Lean Techniques in Construction Industry: State of the Art

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Abstract - Several construction industries around the world have started to implement lean techniques to eliminate waste and to increase their project performance. Lean principles applied in construction industry can result in waste elimination, continuous flow and improved reliability. An extensive literature review was carried out to understand the principles, philosophy and barriers in implementing lean techniques in construction industry. Lean construction is a new technique introduced in the construction industry with the aim of delivering the project with maximum value and minimum wastage. This paper discusses the development of lean concept and its application in the construction industry under the following headings: Overview of lean management, lean principles, waste elimination, lean construction techniques, key concepts of lean construction and barriers in implementing lean techniques. This paper also discusses the challenges faced in implementing lean techniques in construction industry. Finally, the areas that need further research are highlighted and the need for incorporating lean techniques is emphasized.

Keywords — Construction Projects, Implementation, Lean Construction, Lean Techniques, Productivity, Waste Minimization

I. INTRODUCTION

There is a constant need in the construction industry to improve quality, productivity, efficiency and value for customers. Most of the professionals agree that the industry is prone to cost overrun, time overrun and material wastages [5]. The major issues in the construction industry are poor quality, lack of co-ordination, low productivity and high cost due to material wastage. Continuous innovation and improvement are necessary to sustain in the current competitive market place. Lean construction is a latest management technique introduced in the construction industry with the aim of delivering the project with maximum value and minimum wastage. Lean construction can be seen as a new paradigm for project management [2]. Over the last decade, lean concept has made a significant impact in the construction industry. Lean was first introduced in the manufacturing industry and then later implemented in construction industry. Lean manufacturing principles were introduced in the construction industry to enhance the productivity. Lean based tools have emerged and have been successfully implemented in construction projects with the focus on increasing value for customers and making profits [53]. Lean construction tools measures effectiveness by cycle time, defection rate and completion of planned work per week. According to Lean Construction Institute, the companies using the Last Planner System have been able to deliver the project on time and at budget under stress-free production planning and control process [2]. Many construction companies around the world have applied lean construction to improve the project performance and to eliminate the waste. Lean creates more value for customers with fewer resources. Lean construction has produced significant improvements on complex and unique projects.

II. OVERVIEW OF LEAN MANAGEMENT

After the mass production system invented by Henry Ford, the next major evolution was Toyota production system (TPS) devised by Taiichi Ohno. Lean production was first developed in 1950s to reduce waste in production process. The term lean was coined by the research team during the International Motor Vehicle Program to contrast it with craft and mass forms of production [74]. The main aim of Lean Production (LP) in Japanese is Muda which means to avoid waste of time, money and equipment [69]. Zimmer and Salem [80] explained lean construction as a continuous process of eliminating waste by focusing the entire value stream, pursuing perfection and meeting all customer requirements [18],[20],[55],[78]. Lean techniques were first introduced in the manufacturing industry and later applied in the construction industry.

Monden and Ohno introduced the Toyota Production System (TPS) with goals such as reduction in cost, quality assurance, and respect for humanity to ensure sustainable growth [46],[51]. Monden identified four main elements of the TPS: just-in-time (JIT), autonomation, workforce flexibility, and creative thinking [54].

According to Koskela, 'Lean' is a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value [2],[37]. During the mid-1990s, the primary importance was on reducing internal waste from production processes. However, value stream concept has evolved over time with the organizations adopting it. The

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critical point in lean thinking was the move away from merely removing waste and cost reduction to an approach that contingently seeks to enhance value for customers and links this to customer needs [28]. Lean construction is the adoption of lean manufacturing principles in construction industry to improve the construction process by reducing cost and maximising value [10], [38]. Lean helps in balanced use of people, material and resources [4].

The main aim of Lean Production is delivering value by eliminating waste and ensuring undisturbed workflow. Having both the characteristics of "production" and "service" systems, the construction industry has taken some effort towards implementing the lean production concept [29], [54]. Though lean production was successful in manufacturing industry, many believed that it would not be suitable in the construction world because of its unique and complex projects. The end or final products differ significantly in construction and manufacturing industry. In addition to that, the construction industry has three other features that differentiates it from manufacturing: Onsite production, one-of-a-kind projects, and complexity [17],[37]. The outcome of on-site, one-of-a-kind, and complex production is increased uncertainty in construction industry which can be overcome in manufacturing industry by increasing control over the production process. In construction industry, quality is more closely associated to product conformance whereas in manufacturing sector quality is primarily related to process control [54]. However, construction industry has both production and service characteristics and hence it has started applying lean production concept.

