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RESEARCH ARTICLE

## Lean Construction Implementation in the Saudi Arabian Construction Industry

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### Abstract

The Kingdom of Saudi Arabia (KSA) has witnessed a huge increase in construction during the last two decades. However, many projects experienced time delays, cost overruns and the generation of massive amounts of waste. To address these challenges, lean construction has been introduced into the Saudi construction industry; however, it is still in its infancy. This study therefore investigates the current state of lean construction implementation in the construction industry in the KSA. The objectives are to identify: the types of construction waste, level of use of tools that support the implementation of lean construction, stages of application of lean methods, and the benefits of lean construction. To achieve these objectives, a structured questionnaire survey of 282 construction professionals was carried out. After the analysis of the collected data using mean score and Anova test, the following conclusions were made. In the construction industry in the KSA, waiting is the most common type of waste, while Computer Aided Design (CAD) is the conventional tool supporting the implementation of lean construction. Furthermore, the data suggests that lean construction is most commonly used in the construction stage of projects while customer satisfaction is the main benefit derived from lean construction practices. This study concludes that the level of implementation of lean construction in the KSA construction industry is increasing. The results will help benchmark the current state of lean construction implementation, which will enable the construction industry to identify strategies to implement lean construction in Saudi Arabia in accordance with their needs and project goals, to achieve better productivity.

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## Keywords

**Construction waste, lean Construction, lean construction tools, Saudi Arabian construction industry**

## Introduction

The Kingdom of Saudi Arabia (KSA) has experienced an unprecedented rise in construction projects during the last twenty years (Ikediashi, Ogunlana and Alotaibi, 2014). Thus, the Saudi construction industry is booming, with the current expenditure rising to more than US\$120 billion a year (Alrashed et al., 2014). Currently, the kingdom's construction industry encompasses 15% of its workforce and consumes more than 14% of the country's energy (Dhahran International Exhibition Company, 2015). However, construction projects in the KSA normally have poor performance, which is mainly due to huge time and cost overruns (Assaf and Al-Hejji, 2006). Furthermore, massive environmental waste is also generated by the construction industry and the Saudi government issued a decree that requires all construction companies to meet new resource consumption standards to minimize the impact of waste in the construction industry (McCullough, 2014). In addition, there has been an increase in occurrences of buildings collapsing before reaching the end of their expected lifespan (AMEInfor, 2014). The Saudi Council of Engineers report that the average lifespan of a Saudi building is between 25 and 50 years, compared to the 100 years observed in other countries (AMEInfor, 2014).

To address these challenges, lean construction has been introduced into the Saudi construction industry, and several contractors have realized the significance of implementing lean construction (AlSehaimi, Tzortzopoulos and Koskela, 2009). The lean construction concept is based on the Toyota Production System (TPS), which has been transformed into a newly systemized construction method. It aims to complete a project that meets customers' requirements through waste reduction. It also emphasizes that every process within the construction project is critical for the improvement of the project, considering the integrated approaches such as lean and green (Banawi, 2013). Lean construction also minimizes the direct cost of effective project delivery management and assists construction managers in making informed project decisions at all levels of the project. Furthermore, lean construction promotes continuous improvement by encouraging reflection on lessons learned (Lehman and Reiser, 2000).

However, lean construction in Saudi Arabia is still in its infancy. The implementation of lean construction concepts in complex projects has not yet begun. Due to the lack of lean construction adoption in the KSA, which has been constrained by various factors such as poor equipment, an unskilled workforce, and ineffective planning, it is hard to conduct effective research in this area (AlSehaimi, Tzortzopoulos and Koskela, 2009). To increase the awareness and understanding of the lean concept in the Saudi Arabian construction industry, an overview of the current status quo of lean construction application is urgently required. However, no such studies exist in the current body of knowledge due to the lack of real data or empirical information in Saudi Arabia. Furthermore, the lack of a comprehensive overview of lean construction implementation in Saudi Arabia also prevents more in-depth studies in this area.

Therefore, this study aims to provide an understanding of the implementation of lean construction in the KSA construction industry. Through a structured questionnaire survey of 282 construction professionals in the construction industry in the KSA, this study mainly investigates (1) major types of waste, (2) the current tools/techniques that support the

implementation of lean construction, (3) stages of application of lean methods, and (4) the benefits of lean construction. This study will enable stakeholders such as project owners, contractors, consultants, vendors, and the government to have a clear picture of the level of implementation of lean construction in the Saudi Arabian construction industry. In addition, this study provides a platform from which to conduct further studies of lean construction, and promote its application in the construction market in Saudi Arabia.

