

APPLICATION OF LEAN PRINCIPLES IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

I. Maradzano^{1#}, R.A. Dondofema¹ & S. Matope^{1*}

ARTICLE INFO

Article details

Presented at the 30th annual conference of the Southern African Institute for Industrial Engineering (SAIIE), held from 30 September - 2 October 2019 in Port Elizabeth, South Africa

Available online 15 Nov 2019

Contact details

* Corresponding author
smatope@sun.ac.za

Author affiliations

¹ Department of Industrial Engineering, University of Stellenbosch, South Africa

The author was enrolled for an M Eng. (Research) Industrial Engineering degree in the Department of Industrial Engineering, Stellenbosch University, South Africa

DOI

<http://dx.doi.org/10.7166/30-3-2240>

ABSTRACT

South Africa is a developing country that invests billions of rands annually in the construction industry. This industry consumes resources and, inevitably, waste is generated during the process. Although numerous approaches have been developed to improve quality, efficiency, and effectiveness in this industry, lean principles offer the ability to minimise and/or eliminate non-value adding work, thus increasing value for the client. This paper highlights the lean construction tools currently used worldwide, and the benefits of adopting lean construction. The study surveyed publications on the application of lean principles in the construction industry, and identified tools yet to be implemented in the South African construction industry with specific reference to electrical and mechanical engineering services. The study used a systematic review methodology to identify different lean construction concepts, and developed a lean implementation framework. The framework was then evaluated using a local case focusing on electrical and mechanical engineering services in the construction industry. The improved framework after evaluation consists of eight steps.

OPSOMMING

Suid-Afrika is 'n ontwikkelende land wat miljarde rande jaarliks in die konstruksiebedryf belê. Hierdie industrie verbruik hulpbronne en genereer afval tydens die proses. Alhoewel vele benaderings reeds ontwikkel is om die gehalte, effektiwiteit en doeltreffendheid in hierdie industrie te verbeter, bied lenige beginsels die vermoë om take wat nie waarde toevoeg nie te minimeer en/of te elimineer. Hierdie artikel beklemtoon die lenige konstruksietegniese wat wêreldwyd gebruik word saam met die voortspruitende voordele. Publikasies rakende die toepassing van lenige beginsels in die konstruksiebedryf is nagevors en tegniese (gespits op elektriese en meganiese ingenieursdienste) wat nog nie in die Suid-Afrikaanse bedryf toegepas is nie, is identifiseer. Hierdie studie het 'n sistematiese hersieningsmetodologie gebruik om die verskillende lenige konsepte te identifiseer en het daarmee saam 'n lenige implementeringsraamwerk ontwikkel. Hierdie raamwerk is evalueer aan die hand van 'n plaaslike gevallestudie. Die verbeterde raamwerk bestaan uit agt stappe.

1 INTRODUCTION

Lean manufacturing methodology helps to identify and eliminate or reduce waste in any production process. Waste can be defined as any non-value adding activity in any production process [26] [44]. These non-value adding activities do not improve value; they only increase cost and overall production time [40]. However, non-value adding activities should be distinguished from essential non-value adding activities and non-essential value adding activities [51]. By planning adequately, with proper supervision and correct decision-making based on accurate information and procedures, lean manufacturing principles, if implemented in the South African construction industry, have the

potential to eliminate waste, which takes place through the removal of non-essential value adding activities; this leads to cost reduction and performance improvement [7]. Eventually this will improve the overall construction time and deliver quality projects timeously [61].

The construction industry has been lagging (compared with the manufacturing industry) in implementing and improving lean principles and methodologies [6]. This criticism has stimulated research on the application of lean manufacturing principles in the construction sector – hence the coining of the term ‘lean construction’ [52]. Lean construction’s roots can be dated back to the late 1990s [48]. Koskela and Howell [48] proposed analyzing construction activities using production engineering analytical tools. Efforts were made to improve productivity and increase competitiveness in the construction industry. Currently, construction industry participants are exploring new techniques, practices, and processes to make the industry less wasteful [12]. Lean principles, when applied in the construction industry (which will be referred to as ‘lean construction’ in this paper), offer innovative ways to manage construction projects while reducing waste and improving quality, efficiency, and performance.