The concept of lean technique can be described as follows [33]

- A focus on waste reduction and sources of waste in relation to the delivery of services that indicates value to the end customer
- End customer preference is made the reference to decide what is to be considered as value and waste
- Managing production and supply chain based on demand pull approach
- Approaching production management through focus on processes and flows of processes
- Approaching waste reduction issues through application of a system's perspective

III. LEAN PRINCIPLES

Lean techniques in construction industry includes the following 11 principles as shown in Figure A

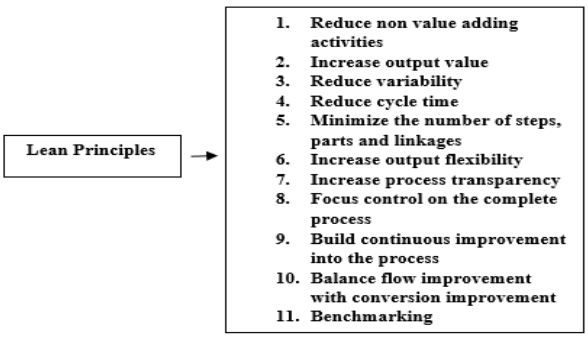

Figure - A – Lean Construction principles

Lean thinking as stated by Womack and Jones [75] has five points as shown in Figure B

Figure - B – The five principles of lean

A. *Specifying Value:*

The customer can define the value, where the customer can be considered to include all downstream operations. In construction industry it can be applied by focusing on client's value.

B. *Identifying value stream:*

The value stream includes analyzing and identifying three types of actions, namely activities creating value, activities creating no value but determined to be unavoidable, and activities creating no value and determined to be avoidable [62]. This step involves identifying the steps that do not add value to the activity in value stream and eliminates them.

C. *Value Flow:*

Once waste and variations are eliminated, flow has to be taken into consideration and the value flow has to be streamlined. Flow is the opposite of batch and queue. The aim of flow is to make a product progress from concept to customer, without interruption or delay. In construction, Koskela [36] developed several practices from the flow principle like reducing variability (standardisation), increasing process transparency (visual control), and others. By minimizing delays, inventories, defects and downtime, interruption in value flow can be avoided.

D. *Pull*

Pull is closely related to the "pull system" that is another important aspect of Just-in-time. The end user pulls the production, such that a product is produced only to meet the requirements, and thus avoids excess production and reduces inventory**.**

E. *Perfection*

This indicates that there is no end to how much better a process can become through the constant application of lean methodology. This is very similar to the Japanese concept of kaizen, which is often translated as continuous improvement in the West. Lean is about continuous improvement through identification and reduction of waste [8], [28], [56].

Lean techniques focus on minimising the waste in any form to maximise the value [23]. Waste reduction and elimination is an important process in lean construction. To improve the project performance and to satisfy the client needs, the waste has to be identified and eliminated.

IV. WASTE ELIMINATION

Waste is defined by the performance criteria for the production system. Howell [29] argues that there is a need to maintain pressure on every activity to ensure continuous improvement through the reduction of cost and duration of

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each activity [6]. The key concept of Lean Project delivery process is to reduce and eliminate waste [26],[32],[42],[57].

Waste is anything that creates no value for the owner or client [50]. Waste can be classified into several categories. According to Taichii Ohno [51] wastes can be categorised under seven groups in construction industry - overproduction, waiting, transportation, processing, inventory, movement and making defective products [71].

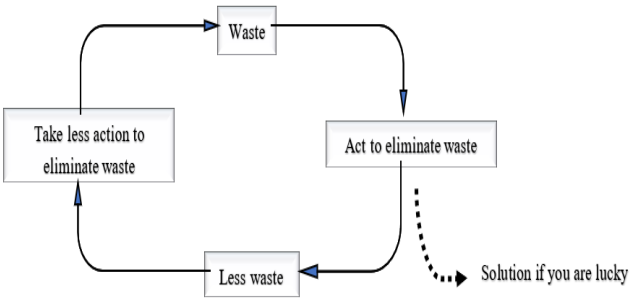

Figure - C – Waste elimination cycle

Waste is defined in relation to value. When focus is on waste, concentration is on what should not be done and so it is easy to lose sight of value. Focusing on value is more effective and fruitful rather than focusing on waste [50] (Figure C). When value is delivered, waste is perhaps not even created so there is no need for elimination in the process.

