Roles of lean tools in minimizing waste in the building construction process

Accepted 29th February 2023

ABSTRACT

The scrutiny of construction project performance has exposed the challenges plaguing the construction industry, including frequent deadline delays, ineffective management, low competitiveness, low productivity rates, cost overruns, and low customer satisfaction. Due to its potential to eliminate waste, increase value, lower cost overruns, and boost overall customer satisfaction, lean construction has been recognized as an industry-wide effective alternative to improve project delivery. Existing research on lean construction has focused on statistical outcomes of lean adoption but has neglected the perception of construction professionals. The study obtained data from varying sources, adopting qualitative methods to identify and analyze the lean tools adopted in construction projects and their perceived impacts on minimizing construction waste. The theoretical framework was created using data from existing literature on the common challenges in construction, and lean construction. The results of the study indicated that the conceptual, design, and construction stages were affected by design approval delays, incomplete design documents, redesign requests, material delivery delays, incomplete design documents, delays between processes, and poor workmanship, among others. The results also showed that tools such as computer aided-visualization, cross-functional process charts, Building Information Modelling, pre-fabrication, and Root Cause Analysis had been increasingly adopted to improve design sustainability and tackle construction waste. They showed that construction professionals rated the performance of lean tools on cost at 68% and the performance of lean tools on schedule at 74%. Lean tools were also perceived to be effective in reducing waste due to waiting, defects, transportation inventory, processing, and overproduction during construction processes.

Key words: Construction processes, waste, productivity, lean tools, lean construction.

INTRODUCTION

The increasing contribution of the construction industry in framing the economic, political, and physical environment of cities across the world has attracted an increased level of attention to the performance of its products. With an estimated $10trillion generated in total annual revenues within the industry, its contributions to economic growth cannot be overstated and its performance should be placed at a high priority (The World Economic Forum, 2016). Several strategies that have been proposed to monitor the industry's performance have however exposed multiple challenges plaguing the industry including deadline delays, resource wastage, poor management, cost overruns, and low customer satisfaction among others. These challenges have compelled the industry to reconsider its practices, resulting in an increased search for strategies that improve productivity within the industry and the sustainability of its offerings (De Calvaho et al., 2017). The efforts have resulted in the recognition of lean methodology from the...
manufacturing industry, and the adoption of its principles in construction projects.

To investigate the adoption of lean tools in the construction industry and the impacts on construction projects, it is important to understand some of the stages involved in these projects. In this regard, Atunes and Gonzalez (2015) described key stages involved in construction, beginning with the concept development stage, which involves the identification and analysis of potential solutions to the customers’ requirements with their preliminary estimates. They described the design stage as one where detailed plans, building elevations, and design specifications are developed to describe how the building project will be executed. They described the construction stage as one where the building project will be executed, and the building product will be erected to match the details specified in the design plans. They described the finishing stage as one where the building product will be ornamented, completed, and delivered to the customer or project sponsor.

Understanding the construction challenges that plague the construction industry is also key to identifying the impact of lean tools on the industry. Ansah et al. (2016) identified transportation waste as an area of waste that results from the inefficient handling of material delivery to construction sites. They also identified waste due to waiting, in form of idleness between processes as another area of construction waste that results from poor stakeholder communication and slow execution of work by project resources. They further identified defects in the form of deliverables that don't satisfy design requirements, as an area of construction waste, which results from incomplete requirement definition, scope changes, or procurement of substandard materials. In addition to these, they also identified other areas of construction waste that constitute construction challenges, including motion, processing, inventory, and overproduction waste.

Lean principles have been integrated with traditional management of construction projects to eliminate or mitigate some of the challenges plaguing the industry. Karningsih et al. (2017) identified root cause analysis as one of the adopted lean tools, describing it as an organized evaluation of project issues or risks to identify their root causes, possible triggers, and mitigation strategies. Bajjou et al. (2017) identified visual management as another adopted lean tool in construction, describing it as a tool that is deployed to create simple, transparent, and secure construction processes and environments by erecting digital billboards, security signages add graphical dashboards, among other visual tools. Further, value stream mapping has been observed by Karningsih et al. (2017) as another lean tool adopted in construction. They described it as a graphical tool that is deployed to analyze systems and process flows to identify information and material movement across the value stream in construction processes. Bajjou et al. (2017) described prefabrication as another lean tool adopted in construction and described it as a process that involved the manufacturing and assembly of building components in off-site locations before they are deployed to construction sites for installation. In a study conducted by Erol et al. (2015), last planner system is described as another lean tool adopted in construction, describing it as a tool that pulls work packages at pre-established intervals to ensure that workflow remains uninterrupted throughout the construction process.