## Literature review

### LEAN CONSTRUCTION

The term “lean” originated from the Toyota Production System (TPS) developed in the 1990s. It describes the strategy that the company adopted to enhance production and consumption efficiency of its auto goods and services (Ahrens, 2006; Howell and Ballard, 1998; Womack and Jones, 2003). The concept of lean has its foundation in the deployment of reproducible activities by Fredrick Winslow Taylor (Taylor’s theory) and its best historical implementation was based on Henry Ford’s conveyor belt invention that led to mass production observed in the 19<sup>th</sup> century (Vieira and Cachadinha, 2011). A major shift in the philosophy of manufacturing then occurred in Japan in 1949 when Toyota sales dwindled forcing them to retrench many their workers after the company’s evaluation showed that Taylor’s mass production was insufficient and thus had to be reviewed and revised (Ahrens, 2006). This led to the introduction of the Toyota Production System (TPS), which resulted in the establishment of lean production in the 1990s. The Toyota Production System was applied together with Total Quality Control (TQC) and was meant to reduce waste and causes of manufacturing defects (Anvari, Ismail and Hojjati, 2011). The same concept has been adopted in the western world with the term ‘lean thinking’ (Womack and Jones, 1996). Furthermore, the construction and manufacturing industries have borrowed it, hence the terms “lean construction” and “lean manufacturing” respectively.

Lean construction involves ways of designing production systems to minimize waste in materials, time, and human effort, with the aim of generating maximum cost-effective value (Howell, 1999; Pinch, 2005). It is concerned with a holistic pursuit of concurrent and continuous improvements in the design, construction, activation, maintenance, salvaging and recycling in building projects (Howell, 1999). The term ‘lean construction’ was coined by the International Group for Lean Construction at its first meeting in 1993 (Howell, 1999). Lean construction could be in the form of setting milestones and strategy identification of long lead items, specifying hand offs and identifying operational conflicts, and making work ready planning to ensure that work is made ready for installation; re-planning as necessary (Aziz and Hafez, 2013). This system advocates identifying the root causes of waste, removing those causes with related tools and techniques, and encouraging the prevention of waste rather than reactively attempting to overcome the negative effects of loss (Lapinski, Horman and Riley, 2006; Womack and Jones, 2003).

There are five main principles of lean construction which help to bring production effectiveness in construction (Howell, 1999). These principles were initially specified by (Womack and Jones, 1996), as essential for lean thinking. First, the value of the construction is identified based on the views of the customer. Second, value streams are generated based on the delivery value. Third, the removal of waste by various processes influences the flows within work processes. Fourth, the creation of a system of pull production ensures the system does not allow delivery of materials until they are needed. Fifth, the recognizing or pursuing

of perfection helps to improve systems and processes and this needs to be constantly sought. These five principles are the principles for the optimization of the system from which a common spirit flows (Kumar et al., 2013).

Lean construction is reported to lead to increased quality and productivity in the construction industry. For instance, Forbes and Ahmed (2011) reported that the implementation of lean construction concepts increased the quality and productivity of construction projects by about 77%. Lean construction results in improved working conditions at the construction sites by decreasing physical and psychological stress (Alwi, 2003). Lean construction enhances work flow by reducing upstream variability, which could be achieved via improved project coordination amongst others (Abdelhamid and Salem, 2005; Vieira and Cachadinha, 2011).

The adoption of lean construction by AEC firms is still in a transition phase (Sarhan and Fox, 2012) due to lack of understanding about lean thinking concepts and its implementation in construction, along with structural (from an organization perspective) and cultural barriers. Institutional waste, focusing on dynamics of systems and relationships within organizations, has more influence on lean construction implementation (Sarhan, Pasquire and King, 2014). It is argued that relationships can be generated among lean project management and conventional methods through restructuring for enhancement of organizational integration (Ballard and Tommelein, 2012). However, organizational culture plays vital role for such integrations. Furthermore, traditional approaches present significant barriers to adopting innovative approaches such as lean construction (Forbes and Ahmed, 2011). There is a need for more empirical evidence to align the lean construction theory to maximise the benefits of lean thinking concepts (Sarhan and Fox, 2013).

Currently there exists a variety of lean tools and techniques, including the Last Planner System, Value Stream Mapping (VSM), Standardized Work, The 5S process, Kaizen, Total Quality Management (TQM), increased visualization, Fail Safe for Quality and Safety, Daily Huddle Meetings, First run studies, The Five Why's, Just in Time (JIT), Plan of Conditions and Work Environment in the Construction Industry (PCMAT), Concurrent Engineering, Pull 'kanban' system, Error Proofing (Poka-yoke), Target value design (TVD), Partnering, Total Productive maintenance (TPM), Computer Aided Design (CAD) and Six Sigma. Table 1 shows the summary of lean tools/techniques that support the implementation of lean construction processes.

The concept of waste in construction is still evolving. Viana, Formoso and Kalsaas (2012) reported that the effort of the construction management community for understanding waste is relatively small, compared to other topics, and many studies about waste have focused on the consequences, not on the root causes that should be avoided. Waste is normally understood in two dimensions, i.e. instrumentally and intrinsically, with the main aim to reduce or eliminate for performance improvement (Koskela, Sacks and Rooke, 2012). These interpretations of waste are different in construction which requires empirical justification, conceptual compatibility, persuasiveness, and motivation for action (Koskela and Bølviken, 2013). Creating value and only value is the best way to reduce waste in design and construction (Mossman, 2009).

