value added activity which can be information, people or shape of materials. Understanding and improving processes are essential to improve productivity and lean construction provides modern process improvement. In addition, it is done right the first time and as the customer has high requirement on it. Moreover, eliminating waste makes product flow by establishing a rate of flow, thereby synchronizing all the activities as well as focusing on the potential constrains. Pull of a customer can be achieved by stopping making anything upstream until needed downstream and when it is needed, it should be done quickly and with correct quality. Then, pursuing perfection is done by increasing the flow rate, creating transparency and striving for zero defect. Thus, to make construction lean, firstly site assembly waste must be minimized followed by making lean techniques for dynamic construction. On the other hand, non-added value can be divided into two main categories. Firstly, non-value added activity necessary waste as no value is created, thus cannot be eliminated based on the current technology, policy or thinking and this violates proper project coordination, regulation, company mandate as well as law (Ballard, 2000). Non-activity pure waste consumes resources, but creates no value in the eyes of the customer and examples can be given in terms of waiting time, inventory, rework as well as excess check-offs (Marhani et al., 2012) (Fig. 1). On the other hand, Wahi et al. (2016) maintained that flow of processes usually supports conversion processes and examples include transport, storage as well as movement with a few exceptions, as such processes do not add value. Both conversions and 'flows' expend costs and take time. The objective of this paper is to review the implementation of lean construction techniques in construction industry at various places. The specific focus of the review is on reducing unnecessary cost (waste) throughout the whole life of the project in order to reduce production time, enhance quality, improve wages, enhance safety environment for workers and increase customer satisfaction.

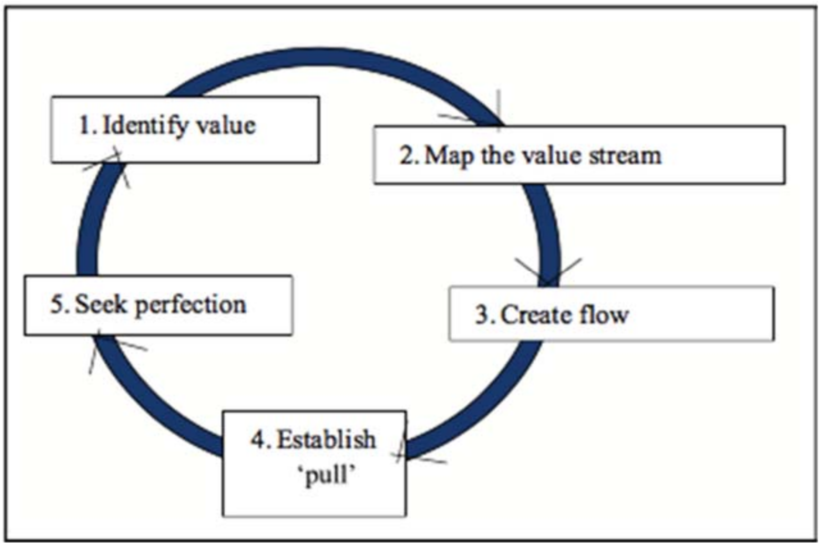

Figure (1): Value maximization according to lean construction (Marhani et al., 2012)

Current Planning Method (Conventional Method) for Construction Projects

The project management profession is becoming increasingly necessary as construction industry moves to more integrated and concurrent procurement systems for various reasons (Cleland and Ireland, 2007). The main focus was on setting cost, time and quality targets and then meeting these targets. Construction is unique and hence management concepts and tools have to come from within. Project manager has to do mainly with maximizing efficiency and predictability given the scenario. Roberts and Wallace (2004) illustrated that boundaries and "rules of the game" were assumed to be fixed, which implies the use of standard forms of contracts. Project managers along with others would turn their attention to bringing progress back in line with the pre-set schedule (PMBOK Guide, 2011). This is often done by adding more resources by various ways, such as increasing number of workers, materials and hours of work at the expense of meeting cost targets.