Lean tools have become increasingly adopted in construction, as construction organizations have deemed these tools beneficial in optimizing the delivery of their construction projects and in improving the sustainability of their building products. According to De Carvalho et al. (2017), the adoption of lean tools such as value stream mapping and root cause analysis has proved useful in the improvement of construction project workflow and reducing their delivery times. Existing literature on lean adoption in construction shows that current research has been focused on the adopted lean tools and their statistical outcomes on construction projects. Existing literature lacks comprehensive research on how lean tool adoption is perceived by professionals within the construction industry.

This study systematically identified and analyzed the perceived impacts of adopted lean tools in minimizing waste in construction projects, with the aim of understanding how lean adoption is perceived by professionals within the construction industry. Specifically, this research aimed at (i) Identifying the different stages involved in the construction process; (ii) describing some key challenges encountered within the construction industry; (iii) investigating the lean tools currently adopted in construction projects; and (iv) investigating the perceived impacts of lean tools in minimizing construction waste.

Following this introduction, the research is divided into four parts. The next section discussed the research methodology and solution approach of the research, outlining the research settings, population sample, as well as data collection and analysis approaches. The third section presented the results from the survey and interviews conducted, while the fourth section provided conclusions to the research, with a focus on key findings, relationships between key findings and literature review, as well as recommendations for future research.

**MATERIALS AND METHODS**

The research methodology of this research was based on assessing the impacts of lean tools in minimizing construction waste, as perceived by professionals within the construction industry. As a result, the research adopted a qualitative approach to gather data using literature review, surveys, and semi-structured interviews. The study...
collected secondary data from existing literature on construction waste, lean construction, and sustainability, while the primary data was collected through semi-structured interviews, as well as open-ended and closed-ended surveys. The primary data were analyzed thematically using the survey monkey software, to identify recurring themes from the surveys and interviews. The thematic analysis was adopted to investigate lean adoption patterns as perceived by professionals within the construction industry. The research methodology was composed of five core steps. The following is a brief description of these steps:

1. Identifying construction professionals and the stages involved in building projects.
2. Identifying key metrics adopted by construction professionals in measuring the performance of building projects.
3. Investigating recurring construction challenges and areas of waste identified by construction professionals in building projects.
4. Analyzing the key lean tools adopted by construction professionals in tackling challenges in building projects.
5. Investigating and analyzing the perception of construction professionals on the performance of lean tools in minimizing waste in building projects.

Step 1

The first step involved identifying the different professionals that were involved in key construction projects. As the research aimed at understanding the perceived impact of lean tools on construction performance, this step was targeted at identifying the categories of construction participants before understanding their perceptions. This step also involved identifying the key stages of construction projects as identified by construction professionals. The review of existing literature identified five stages including concept development, design, construction, finishing, and maintenance. This step involved understanding the stages of building projects that construction professionals were largely involved in.

Step 2

The second step then described the metrics used by the identified construction professionals in evaluating the performance of their building projects. The identified metrics would be later used in understanding how these construction professionals rate the performance of their adopted lean tools. The review of existing literature identified performance metrics including cost, schedule, quality, human resources, and material resources. This step identified the resources that were mostly monitored by the identified professionals during building construction.

Step 3

The third step investigates the areas of waste identified by the construction professionals during the stages of building projects. The literature review discussed seven key areas of waste identified in lean methods including waiting, motion, defects, transportation, overproduction, over processing, and inventory. In this step, the study analyzed the most recurring forms of waste or inefficiencies that were experienced by construction professionals in building projects.

Step 4

The fourth step considered the previous three steps and uses the information gathered to investigate the lean tools that have been adopted by construction professionals in tackling construction waste. The review of existing literature identified common lean tools adopted in construction including visual management, root cause analysis, value stream mapping, building information modeling, last planner system, and prefabrication among others. This step investigated the lean tools mostly adopted by construction professionals in waste in building projects.

Step 5

The last step of the research methodology examined the perceived impacts of lean tools on improving construction performance. This step investigated the perception of construction professionals on the performance of lean tools in building projects. It investigated how lean tools were deemed to perform in line with key performance metrics that were monitored by construction professionals. It also analyzed the performance of lean tools in line with minimizing identified areas of construction waste. This step considered the previous steps and was targeted at providing the answer to the central question of the research (Figure 1).