Many studies have identified the causes of waste in construction projects. Ohno (1988) suggests that the causes of waste are related to over production, waiting, transportation, over processing, inventory, movement, and defects. Macomber and Howell (2004) revealed that under-utilized human potential is a cause of waste, while Koskela (2004) added making-do. Making-do is the circumstance in which the task is begun without all the required standard inputs. Input here refers

**Table 1** Summary of the lean tools/techniques that support the implementation of lean construction

Lean Tools/Techniques	Definition	References
The Last Planner System (LPS)	To achieve lean goals of reducing waste, increasing productivity, and decreasing unpredictability, mainly through a social process, by trying to make planning a mutual attempt and by increasing the reliability of the commitment of team members. In construction, LPS was a method that forms workflow and deals with project variability.	(Lehman and Reiser, 2000; Watson, 2003); (Ballard and Howell, 1994; Salem et al., 2005)
Value Stream Mapping (VSM)	This tool establishes the current state of the construction process or supply chain to identify the wastes. The future state helps to develop improvement strategies.	(Arleroth and Kristensson, 2011)
Standardized Work	Flexible regimentation lean construction tool involving the development of a common way for performing specific construction processes based on the available evidence.	(Toussaint and Berry, 2013)
The 5S Process	The 5Ss are sorting, straightening, shining, standardizing, and sustaining the facilities and processes used in construction. The 5S process increases the productivity of the project since it reduces the time spent searching for supplies, tools, and equipment etc.	(Umstot, 2013)

Table 1 continues on the next page

Table 1 (Continued)

Lean Tools/Techniques	Definition	References
Kaizen	The Japanese word for continual improvement, Kaizen promotes the idea that every process can and should be continually evaluated and improved in terms of time required, resources used, resultant quality, and other aspects relevant to the process.	(Sniegowski, 2013)
Total Quality Management	Most of the substantial tools used to address construction performance issues are based on the concept of plan-do-act. Functions involve identification and evaluation of the problem, developing, and implementing solutions, and evaluating and measuring the results.	(CEC, 2005; Marosszeky et al., 2002)
Increased visualization	Communicating key information effectively to the workforce through posting various signs and labels around the construction site; workers can remember elements such as workflow, performance targets, and specific required actions if they repeatedly see them.	(Conte and Gransberg, 2001; Salem et al., 2005)
Fail Safe for Quality and Safety	This is a lean construction tool that ensures no harm or minimum is sustained in the event of specific failures.	(Ogunbiyi, 2014)

Table 1 continues on the next page

Table 1 (Continued)

Lean Tools/Techniques	Definition	References
Daily Huddle Meetings	These are held to obtain the full involvement of employees in issues regarding the project and to encourage employees to solve problems together. Two-way communication is the key to the daily huddle meeting process to achieve employee involvement.	(Adamu and Hamid, 2012; Aziz and Hafez, 2013; Ogunbiyi, 2014; Salem et al., 2005)
First run studies	First-run studies are utilized to remodel important tasks. Operations are scrutinized thoroughly, and ideas and suggestions are raised to explore alternative ways of doing the task. The PDCA (plan, do, check, and act) cycle is used to build up the first-run study.	(Aziz and Hafez, 2013; Ballard and Howell, 1997; Ogunbiyi, 2014)
The Five Why's	This is the lean construction iterative-question-asking technique that elucidates "cause-and-effect" mechanisms associated with a problem. It is a problem-solving tool that aims to find the root cause of a construction-related issue or problem. The questions are usually specific to the project and are not limited to five questions.	(Aziz and Hafez, 2013; El-Kour, 2009; Nielsen and Tezel, 2013)

Table 1 continues on the next page

Table 1 (Continued)

Lean Tools/Techniques	Definition	References
Just in Time (JIT)	JIT in lean construction is a tool that ensures reduced flow times: production times and response times (end-to-end or between contractors and clients). JIT may include demand-flow or continuous-flow.	(Ogunbiyi, 2014)
Plan of Conditions and Work Environment in the Construction Industry	This is a lean construction tool that assures occupation safety and health management. It manages safety requirements through the risk management cycle consisting of continuous identification of risk, evaluation, and control.	(Aziz and Hafez, 2013; Ogunbiyi, 2014)
Concurrent Engineering	This is an improved design process characterized by rigorous 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.	(Ballard and Howell, 2003; Koskela, 1992; 1994)
Pull 'kanban' system	The pull systems are a lean approach developed in the automotive industry as a mechanism to pull materials and parts throughout the value stream on a JIT basis.  The Productivity Press Development Team (2002) mentioned that the Japanese word "Kanban" means 'card' or 'sign' and is the name given to the inventory control card used in a pull system.	(Arbulu, Ballard and Harper, 2003; Team, 2002)

Table 1 continues on the next page

Table 1 (Continued)

Lean Tools/Techniques	Definition	References
Error Proofing (Poka-yoke)	Poka-yoke is a Japanese word which can be defined as “error-proofing”. Shingo introduced Poka-yoke devices as new elements to avoid defective parts from flowing through the process. It is a lean tool that engages all forms of activities and devices that could help avoid an error from happening.	(Abdelhamid and Salem, 2005; Conner, 2009)
Target value design (TVD)	This approach applies methods for the design to be developed in accordance with the constraints, especially cost (e. ‘deign-to-cost’ or ‘design-to-targets’. TVD considers the customers’/ clients’ and stakeholders’ vision to define such restrictions and deliver the required target values.	(Miron, Kaushik and Koskela, 2015)
Partnering	This approach lead to collaboration and open exchange of information which implies a potentially radical change in the management practices and organisational structures.	(Barlow, 1996)