Alinaitwe [7] explained that implementing key concepts of LC such as Just-In-Time (JIT), Total Quality Management (TQM), Business Process Re-engineering (BPR), Concurrent Engineering (CE) and Last Planner System (LP), Value Based Management (VBM) and OHSAS 18001 can improve the project performance while reducing construction waste [44],[64]. According to majority of the researchers, pre- construction and construction are the best time to implement the Lean Construction concepts. These stages are vital due to selection of material, equipment and labor during pre-construction stage [35] and reduction of construction waste during construction stage [77].

Management commitment, focus on measurable and actionable improvement, involvement and learning are the four factors which are considered important to implement the lean philosophy [35]. Lack of balance among these four factors may have a negative impact. For example:

- lack of management's commitment and changed priorities will be rapidly visible and demotivate other parties

- primary emphasis on learning and involvement, without simultaneous attack on real, urgent problems, does not lead to bottom line results [35], [66].

V. Lean Construction Techniques

Value is the most important lean principle which can be defined only by the customers. Lean tools and techniques help in identifying and eliminating waste that adds no value to the project [41],[53]. Implementation of lean techniques in construction projects results in better productivity.

A. *Last Planner System*

The main goal of Last Planner System (LPS) is to evaluate the workers performance based on their ability to achieve their commitments and to make realistic planning. LPS is a technique that addresses uncertainty and shapes workflow. Uncertainty and variations in production system can be managed by employing production planning and control methods [70],[71]. Last planner is an example of production planning and control which has been successfully implemented and applied to complex construction projects to improve the workflow reliability, improve production performance and to promote production control by engaging all members of the project team [15],[27]. It provides a basis for look ahead schedule. According to Seppanen [65], the goal of LPS is to achieve the aim of lean such as reducing and eliminating waste, increasing productivity and decreasing unpredictability by making a realistic planning and by increasing the team members commitment [1].

The objective of Last Planner is to pull activities by reverse phase scheduling through resource optimization and proper team planning. This tool is similar to the Kanban system and production leveling tools in Lean manufacturing [53].

LPS consists of four levels of planning processes with different chronological spans: master scheduling, phase scheduling, lookahead planning, and commitment planning (Figure D) [13], [27], [60].

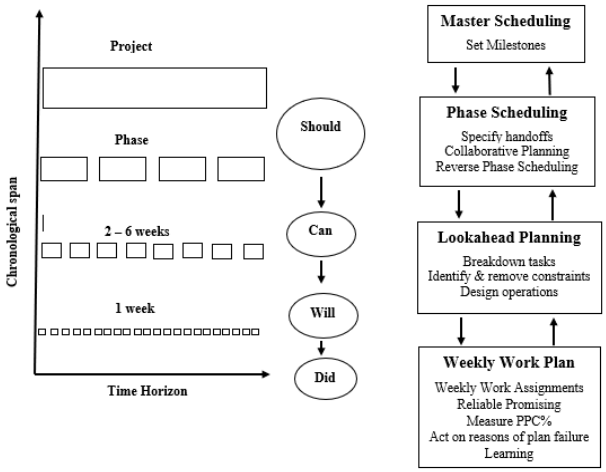

Figure - D – Planning stages in the Last Planner system

The Last Planner System involves the following steps [43]:

- Developing the overall planning sequence and milestones (Master and Phase plans).
- Six Week Look Ahead Planning to support the overall plan (continuous six week rolling schedule tied to milestones) [79].
- Constraint Removal such as, making sure engineering is ready and resources are available.
- Weekly Work Planning (weekly work schedule). At this point activities are unconstrained.
- Measuring Planned Percent Complete (PPC) (determines the effectiveness of the weekly plan, e.g., seven out of ten items completed is a PPC = 70%).
- Identifying and assessing the reasons for the failure of a plan recorded for the activities which are not 100% completed.