Ballard and Howell (1997) clarified that non-critical paths have relatively small delays that do not influence the project overall duration. As discussed before, the project manager's role is to control duration by taking necessary action when progress deviates from the overall project plan (schedule). Cleland and Ireland (2007) discussed that whilst this approach seems logical, it often causes waste and inefficient performance. In addition, projects are becoming more complex and the need to finish projects more quickly makes the task of controlling progress very hard and firefighting often results in higher cost or short cuts (Ballard, 2000).

Effective Construction Production Planning Method (Buffers)

Ballard (2000) elucidated that in manufacturing, the term buffer often refers to physical stock of raw materials and work in process, which implies incomplete product waiting to be developed further by the remaining sub-processes or inventories (finished goods). In the case of construction projects, a buffer can also be represented by the time allocated between the start of two inter-related activities. Koskela and Huovila (1997) stated that within the context of lean construction, buffer is a waste. Therefore, the more the time allocated, the more the process inflow and it is often referred to in construction as work in progress generated (Ballard, 1997). Although the actual production time may become efficient by the use of buffers, the total project duration may be unaffected and so is cost. The actual productive activities may be leaned, but the waste is still present in the form of buffers (Ballard, 1998). Martens and Vanhoucke (2017) provided that buffers are not lean and have considerable costs associated with them. In this regard, their use may be a temporary step in gaining data on how long particular tasks actually require when upstream variability and uncertainty are not allowed to affect value adding production (Martens and Vanhoucke, 2017). Of course, inflow variation and uncertainty will always remain in all project management activities regardless of the planning or PM techniques used (Ballard, 2000). Fig. 2 is concerned with the progress of an activity that uses the output of another (For example, the delivery of materials or prefab units to the site). In traditional planning, no buffer is allocated, so construction starts immediately after delivery and hence delays in subsequent delivery would result in the work force (and all related plants and machines) having to wait. The rate of progress is depicted in the line starting at “0” and ending at “end date”. In the case of allocating a buffer (time between (0) and “delayed start”), the work force in charge of this activity would complete the activity much faster (risk of waiting is limited). Subsequently, the new activity duration (time between “delayed start” and “end date”) would now represent the true duration of this activity (no disruptions because previous activities are hidden). Once the true productivity level for an activity is determined, the planner can reduce the size of the buffer and hence the overall duration and cost of the project.