Table 1 continues on the next page

Table 1 (Continued)

Lean Tools/Techniques	Definition	References
Total Productive maintenance (TPM)	This tool as an integrated approach to maintenance that focuses on proactive and preventative maintenance to maximize the operational time of equipment, TPM blurs the distinction between maintenance and production by placing a strong emphasis on empowering operators to help maintain their equipment.	(Al-Aomar, 2012; Asay and Wisdom, 2002)
Computer Aided Design (CAD)	In this approach, engineering designs may be created and tested using computer simulations and then transferred directly to the production floor where the machinery uses the information to perform production functions.	(Diekmann et al., 2004; Khanzode, Fischer and Reed, 2005)
Six Sigma	An organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and scientific method to make dramatic reductions in the customer defined defect rates.	(Linderman et al., 2003)

to machinery, personnel, tools, external conditions, instructions, and so on. Additionally, Bossink and Brouwers (1996) defined significant causes of construction waste into six sources: residual, operational, materials handling, procurement, design, and other sources that may not add value to the project. Furthermore, Garas, Anis and El Gammal (2001) classified waste under two main headings; first, material-related waste, namely over-ordering, over-production, mishandling, bad storage, manufacturing defects, and theft and vandalism. Second, waste as related to time, such as waiting, stoppages, clarifications, variations in information, rework, errors, and interaction between various specialists. Other studies have identified the most frequent types of waste in construction (Aziz and Hafez, 2013; Engineers Australia, 2012; Koskela, 2004). In no specific order, these are: Waiting (on people, information, material), Corrections (re-work), Transportation (haulage and soluble handling), Motion, Over-processing (wrong methods), Inventory (storage), over production (building ahead of time) and Making do.

## Research method

To investigate the implementation of lean construction in the Saudi Arabian construction market, a broad questionnaire survey was conducted to understand the extent to which lean construction tools and techniques have penetrated the industry. The questionnaire was designed to include two major sections. The first section obtains general information about the respondents, and the second (main) part attempts to find the answers of following questions:

1. What are the major types of waste in the Saudi construction industry?
2. What is the level of use of lean tools and techniques in the KSA construction industry?
3. In which stages is lean construction implemented the KSA construction industry?
4. What are the benefits of implementing lean construction in the KSA construction industry?

A total of 800 questionnaires were dispatched to individuals involved in the construction industry, and 282 responses were received, representing a response rate of 35%. The survey was started in March 2015 in Saudi Arabia. The potential respondents were approached in two ways. First, an online questionnaire survey using Survey Monkey was conducted with members of the Saudi Council of Engineers that included Suppliers, Specialty Contractors, General Contractors, subcontractors, Architects, Project Managers, and Clients. An invitation letter and questionnaire was sent to Saudi Council of Engineers first to seek their assistance with the questionnaire survey. Thereafter, the Saudi Council of Engineers helped by sending the survey request to its members, which resulted in 155 respondents returning their completed questionnaires. Second, hardcopy questionnaires were sent out to 300 individuals from contracting companies, consulting companies, academics, government, and clients. This strategy resulted in an additional 127 respondents returning completed questionnaires. The respondents provided information on the implementation of lean construction in their individual projects, which was analysed and will be presented in the following sections.

## Results and analysis

Figure 1 presents the background information of 282 respondents, including their organization, experience, education background, organization or company size based on the number of employees, approximate annual revenue (for the year 2014) of their company, and the status of their ISO certification.