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B. Just in Time

Just in Time is a Japanese management philosophy which was first developed by Taiichi Ohno within the Toyota manufacturing plant to meet the customer demands with minimum delays [47]. JIT can be described as continuous improvement of procedures, equipment and processes to reduce and eliminate inventories. According to Koskela [35], three methods linked with JIT, optimize inventories according to backward requests (Japanese: Kanban), construction leveling and decreasing the number of setup activities. In JIT inventories are kept to bare minimum and based on the current demands, inventories are ordered [12].

C. Increased visualization

Increased visualization is an effective way of communicating the key information related to safety, schedule and quality to the workers [48],[72]. Workers can be certain of elements such as workflow, performance targets, and specific required actions.

Setting up instructions for material and equipment storage reduces waste, such as the time for searching and transportation. These plans can then be displayed which is a form of visual management and referred to convey the performance standard [43].

D. Daily huddle meeting (Tool-Box meeting)

Daily huddle meeting is a weekly work plan meeting which focuses on the assignments to be completed during the following week [40]. According to Abdelhamid and Salem [2], the key of the daily huddle meeting is two-way communication. The employee satisfaction will increase with problem-solving involvement and some training that is provided by other tools. Daily huddle meeting ensures quick response to problems through empowerment of workers, and continuous communication through the toolbox meetings [10].

E. Five S Process (Visual work place)

Lean construction pictures the project as a flow of activities that creates value to the customer [21]. The 5s process (sometimes referred to as the Visual Work Place) is about “a place for everything and everything in its place” [53]. The following are the Japanese words that describe those actions [58] – Seiri (Sort), Seiton (Set in Order), Seiso (Shine), Seiketsu (Standardize), Shitsuka (Sustain) [45].

Seiri (Sort) - the removal of all unnecessary tools and parts, putting in order

Seiton (Set in Order) - deployment of work, workers, equipment, parts and instructions in such a way that the flow of work is free from inefficient tasks

Seiso (Shine) - cleaning workplace and all the devices used

Seiketsu (Standardize) - making sure procedures are standardized and reproducible

Shitsuka (Sustain) - helps maintain introduced procedures and rules

The results from implementing 5S includes safety improvement, productivity, quality, creation of space, reduced lead times, cycle times, increased machine uptime, improved morale, teamwork, and continuous improvement (kaizen activities) [53].

F. Fail safe for quality and safety

Shingo [68] introduced Poka-yoke devices as new elements that prevent defective parts from flowing through the process. Fail safe can be expanded to safety but there are possible hazards instead of potential defects which is related to the safety risk assessment tool from traditional manufacturing practice. Both elements require action plans that prevent bad results [2],[53]. Fail safe for quality is about consistent focus on quality and safety issues from the beginning till the end. Potential quality and safety improvement practices are constantly examined.[54].

G. First run studies

First Run Studies are used to redesign critical projects and it is a part of continuous improvement effort which includes productivity studies and review work methods by redesigning and streamlining the different functions involved [11], [24]. Video files, photos, graphics or illustrations are commonly used in the studies to illustrate the work instruction. The first run of a selected craft operation should be explored in detail, bringing ideas and suggestions to explore alternative ways of doing the work. A PDCA cycle (plan, do, check, act) is recommended to develop the study [2], [53].

VI. KEY CONCEPTS OF LEAN CONSTRUCTION

A. Concurrent Engineering

According to Koskela [35], Concurrent Engineering primarily deals with product design base and it refers to an enhanced design process characterized by severe upfront requirements analysis, incorporating the constraints of subsequent phases into the conceptual phase and tightening of change control towards the end of the design process [61].

B. Value Based Management

The main characteristic of value-based management is continuous improvement to increase customer value. Value based strategy refers to “conceptualized and clearly articulated value as the basis for competing”. Firms utilizing value-based strategies are customer oriented in contrast to competitor-oriented firms [1], [35], [71].

C. Lean Project Delivery System

In the Lean Project Delivery System, it is expected that the project delivery team should not only deliver what the customer wants but also make the customer decide what they want [76]. Consequently, it is required to understand customer purpose and constraints, show the customer alternative means for achieving their purposes beyond those they have previously considered, and to help customers understand the outcome of their desires. This process certainly changes all the variables: ends, means and constraints [16].