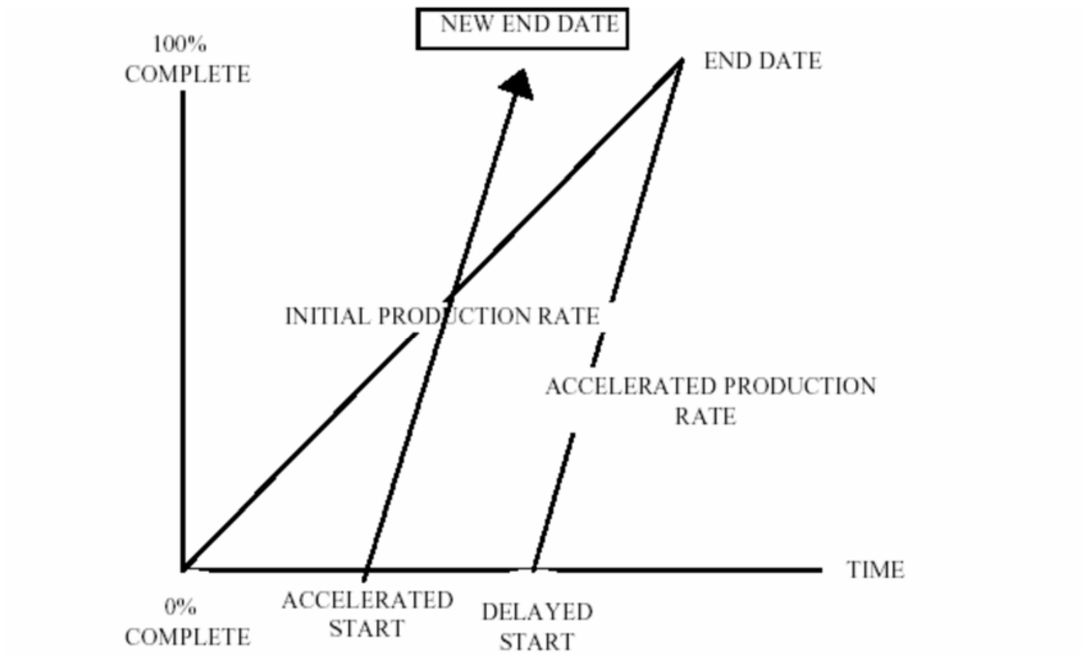

Figure (2): Graphical representation to reduce flow variation, then start sooner (Ballard and Howell, 1997)

Table 1. Differences between traditional planning method and last planner system based on several published works

Key characteristics	Traditional planning method	Lean last planner system
Method of production (Ballard, 2000)	Push	Pull
Planning tool (Lean Construction Institute, 2001)	CPM	LK
Work planning (Winch, 2007)	Making planning for the whole work.	The concept puts emphasis on the work that actually has to be done to recognize the desirable outcomes.
Activities identification (Winch, 2003)	When it will be done and how long it will take.	It is focused on how an activity can be done and whether it can be completed within time by the judgment of an expert who may be the contractor or the foreman.

Last Planner System for Lean Construction

The last planner is a planning system developed by Lean Construction Institute to address some of the problems of the traditional planning system (Ballard, 2000). This also draws on the same idea of shielding production from upstream variation and uncertainty and introduces upstream variation and uncertainty as well as promoting practices that are closely related to the lean construction principles originally conceived by Toyota (Ballard, 2000). Shange and Sui Pheng (2014) stated that it is notable that the principle of the last planner system is to pull production down from the master program as opposed to the use of the master program to push production forward. In addition, the system encourages the application of pull instead of push. In other words, downstream activities determine the size of workable backlog. The resources, such as materials to be delivered or progress required from upstream activities, are determined by the progress of downstream activities, which means that activities are dependent on these resources (Nesteby et al., 2016). This pull type of system ensures that only the necessary resources and work are being delivered, hence reducing the need for physical buffers (storage space or time) (Ballard, 2000). Managers applying this concept must ensure that the system allows for true inflow variation of each activity or process, otherwise the risk of disruption and stoppage becomes high. Ballard (2000) stated that the system emphasizes the need for a mean of assessing the performance of the various levels of the plans. The system should determine where to intervene. Brioso et al. (2017) illustrated that the match between output and directive at each level should be measured and causes for mismatch must be understood. For instance, the match between 'will' and 'did' is measured by percent plan completed (PPC). In case of a mismatch, the last planner must investigate the sources of the problem and, in particular, these mismatches could not have been caused by the unavailability of resources or work in progress. Similarly, project level plans can be based on true activity durations. Future mismatches between progress and these plans must be thoroughly assessed. The system therefore emphasizes measurement of performance and continuous improvement.

Brioso et al. (2017) described that last planner can be identified as a person with the expert or specific knowledge of how to actually produce the output that is required by the specific project task and the person can be a sub-contractor, a manager or a foreman. Shange and Sui Pheng (2014) stated that the system requires the last planner to decompose larger tasks into specific work assignments that can be given to individual construction operatives or teams to be completed in a relatively small time window such as 1-2 weeks. The assignment concept puts emphasis on the work that actually has to be done instead of creating a further plan that simply recognizes the outcome that is desired (Ballard, 2000). Nesteby et al. (2016) provided that as work progress and experience increase, the last planner is able to generate a better assignment through a process of reflection, learning and corrective actions. Table 1 describes differences between the tradition planning method and the last planner system.

Evaluation of Lean Construction Techniques

Lean construction principle can only be applied fully and effectively in construction by methods focusing on improving the whole process. This means that all parties must be committed, involved and work to overcome obstacles that may arise from traditional contractual arrangements. In addition, data collection must be carried out before evaluating lean techniques. Li et al. (2017) used both interview and questionnaire in various case studies for their evaluation. Accordingly, evaluation of lean construction has been conducted utilizing both methods.