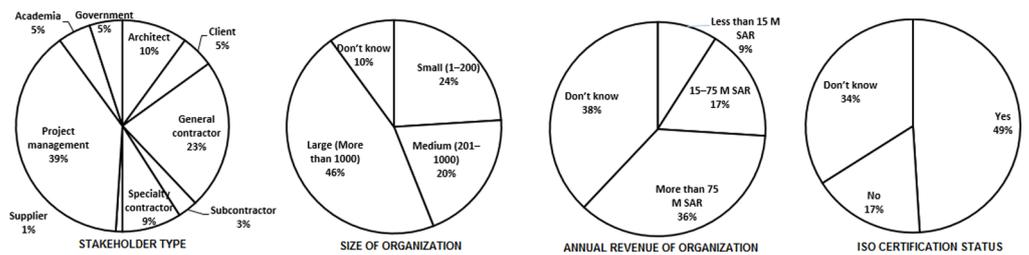


Figure 1 Respondents' organization profile

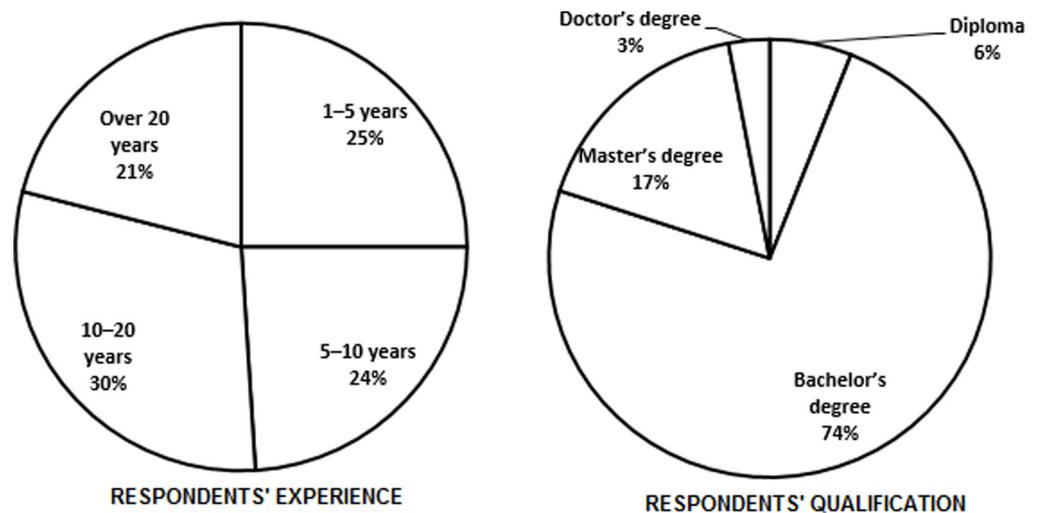


Figure 2 Respondents' profile

The respondents involved in the survey were architects, clients, general contractors, suppliers, project managers, academics, and government officials. Most respondents were from project management companies (39%) and general contractors (23%), followed by design consultant companies (10%) and specialty contractors (9%). The diversity of their professional backgrounds will help to provide a balanced view for the research topic.

In this study, companies were categorized into small (less than 200 employees), medium (201–1000 employees), and large (more than 1000 employees). The results showed that 24% of the respondents were from small companies, 20% from medium companies, and 46% from large companies. Additionally, company size was also analysed regarding approximate annual revenue (financial year 2014), revealing that 9% of companies made less than US \$2 million, 17% made between US \$4 million to US \$20 million, and 36% of companies had a revenue of more than US \$20 million. These results confirm that large companies dominate the Saudi Arabian construction industry.

The International Standard Organization (ISO) certifies organizations based on proven credibility and quality, especially on products or services that meet customers' expectations. The analysis of the status of ISO certification of the Saudi Arabian construction companies showed that nearly half of the organizations have acquired the certification, significantly higher than those that have not acquired the certification (17%).

In Figure 2, educational background and professional/work experience for most respondents found they were highly educated (74% have bachelor degree) and experienced (75% have more than 5 years' experience), which will ensure the reliability of the research results

## Data analysis

### TYPES OF CONSTRUCTION WASTE

This section shows the results of the data analysis of the types of construction waste in the Saudi Arabian construction industry. As shown in Table 2, “Waiting” has the highest mean value of 3.58 and is ranked first. This is closely followed by “Making do” with a mean value of 3.43 and thus ranked second. From the rear, “over production” is ranked lowest with an overall mean of 2.96. Except for over production (mean score = 2.96), all types of waste have a mean score higher than 3.00. This suggests that they are very common in the construction industry in the KSA.

ANOVA statistical tests were employed to examine whether the types of waste are significantly different between “large” and “small and medium” construction companies. Table 2 shows that except for over-processing and over production, P-values for other types of waste are greater than the significant value of 0.05, showing that the null hypothesis is valid, which means there is no statistically significant difference in types of waste between large and small-to-medium companies.

As the P-values for “Over processing” and “Over production” are 0.002 and 0.027 respectively, and less than the significance level of 0.05, the null hypothesis is thus rejected. Over processing is a result of the implementation of the wrong methods. For example, in design process, over engineering is considered as over processing; likewise, in the construction stage, stockpiling excess material for concreting near plant or mixer causing double handling (for arrangement of materials) does not contributing to a good outcome i.e. a batch of concrete for a specific pour at a given time. Similarly, over production is the production of building ahead of time and more than is required (Bertelsen and Koskela, 2002). These types of waste are more significant for smaller companies as they have limited resources compared to large companies with large production units. Thus, the percentage of waste in large companies from these two types is relatively small compared to overall production.

Table 2 Types of waste in the Saudi Arabian construction industry

Types of Waste	Overall Mean	S.D.	Rank	Small and Medium companies	Rank	Large companies	Rank	ANOVA $p$ -value
Waiting	3.58	1.14	1	3.49	1	3.56	1	0.076
Making do	3.43	1.94	2	3.44	2	3.45	2	0.670
Corrections	3.38	1.13	3	3.30	4	3.37	3	0.096
Transportation	3.38	1.09	4	3.42	3	3.34	5	0.852
Motion	3.28	1.16	5	3.23	5	3.35	4	0.661
Over-processing	3.25	1.14	6	3.14	6	3.21	6	0.002*
Inventory	3.04	1.15	7	3.23	5	2.88	7	0.046
Over Production	2.96	1.17	8	3.14	6	2.76	8	0.027*

Note: 1= Strongly Disagree to 5= Strongly Agree

These two types of waste are similar for both small-to-medium and large companies but the nature of type is different. Poor management practice is a key reason for over processing and overproduction. Furthermore, poor quality control and lack of a quality assurance system play a vital role.