RESULTS AND FINDINGS

As detailed in the methodology section of the present study, the steps taken to conduct the research were key to answering the main research question of understanding the perceived impacts of lean tools on minimizing construction waste. To answer this question, surveys were sent to a sample population of 31 construction professionals, including project managers, architects, vendors, engineers, contractors, sub-contractors, drafters, and quantity surveyors. The sample population included construction professionals who had been involved in multiple construction project types, including design-only, design and build, maintenance, products, and supply-based projects, among others. The following shows the findings
and results obtained from these professionals in answering the research question.

**Stages of construction projects**

As part of the survey questions, the professionals identified key areas of construction projects, in which they had been involved. Table 1 shows the distribution of construction project stages as identified by construction professionals. According to the results, the most identified stage of building projects was the design stage, as 27 (87%) of the total respondents had identified involvement in this stage during building projects. These 27 professionals included 24 who had worked as architects, 13 who had worked as architects, and three who had worked as contractors and
subcontractors. The next most identified construction stage was the concept development stage, as 24 (77%) of the total respondents had identified involvement in this stage. These 24 professionals included 21 who had worked as architects, 11 who had worked as project managers, and six who had worked as drafters.

The next identified construction stage was the construction stage, as 22 (71%) of the total respondents had identified involvement in this stage. The 22 professionals that identified this construction stage included 20 who had worked as architects, 13 who had worked as project managers, five who had worked as drafters, and three who had worked as contractors. Furthermore, 19 (61%) of the total respondents identified involvement in the finishing stage of building projects. The 19 professionals included 16 who had worked as architects, 11 who had worked as project managers, four who had worked as drafters, and three who had worked as contractors. The final stage identified was the post-construction maintenance stage, which was identified by 10 (32%) of the total respondents.

**Metrics of project performance evaluation**

Another survey question focused on identifying the metrics used by the identified construction professionals in evaluating the performance of their building projects. According to the results, project quality was the most identified metric by professionals, as 26 (84%) of the total respondents identified this metric for evaluating project performance. The 26 professionals included 21 who had been involved in the concept stage, 20 who had been involved in the design stage, 17 who had been involved in the construction stage, and 16 who had been involved in the finishing stage. The next most identified metric was project cost, as 22 (71%) of the total respondents identified this metric for evaluating project performance. The 22 professionals included 19 who had been involved in the concept stage, 20 who had been involved in the design stage, 15 who had been involved in the construction stage, and 11 who had been involved in the finishing stage.

The results showed that project schedule was the next most identified metric, as 14 (45%) of the total respondents identified this metric for evaluating project performance. The results indicated that the 14 professionals included 10 who had been involved in the concept stage, 12 who had been involved in the design, construction, and finishing stages, as well as four professionals who had been involved in the maintenance stage. The final metric identified was project resources, in which four (13%) of the total respondents identified the metric for evaluating project performance.

**Areas of construction waste**

The results showed key areas of construction waste, as identified by the construction professionals during building projects. According to the results, the most identified area of waste was waiting, as 23 (77%) of the total respondents identified this as a recurring area of waste in their building projects. The 23 professionals included 16 who had been involved in the concept stage, 20 who had been involved in the design stage, 17 who had been involved in the construction stage, 13 who had been involved in the finishing stage, and 6 who had been involved in the maintenance stage. The results also indicated that 16 (53%) of the total respondents identified defects as a recurring area of waste in their building projects. The 16 professionals included 14 who had been involved in the concept and design stages, 13 who had been involved in the construction stage, as well as 10 who had been involved in the finishing stage. (Figure 2).
The next area of waste identified was transportation, which 11 (37%) of the total respondents identified as a recurring area of waste during building projects. These 11 professionals included 10 who had been involved in the concept stage, nine who had been involved in the design stage, six who had been involved in the construction stage, and eight who had been involved in the finishing stage. The next identified areas of waste were motion waste and inventory waste which were identified by eight (27%) of the respondents as recurring areas of waste in building projects. The last areas of waste identified were overproduction and processing waste, which were identified by four (13%) and two (7%) of the total respondents respectively, as recurring areas of waste in building projects.