Value Management (VM) for Eliminating Unnecessary Cost through the Whole Life Cycle Cost of the Project

Rashwan et al. (2016) illustrated that value management in construction is a proactive, creative and problem-solving service. It involves using a structured, multi-disciplinary, team-oriented approach to make explicitly the client’s value system using functional analysis to expose the relationship between time, cost and quality. Kelly et al. (2004) claimed that strategic and tactical decisions taken by the client and the design team are audited against the client’s value system at targeted stages throughout the development of a project and/or the life of a facility. This is comprised of manufactured components, where components form elements, elements form spaces, spaces reflect corporate organization and client strategy as shown in Fig. 3. Kelly et al. (2004) described that value engineering (technical level) is an organized approach to provide the necessary functions at the lowest cost without compromising quality and it is concerned with both client and contractor and applicable at technical level to improve design solutions. Kelly et al. (2004) stated that both value management and value engineering are conducted through a workshop at an early stage of the project. Major stakeholders must attend the workshop to recognize the client objectives, participate in making the client value system and keep monitoring the implementation of the client value system through the whole life cycle of the project. However, VM is more likely to be found as rigid application of set tools and techniques to engineer out excess cost without due consideration of value or process (Rashwan et al., 2016). It is frequently viewed as extra to the construction process rather than an integral part of it and it is often called value engineering or sometimes value analysis (Marhani et al., 2013). Rashwan et al. (2016) stated that VE can be carried out by providing sustainable design in construction industry through improving thermal insulation by 55% as well as reducing the cost for each activity (item) at the construction stage by 40%. Fig. 4 shows the relation between cost and time according to VE. It mainly shows the cost savings through the application of VE even before the design phase without compromising quality through the design phase.

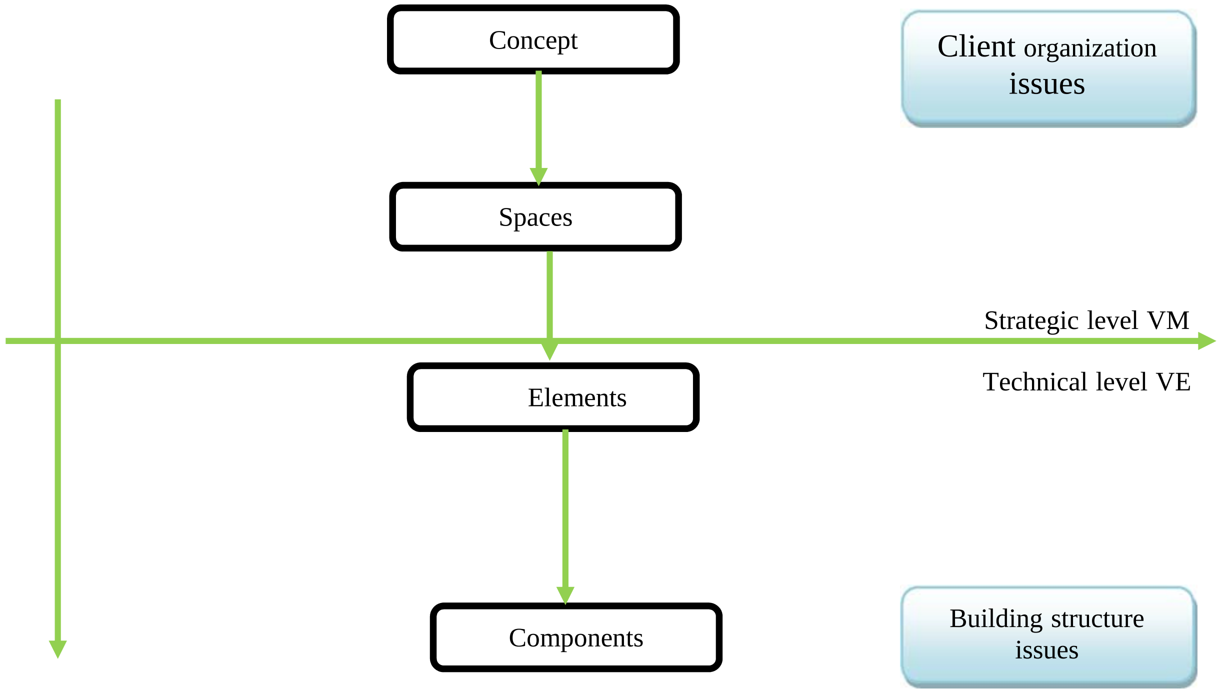

Figure (3): Differences between VM and VE (Kelly et al., 2004)