### LEVEL OF USE OF TOOLS THAT SUPPORT THE IMPLEMENTATION OF LEAN CONSTRUCTION

Even though it has already been established that lean construction methods are important for achieving beneficial results, it is important to understand the different levels of implementation of these methods. Table 4 shows how often different lean methods are implemented in the current Saudi Arabian construction industry. Results obtained are consistent with previous studies such as by Gao and Low (2014), which indicates that the adoption of lean/techniques in the construction industry is very prolonged. Forbes and Ahmed (2011), suggest this is because of the averse-to-change nature of the construction industry.

As shown in Table 3, 12 tools/techniques have mean  $\geq 3.0$ , while the other 5 tools/techniques have a mean value of  $< 3.00$ . Therefore, this is taken to mean that 12 tools/techniques are important for supporting the implementation of lean construction in the construction industry in the KSA. They are computed aided design (mean value = 3.97), preventative maintenance (mean value = 3.60), safety improvement program (mean value = 3.60), visual inspection (mean value = 3.55), continuous improvement program (mean value = 3.35), daily huddle meetings (mean value = 3.34) and Total quality management (mean value = 3.23). Others are Use of prefabricated material (mean value = 3.18), Target value design (mean value = 3.15), concurrent engineering (mean value = 3.14), Just-in-time (mean value = 3.12) and Plan of Conditions and Work Environment in the Construction Industry (mean value = 3.12). From the rear, Six sigma and Kanban are ranked at the bottom of list by both small and large construction companies, as they are not popular and are rarely used by construction professionals.

ANOVA tests were conducted to evaluate whether there is a significant difference in the use of the tools between large and small-to-medium companies. Of all the tools identified in Table 3, the result reveals that only the use of the Safety Improvement Program is significantly different between large and small with p-value  $< 0.05$  (0.020). The reason for the difference between both types of companies can be attributed to the high-level focus on safety in large companies, but not in small companies who are usually contracted to execute small projects in the KSA. The other tools have p-values  $> 0.05$  (Table 3) indicating that there is no significant difference in their use to support the implementation of lean construction in both large and small-to-medium companies.

### STAGES OF APPLICATION OF LEAN METHODS IN THE KSA CONSTRUCTION INDUSTRY

There are different stages in any construction project: planning, design, construction, operation and maintenance, commissioning, and handover. Mehta, Scarborough and Arm Priest (2008) describe stages of construction project delivery. The planning stage is where the proposed project is defined in terms of its function, purpose, scope, size, and economics. The design stage is where the client's design concept is produced graphically for visualisation and appreciation. The construction stage is where the project design by architects or engineers is realised by assembling the elements that make up the design. The commissioning/handover stage indicates the practical completion of a project and the handover by the constructor to the client. Usually, a commissioning professional is assigned to check whether the proposed

Table 3 Level of use of tools that support the implementation of lean construction

Tools	Overall Mean	S.D.	Rank	Small to medium companies	Rank	Large companies	Rank	ANOVA <i>p</i> -value
Computer-aided design	3.97	1.55	1	4.04	1	3.92	1	0.747
Preventive maintenance	3.60	1.41	2	3.47	4	3.66	3	0.309
Safety improvement program	3.60	1.40	3	3.55	3	3.77	2	0.020*
Visual inspection	3.55	1.44	4	3.62	2	3.49	4	0.783
Continuous improvement programs	3.35	1.43	5	3.29	6	3.32	5	0.274
Daily huddle meetings	3.34	1.36	6	3.28	7	3.31	6	0.272
Total quality management	3.23	1.47	7	3.15	8	3.25	7	0.566
Use of prefabricated materials	3.18	1.68	8	3.33	5	3.16	12	0.145
Target value design	3.15	1.56	9	3.08	11	3.18	10	0.786
Concurrent engineering	3.14	1.53	10	3.14	9	3.18	11	0.796
Just-in-time techniques	3.12	1.52	11	3.12	10	3.06	14	0.509
Plan of Conditions and Work Environment in the Construction Industry	3.12	1.50	12	2.95	12	3.25	8	0.219
Computerised planning system or ERP	2.98	1.72	13	2.78	15	3.20	9	0.140
Last planner system	2.96	1.50	14	2.87	13	3.04	15	0.631
Information management system	2.96	1.70	15	2.76	16	3.16	13	0.181

Table 3 continues on the next page

Table 3 (Continued)

Tools	Overall Mean	S.D.	Rank	Small to medium companies	Rank	Large companies	Rank	ANOVA p-value
5S	2.85	1.71	16	2.82	14	2.84	16	0.840
Six Sigma	2.48	1.69	17	2.45	17	2.58	17	0.352
Kanban	1.93	1.61	18	1.80	18	1.99	18	0.408

Note: 1= Never to 5= Always

Table 4 Stages of application of lean methods in the KSA construction industry

	Overall Mean	S.D.	Rank	Small and Medium	Rank	Large	Rank	ANOVA p-value
Construction stage	3.83	1.04	1	3.69	1	3.94	2	0.151
Design stage	3.81	1.1	2	3.6	3	3.95	1	0.025*
Planning stage	3.72	1.15	3	3.65	2	3.75	4	0.654
Operation and maintenance stage	3.7	1.13	4	3.6	3	3.79	3	0.383
Commissioning and handover stage	3.59	1.14	5	3.52	4	3.64	5	0.671

Note: 1= No implementation to 5= Complete implementation

plan is as built. The operation/maintenance stage indicates the practical use of the project by occupiers. Throughout the project life span, maintenance works on dilapidated or weakened elements are expected to be carried out at regular intervals. All these stages are important and special teams are allocated to each stage. The implementation levels of lean construction at each project stage are tabulated in Table 4.