**Adopted lean tools**

To understand the perceived impact of lean tools, the research sought to identify the lean tools adopted in tackling construction waste. As shown in Table 2. The results indicated that visual management tools were the most adopted lean tools by the professionals, as 20 (65%) of the total respondents identified them as adopted tools for minimizing waste. 17 professionals had adopted visual management tools for tackling waiting waste, 10 professionals had adopted them for handling defects, nine had adopted them for tackling transportation waste, six professionals had adopted them for tackling motion waste, and five had adopted visual management tools for tackling inventory waste. The results showed that prefabrication was identified by 12 (39%) of the total respondents in tackling construction waste. 10 professionals had adopted prefabrication for handling waiting waste, eight professionals had adopted it for tackling defects, five professionals had adopted them for tackling transportation waste and three professionals had adopted prefabrication in tackling motion and inventory waste.

The results show that 16 (52%) of the total respondents had adopted Building Information Modelling (BIM) tools for dealing with construction waste. 11 of the professionals had adopted these tools for tackling waiting waste, six had adopted them for tackling defects, five had adopted them for tackling motion, transportation, and inventory waste, while four had adopted BIM tools for tackling overproduction waste. The results showed that nine (29%) of the total respondents identified root cause analysis as a lean tool for handling waste in building projects. Six of the professionals had adopted root cause analysis for tackling waiting waste, five had adopted it for dealing with defects, four had adopted it for tackling transportation waste, and three professionals had adopted root cause analysis for tackling motion waste. Finally, the results show that three (10%) of the total respondents had adopted value stream mapping for tackling construction waste.

**Perceived performance of lean tools**

In line with the main research aim, this research sought to identify the perception of construction professionals on the performance of lean tools. The professionals assessed the performance of lean tools on construction project budgets and timelines (Table 3). According to the results, prefabrication was rated to be the best performing tool for...
improving project timelines, with an average score of 81%. BIM tools earned an average score of 76%, visual management earned 72%, root cause analysis earned 67%, and value stream map earned an average score of 59%. The results further showed that prefabrication was also rated to be the best performing lean tool with regards to project cost, getting an average score of 72%. BIM tools earned an average score of 69%, visual management earned 67%, value stream map earned 66%, and root cause analysis earned 65%.

In terms of lean performance in reducing construction waste, the results show the perception of construction professionals. The results showed that 81% of participants deemed lean tools to be either effective or very effective in reducing inventory waste, while 74% of the professionals deemed them to be effective or very effective in reducing motion waste. The results further showed that lean tools 68% of the professionals deemed lean tools as effective in reducing transportation waste, while 64% of professionals deemed lean tools as effective in reducing waste due to delays. Furthermore, 62% of professionals viewed lean tools as effective in minimizing defects, 60% of professionals deemed lean tools as effective in reducing processing waste while 58% of professionals deemed lean tools as effective in mitigating waste due to overproduction.

DISCUSSION

In this study, a methodology was developed to understand the impacts of lean tools in minimizing waste in construction as perceived by construction professionals. One of the steps in the research was to identify key areas of waste during construction processes. From the findings, it was deduced that design approval delays, redesign requests, incomplete material specifications, technical debt, inaccurate design documents, and inventory issues, were some of the recurring wastes that largely affected the conceptual design and construction stages of building projects. It was also deduced that waste such as transportation, processing, and overproduction were identified, but were not frequently occurring in building projects.

The next step was to identify lean tools that are being adopted in the industry. From the results, it was deduced that tools like signages and dashboards, as well as prefabrication and BIM tools, were being increasingly adopted within the industry to improve project resource utilization and design sustainability. To answer the main research question, the research aimed at investigating the perceived impacts of lean tools on project cost and schedule. From the results, it was deemed that lean tools were perceived to perform above average in improving project costs and timelines. From the results, it was also deduced that overall, construction professionals deemed lean tool adoption to be effective in reducing processing, defects, transportation, inventory, waiting, and overproduction waste during building construction.

As in any study, the present study is not exempt from limitations. One of such limitations was the limited number of the accessible population, such that the survey only featured 31 participants, compared to the large population of construction professionals. In addition, this study focused on the impact of lean tools on projects metrics such as cost and schedule but did not discuss the impact of lean tools on other project metrics such as project quality and resources. Further research will thus be needed to include a broader population to get greater insight into the perceived impact of lean tools on building projects. Further research will also be needed to identify the perceived impact of lean tools on other project metrics, such as project quality and resources.

ACKNOWLEDGEMENT

The author would like to acknowledge Harrisburg University of Science and Technology for providing the opportunity to conduct this research and the necessary guidance to review existing literature.

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Cite this article as:

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