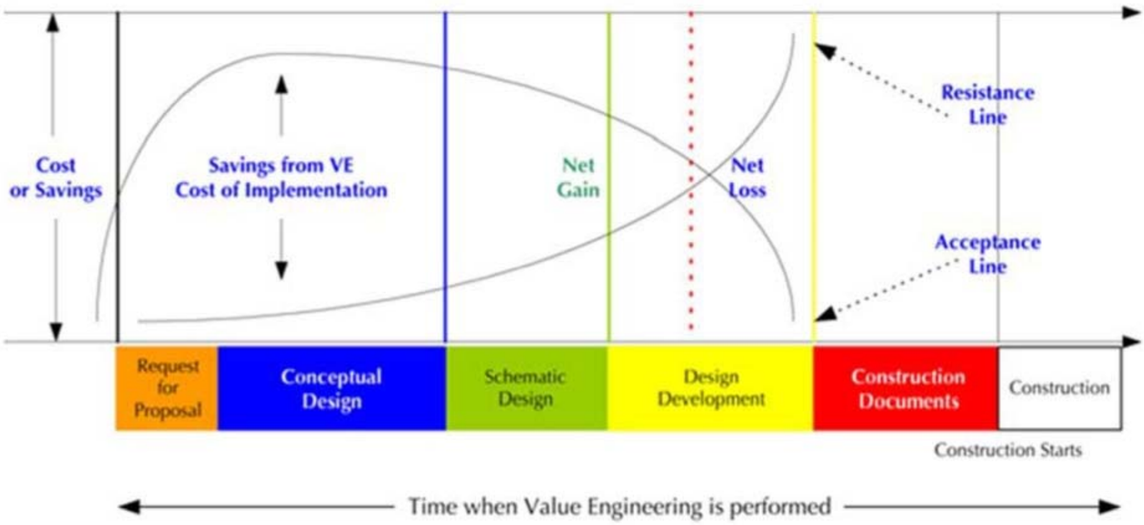

Figure (4): Eliminating unnecessary cost according to applying VE through the design phase (Rashwan et al., 2016)

Off-site Construction Process (Concurrent Engineering)

Applying lean construction can be done at different stages according to the project phases in construction industry (Marhani et al., 2013). However, there is considerable scope for the application of lean thinking to remove waste from the design process. Ballard and Howell (1997) found that system building techniques involve reliance upon standardization of components and prefabrication of building sub-assemblies. System building techniques are now generally viewed as failure, since many of the buildings they delivered were deemed socially unacceptable. Koskela and Huovila (2000) provided that standardization and prefabrication, together with dimensional coordination, remain key features of almost all modern construction works. The production engineering function which can be seen in conventional manufacturing industries assumes a far greater role than we are used to see in construction (Marhani et al., 2013). Moreover, this implies that the design process and even the design philosophy of building is radically transformed so that there is greater emphasis on design for production than on what may be considered as more conventional design attributes such as aesthetic form (Matti Tauriainen et al., 2016). Li et al. (2014) explained that almost all construction projects involve a high degree of mechanization and include an 'assembly' process that combines numerous small or large factory-produced components or sub-assemblies and integrates them to yield a 'customized' or unique product. Currently, construction industry is at the earlier stage of building information model (BIM).