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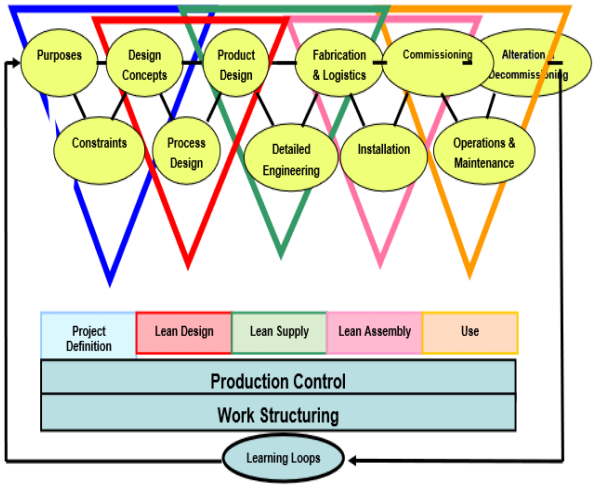

Figure - E – Lean Project Delivery System

According to Ballard [14], the essential features of LPDS (Figure E) include

- the project is organized and managed as a value generating process
- downstream stakeholders are involved in front end planning and design through cross functional teams
- project control has the job of execution in contrast to reliance on after-the-fact variance detection
- optimization efforts are concentrated on making workflow reliable as opposed to productivity improvement
- pull techniques are used to supervise the flow of materials and information through networks of cooperating specialists
- capacity and inventory buffers are used to absorb variability
- feedback loops are incorporated at every level, dedicated to rapid system adjustment; i.e., learning.

VII. Barriers In Implementing Lean Construction

For successful implementation of lean principles in the construction industry, the barriers must be identified [25]. According to the Leong and Tilley [39], not identifying the factors that influence the successful lean construction implementation may lead to the inability of the organization to understand the efforts which should be improved, where these efforts should be focused, or what effort is required to attain the better results. Some Lean Construction techniques and practices which were contained with lean manufacturing cannot be applied directly in construction industry and may need to be amended. According to Abdullah [3], a full understanding of lean manufacturing principles is essential to apply the concept of LC. Studies have reported the lack of exposure on the benefits and need to adopt LC and difficulties in understanding its concepts to be significant barriers to the successful implementation of LC [3], [9], [30], [31], [59]. Many construction companies are hesitant to adopt lean techniques. The barriers can be overcome by conveying the benefits of lean construction through seminars and conferences. The various barriers to the implementation of lean principles is shown in the Table A.

Table - A – Barriers in implementing lean techniques

Barriers	Abdullah et al. (2009)	Sarhan and Fox (2013)	Alinaitwe (2009)	Dulaimi and Tanamas (2001)	Devaki and Jayanthi (2014)	Omran and Abdulrahim (2015)	Kanafani (2015)	Shang and Pheng (2014)
Lack of attentiveness and commitment from top management	X	X	X	X	X	X	X	X
Lack of knowledge of the lean construction approaches	X		X	X		X	X	X
Unfavorable organizational culture		X	X	X	X	X	X	X
Lack of proper training	X			X	X	X	X	X
The tendency of construction firms to apply traditional management concepts	X	X		X	X			
Culture and human attitudinal issues		X			X			
Difficulties in understanding the concept of lean construction	X	X		X		X		

VIII. Conclusion

Implementing lean in construction industry significantly improves the efficiency of construction industry. Introducing lean in construction industry has several benefits such as increased process transparency, reduced project variability and balance flow improvement [72]. To bring out the developmental change in the field of construction, acceptance of lean tool is mandatory. In this paper, evolution of lean concept and the impact of adopting lean techniques in construction industry are explained. The barriers in implementing lean techniques in construction industry has been discussed and the need for implementing lean techniques in construction industry has been emphasized. By implementing lean techniques, construction companies can have a better understanding of waste that are generated which leads to improved efficiency in construction activities. Future research will be conducted on construction organizations that have implemented LC concept by observing their practices on site. A qualitative research approach is suggested to investigate the nature of the significant barriers identified and to propose strategies for overcoming barriers to implement LC.

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