As shown in Table 4, the construction stage has a mean value of 3.83, followed by the design stage with a mean value of 3.81, then followed by the planning stage with a mean value of 3.72. The stages of construction with the lowest mean values are operation and maintenance, and commissioning and handover, with mean values 3.70 and 3.59 respectively. It could be seen that the mean value for all the stages are >3.0 out of a maximum of 5.0. This indicates that lean construction is highly implemented in all stages of construction in the KSA construction industry. However, the commissioning/handover stage has the lowest mean value (3.59). Therefore, future opportunities for improving the level of implementation of lean construction should be concentrated on the commissioning/handover stage.

An ANOVA, P-value analysis was done to check for differences from the mean between the groups. ANOVA P-values vary from 0.025 to 0.671 for different stages for lean construction between the two groups. In these results, the null hypothesis states that the mean

values are equal for both groups for different reasons, as indicated in the table. As the P-value for “Design” is 0.025, which is less than the significance level of 0.05, the null hypothesis is rejected. So, for this technique, large and small-to-medium companies have a different mean and differing opinions from the respondents. More consideration is given to the design of large scale projects and sometimes it takes years to complete just the design phase of larger projects. Whereas in small projects, comparatively less consideration is given to the design phase, which may be the reason for the differences in opinion of respondents across the two groups.

On the other hand, for all other stages of construction, in regards to adopting lean construction methods the ANOVA P-value is greater than the significant value of 0.05 showing that the null hypothesis is valid and there is no significant difference in the mean of data collected for large and small-to-medium companies. The most agreeable point is “commissioning and hand over” for both large and small-to-medium companies.

### BENEFITS OF LEAN CONSTRUCTION

Table 5 shows ranked benefits of lean construction. The results show that generally, the construction industry is mainly concerned about getting improved customer satisfaction (with a mean value of 3.91). Construction companies are categorized into two groups, i.e. “Large” and “small and medium” to provide a clearer analysis of reasons for adopting a lean construction. First, overall means were calculated as varying from 3.91 to 3.42, and then the standard deviations were calculated, varying from 1.22 to 1.46. Analysis of the data enables us to rank the reasons for adopting a lean construction, whereby “Customer satisfaction” is at the top of the list and “Employee satisfaction” ranks last. Quality improvement and increased productivity are two other main reasons identified by researchers worldwide, and these are ranked 2<sup>nd</sup> and 3<sup>rd</sup> in the list.

The benefits of lean construction may differ for different sized companies with different goals and production units (Research, 2013). Thus, an ANOVA analysis was conducted and the results show that only the P-values for the top two ranked reasons (i.e. customer satisfaction and quality improvement) are lower than 0.05. For these two reasons of lean adoption, respondents from large and small-to-medium companies have significantly different opinions. Customer satisfaction and quality improvement are two main factors for evaluating the progress and reputation of any company but it also depends on the clientele and the types and scale of projects undertaken as large companies are often engaged in mega projects whereas small firms concentrate more on small scale construction like housing. The point that both large and small-to-medium companies agree on most is “reduced construction time. This may be because in Saudi Arabia delays in completion of construction projects have increased and construction firms want to complete their projects in shorter timeframes.

### Discussion

Lean construction is a comparatively new concept in the construction industry, which aims to enhance production effectiveness. This research explored the major types of waste, tools that support the implementation of lean construction, benefits of lean construction, and stages of application of lean methods in the KSA construction industry.

Results showed that “waiting” is the most common type of waste in construction projects in Saudi Arabia. This may be due to several factors including processing of bills, delay in supply of materials and staff negligence as reported in previous studies (Aziz, 2013;

Table 5 Benefits of lean construction

Benefits of lean construction	Overall Mean	S.D.	Rank	Small and Medium companies	Rank	Large companies	Rank	p-value
Customer satisfaction	3.91	1.27	1	3.85	3	3.83	4	0.020*
Quality improvement	3.90	1.22	2	3.75	4	3.92	1	0.012*
Increased productivity	3.88	1.26	3	3.93	1	3.76	5	0.109
Reduced construction time	3.86	1.27	4	3.90	2	3.86	3	0.846
Process improvement	3.83	1.24	5	3.74	5	3.90	2	0.576
Better health and safety record	3.73	1.29	6	3.68	6	3.73	7	0.581
Improved supplier relationship	3.63	1.32	7	3.56	7	3.74	6	0.418
Better inventory control/reduced inventory	3.51	1.46	8	3.48	8	3.50	8	0.828
Increased market share	3.45	1.45	9	3.47	9	3.39	9	0.655
Employee satisfaction	3.42	1.33	10	3.37	10	3.39	9	0.271

Note: 1= Strongly Disagree to 5= Strongly Agree

Engineers Australia, 2012; Koskela, 2004). Alwi (2003), suggests that waiting is most important type of waste in Indonesian and Australian construction projects. Alarcon (1997) also identified waste in construction and concluded the same results for the Netherlands.