Building Information Model (BIM)

Abanda (2017) identified Building Information Modeling (BIM) as a process of generating and managing building data during the project life cycle. Typically, it uses three-dimensional, real-time and dynamic building modeling software to increase productivity in building design and construction. Li et al. (2014), Cao et al. (2017) and Abanda (2017) explained that BIM is the most current advanced method widely used in off-site construction. Fadeyi (2017) discovered that it helps the design and construction team to collaborate on a coordinated model, thereby providing team members with better insight into how their work fits into the whole project, which ultimately helps them ensure efficiency. Mutual exchange of data between all stakeholders throughout the whole life cycle of the project is a crucial element for successful implementation of BIM. However, Tauriainen et al. (2016) clarified that BIM requires more training (for professionals and skillful people) to accept BIM technology instead of the current design methods such as CAD. Table 3 shows the advantages of adopting prefabricated buildings and building information model in construction industry based on several published works.

Supply Chain Management for Saving Project Cost in the Design and Production Processes

Chen (2016), Marhani et al. (2013) and Abd Shakur et al. (2016) illustrated that SCM is the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at least cost to the supply chain as a whole. Marhani et al. (2013) justified that supply chain management depends on the following strategies. Firstly, a high level of joint strategy development with different organizations and firms, both upstream and downstream. In addition, there is a common purpose agreement between separate firms and organizations in the supply chain. There are also jointly agreed common goals amongst the members of the supply chain as well as mutual dependence for all firms in the supply chain on the success of achieving those agreed common goals. Strategic partnerships and strategic alliances that involve separate firms (who would normally be in competition with one another) which allow resources, cost, knowledge and risks to be shared may be the keys to moving forward in these important areas. This fundamentally and radically changes the nature of competition (competitive market). Table 2 shows the successful integration in accordance with supply chain management.

Lean Construction Technology (Just In Time) (JIT)

Just In Time (JIT) is in widespread use in the industry's supply chains in case of manufacturing of construction components and is a vital element. In order to deliver lean manufacturing, the suppliers' network must be improved (Nowotarski et al., 2017). Zhang and Chen (2016) stated that the main reason for adopting JIT technology in construction is to fasten the flow of activities and make it move smoothly throughout the construction process. Accordingly, it eliminates waiting as well as the transportation waste between activities, because it focuses on finishing each activity in the project with its required resources in terms of personnel, materials as well as equipment (Li et al., 2017). Richard et al. (2016) mentioned that it utilizes the actual required resources (pull production) according to lean last planner system rather than forecasting resources as in traditional methods. Therefore, overproduction waste can also be eliminated. Total Quality Management (TQM) must be adopted upstream and downstream to ensure that the activities achieved are of high quality and that unnecessary processes (defects) are eliminated. Nowotarski et al. (2017) stated that huge efforts must be implemented to encourage construction industry to adopt the same lean JIT systems, often company-wide, rather than being solely concerned with that part of the suppliers' operations that impacts the manufacturer.

Table 2. Advantages of applying prefabricated off-site assembly in construction industry using BIM based on several published works

Research work	Level of implementation	Advantage	Evaluation of implementation in construction industry
1. Abanda (2017) 2. Koskela (1997) 3. Marhani et al. (2013) 4. Marhani et al. (2012) 5. Ballard (2000) 6. Wahi et al. (2016) 7. Cao et al. (2015) 8. Tauriainen et al. (2016)	Project level	1. Controlled production environment achieved by modularized assembly. 2. Capability to realize continuous improvement. 3. High capability for automation. 4. Decreased site disruption. 5. Reduced thermal loss. 6. Higher sustainability. 7. Minimization of wastages. 8. High recycling chance.	1. Highly used in almost all modern construction works.

Table 3. Successful integration according to SCM, modified by Abd Shakur et al. (2016), based on several published works

Successful integration	References
Long-term partnering and strategic alliance	Abd Shakur et al. (2016); Koskela (1997); Morris (1994)
Leadership and responsibility	Morris (1994); Smith (2002); PMBOK Guide (2011); Koskela (1997)
Incentives and rewards	Morris (1994); Koskela (1997); Abd Shakur et al. (2016)
Flow of information, communication and interaction	Kerzner (2006); PMBOK Guide (2011); Morris (1994)
Common purposes and goals	Koskela (1997); Schoenwitz et al. (2017); Kylili et al. (2016); Morris (1994)