Customer satisfaction is the dominant benefit for adopting lean construction techniques by Saudi Arabian Construction companies. It can be measured by different factors like the overall quality of the completed project, materials used, cost, user feedback, fulfilment of the purpose of the project, meeting health and safety criteria amongst others. Customer satisfaction about the completed project will create a trust bond between the two parties and will likely result in future collaboration. Quality improvement and increased productivity are two other main benefits for adopting lean construction and are ranked 2<sup>nd</sup> and 3<sup>rd</sup> in the list of reasons. These findings are in accordance with those of other researchers, for example, in the Brazil and Netherland construction industries these two reasons were also identified as the main benefits for adopting lean construction techniques (Ballard and Howell, 1997; Banik, 1999).

The results show that there are 12 important tools/techniques that supports the implementation of lean construction in the KSA construction industry. Of the 12 tools/techniques, CAD has the highest mean value, and therefore it is the most important tool/technique. This agrees with previous studies in the manufacturing sector. KarimiAzari et al. (2011), revealed that CAD is moderately used to support lean processes in the manufacturing sector. In addition, the high importance of CAD may be due to the use of the tool for design purpose. In the construction industry in the KSA, CAD is a common design tool used by many construction professionals, especially designers and engineers. Thus, it is very easy for these professionals to adapt the tool for lean construction purposes.

Both large and small-to-medium construction companies in Saudi Arabia implement lean construction methods mostly during the construction stage. Salem et al. (2005) have explained lean construction in detail for different stages of construction projects in the US. Similarly, it is found that lean construction methods are mainly implemented during the construction stage as this stage is associated with maximum activities with respect to time, materials, and cost.

## Conclusion

In Saudi Arabia, construction projects are facing significant delays and wastage of resources. Even though lean construction is regarded as a powerful tool to enhance productivity by reducing wastage, lean construction techniques are not implemented as widely in Saudi Arabia when compared to the rest of the world. A broad questionnaire survey of 282 construction industry professionals was conducted to identify major types of waste, benefits of lean construction, implementation levels of lean tools, and stages where lean methods are implemented in the KSA construction industry.

The most common types of waste in the KSA construction industry in ascending order are waiting, making do, corrections, transportation, motion, over processing, inventory and over production. For both “small and medium” and “large” companies, waiting and making do are the most common types of waste, furthermore, over processing and over production are experienced to a similar degree by both types of companies. In contrast, wastage resulting from ‘transportation’ is highly different between the two types of companies, whereas, ‘inventory’ is the least different type of waste.

The tools that support the implementation of lean construction in the ascending order of popularity are: computer aided design, preventive maintenance, safety improvement programs, visual inspections, continuous improvement programs, daily huddle meetings, total quality management, use of prefabricated materials, target value design, concurrent engineering, just-in-time approach, plan of conditions and work environment in the construction industry, computerised planning system or ERP, information management system, 5S, six sigma and Kanban. In addition, of all the tools, the use of safety improvement programs was found to be different between large and small-to-medium companies in the KSA construction industry.

Furthermore, the benefits of lean construction in the KSA construction industry in ascending order are customer satisfaction, quality improvement, increased productivity, reduced construction time, process improvement, better health and safety record, improved supplier relationships, better inventor control/reduced inventory, increased market share and employee satisfaction. In addition, both customer satisfaction and quality improvement are significantly different between large and small-to-medium companies.

In summary, the following are the main conclusions in this study:

1. Waiting is the most common type of waste in the KSA construction industry.
2. CAD is the most important tool for supporting the implementation of lean construction.
3. Lean construction is highly used in all stages of construction, with opportunities for improvement at the commissioning/handover stage.
4. To achieve customer satisfaction is the major benefit of lean construction in the KSA construction industry.

This study will be helpful for enhancing efficiency, production, and quality of construction projects by providing an understanding of the level of implementation of lean construction in the KSA construction industry. The study provides information about the most common type of waste, and the tools which can be useful for lean construction in all construction project stages in the KSA. Despite the value in the findings, there are opportunities for further research. More research on how lean construction tools/techniques can be applied to eliminate the different types of waste in the construction industry in the KSA should be carried out in future. Additionally, barriers and critical success factors for lean implementation in the construction industry in the KSA should be investigated.

There are limitations to this research. Notably, the findings in this study were mainly based on the results of a broad questionnaire survey. As the survey was conducted for a specific period with professionals working in the KSA construction firms, results may not represent the whole Saudi Arabian construction industry. There is an earnest need to do case study based research which will create guidelines to implement in the KSA construction industry. To obtain more representative results, other methods like interviews, meetings, polls, seminars, and observations should also be conducted.

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