Total Quality Management (TQM) for Improving Construction Productivity

Li et al. (2017), Marhani et al. (2013), Dale et al. (2007) and Terziovski (2007) opined that quality thinking is now almost universally accepted in mainstream construction activities and that the majority of enterprises are using TQM. Dale et al. (2007) illustrated that quality control (QC) is a collective term applied to a range of activities and techniques within the process, which are intended to create known or specific quality characteristics. QA and QC systems are subjected to internal and external audits. In addition, some kind of audit process is essential if any QA or QC system is to operate effectively and ensure continuous improvement as shown in Fig. 5 (PMBOK Guide, 2011). Li et al. (2017) highlighted that TQM eliminates unnecessary processes in construction industry and increases productivity.

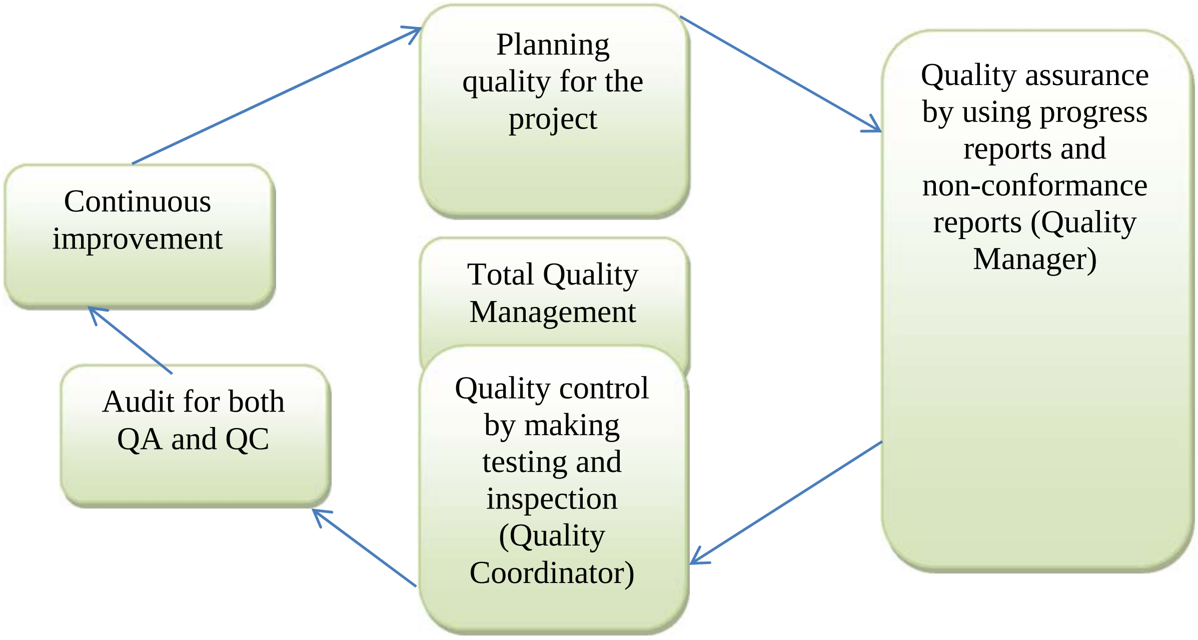

Figure (5): Total quality management components in construction (PMBOK Guide, 2011)

Lean Six-Sigma

Six-sigma can be described as a business improvement approach that seeks to find and eliminate causes of defects and errors in manufacturing and service processes by focussing on outputs that are critical to customers and on a clear financial return for the organization (Abd Jamil et al., 2016; Cortes et al., 2016; Li et al., 2017). Cortes et al. (2016) stated that the concept necessitates the use of basic and advanced quality improvement and control tools by teams whose members are trained to provide fact-based decision-making information according to process analysis. Cortes et al. (2016) clarified that it improves productivity, quality as well as profitability. Cortes et al. (2016) proved that using six-sigma can induce a high chance to reach zero-defect as the ultimate goal. Table 4 shows the advantages of applying total quality management and lean six-sigma in construction projects.

Continuous Improvement Key Performance Indicator (KPI) for Strategic Lean Construction

Kerzner (2006) stated that Key Performance Indicator (KPI) provided UK construction projects with a powerful tool that can be used to assess the performance of a company or a project in relation to the performance of peers. However, the produced data may not necessarily achieve continuous improvement. Obradovic et al. (2016) specified that a key aspect in the use of leading indicator performance data in securing project or industry best practice and continuous improvement is feedback. Feedback mechanisms are multiple and may be complex. Feedback is the essential component that provides information and data on how a company or a project that is presently performing at X level can actually become a company or a project that is performing at or above national or international performance levels (Kylili et al., 2016). Kylili et al. (2016) added that KPI includes client satisfaction in terms of service and product, predictability in terms of cost and time, profitability, productivity, safety, construction time as well as construction cost. Table 5 shows the degree of adopting lean construction techniques in construction industry based on several published research works.

Table 4. Advantages of applying total quality management and lean six-sigma in construction projects based on several published works

Research work	Level of implementation	Advantages	Evaluation of implementation in construction industry
1. Nowotarski et al. (2017); Li et al. (2017); Richard et al. (2016)	Organizational level	1. Controlled production environment.	Almost universally accepted in mainstream construction activities.
2. Marhani et al. (2013); Richard et al. (2016)	Organizational level	2. 'PULL'- orientated production based on actual demand instead of forecast demand.	
3. Marhani et al. (2012); Kerzner (2006)	Organizational level	3. Removal of waste from production process.	
4. Koskela (2000); Kerzner (2006); Dale et al. (2007)	Organizational level	4. Reduction or elimination of inventories or stock buffers.	

Table 5. The degree of adopting lean construction techniques in construction industry based on several published works

Reference \ Technique	TQM	JIT	LPS	BIM	KPI	VM	CE	6S	SCM
Li et al. (2017)	Very high	Medium	High	Very Low	-	Very high	High	Very high	-
Nowotarski et al. (2016)	-	Very high	Not used	Very Low	-	Medium	Low	High	-
Abd Shakur et al. (2016)	-	-	-	-	-	-	-	-	Very high
Zhang and Cheng (2016)	High	Very high	High	High	-	High	High	-	-

Barriers in Adopting Lean Construction Techniques in Several Countries

The barriers in adopting lean construction techniques in several countries were discussed in several published research works. Notably, Li et al. (2017) highlighted the lack of appropriate organizational structure as well as leadership style as the main factors in failing to adopt lean construction techniques in China. Basically, project managers used to follow their superior managers in managing their projects by using the conventinal methods in spite of their awareness of the importance of applying lean construction for providing profits to their projects. On the other hand, Alinaitwe (2009) specified contracts issues and organizational culture as the preventive factors in adopting lean construction in the United Kingdom. Thus, inappropriate organizational structures prevent the labors to work in a systematic manner in accordance to the decision making within the organization and most often labor problems are directly reported to the project managers. Fernandez-Solis et al. (2006) reasoned that lack of staff training is a dominant factor in failing to adopt lean construction in the United States. Therefore, firms are required to change their management system and provide training to their staffs to implement lean construction for a return in profit.

CONCLUSIONS

On the basis of the literature overview, it is evident that there are some initiatives to change project organization and procurement systems, as well as to remove the traditional culture of fragmented design and construction processes. However, construction industry is less impacted by lean production thinking than what could be found in the manufacturing sector with regard to the overwhelming amount of waste in construction processes. Furthermore, there are several barriers which can prevent the implementation of lean construction, such as inappropriate organizational culture, ineffective organizational structure, lack of commitment to create and innovate at work place, lack of understanding on the modern model of network competition (win to win thinking or partnering) rather than competitive tendering and lack of strategic leadership. Furthermore, it must be emphasized that stakeholders in a single project must adopt a common goal to ensure long relationship and mutual trust among them in the project. Moreover, governments should provide regulations for lean construction and encourage all contracting companies in their countries to adopt lean construction by facilitating regular and free training for their staffs as well as continuously monitoring the implementation of lean construction techniques at the construction stage.

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