The South African construction industry contributes to a large extent to the economy of the country, particularly in setting up physical infrastructure [63]. On the other hand, while most of the activities of this industry have negative effects on the environment, these can be improved through changes in the management of waste [28]. The lean construction philosophy originated from the lean manufacturing concept – mainly from the Toyota production system [74] [70] [18]. The successful implementation of lean principles in the manufacturing industry, and the benefits resulting from their adoption, is one of the key reasons for the adoption of lean thinking in construction [33]. The term ‘lean construction’ was introduced by the International Group for Lean Construction at the first conference on lean construction in Finland in 1993 [8]. According to Koskela, Huovila and Leinonen [49], lean construction is “*a way to design production systems to minimize waste of materials, time and effort to generate the maximum possible amount of value*”. Implementation of lean construction principles is paramount in decreasing waste and enhancing the South African construction industry’s overall performance.

1.1 Review of lean techniques

Many projects in South Africa experience time delays and cost overruns and generate substantial amounts of waste. Lean construction has been introduced to address these challenges in the South African construction industry; however, it is still in its infancy. The construction industry is also characterised by poor quality work, poor safety, and negative effects on the environment [18]. From the available literature on lean construction implementation, the appropriateness of lean construction practices in the construction industry remains a subject of substantial discussion [62] [71] [69]. Table 1 summarises nineteen lean tools that are currently being implemented worldwide in lean construction, as identified in the literature. From these nineteen lean tools, only four have been found in the literature as being used in the South African construction industry. Higher level techniques such as Kanban and ‘just in time’ (JIT) are yet to be fully applied.

From the analysis in Table 1, the authors observed that the lean tools used in the construction industry are the Kanban system, value stream mapping, first run studies (plan-do-check-act), total quality management, poka-yoke, failure mode and effect analysis, 5 whys, JIT, increased visualisation, standardisation, last planner system, waste elimination, and continuous improvement. According to Salem, Solomon, Genaidy & Minkarah [69], three characteristics differentiate the construction industry from the manufacturing industry: 1) unique projects, 2) complexity, and 3) on-site production. These key differences make it difficult simply to transfer the lean tools in Table 1 from the manufacturing industry to the construction industry.

Table 1: Lean tools currently used worldwide to support lean construction implementation

Lean tool	Definition	Is the lean tool being applied in the South African industry?
JIT	The JIT method is a supply management tool driven by the customer's demand. Its aim is to maintain a construction material flow that matches the internal/external customer requirements to optimise inventory and work-in-progress [18] [23] [64].	In the collected literature, the authors did not find any evidence of the application of this tool.
The 5s process	This is a systematic housekeeping process that is performed in its five distinctive steps: sorting, straightening, shining, standardising, and sustaining the facilities and processes used in construction. The 5s process increases the productivity of the project, as it reduces the time spent searching for supplies, tools, equipment, etc. [11] [27] [72].	In the collected literature, the authors did not find any evidence of the application of this tool.
5 whys	This is a problem-solving technique used to identify the root causes of a targeted problem. It is a question-asking technique that illuminates cause-and-effect mechanisms associated with a problem [19] [16] [34] [70].	Yes, this tool is currently used in the South African construction industry. [80]
Standardisation	Standardisation can be described as a set of methods, components, or processes in which there is repetition and regularity leading to successful practices – also called 'standard operating procedures' (SOP). This technique allows building in the shortest possible time and with the minimum of effort [38] [64] [45].	In the collected literature, the authors did not find any evidence of the application of this tool.
Prefabrication	This consists of using modularised and prefabricated construction components, and aims to overcome the common production problems encountered during on-site construction (i.e., low output quality, low productivity, high variability, and poor safety) [65] [19] [58].	In the collected literature, the authors did not find any evidence of the application of this tool.
The last planner system (LPS)	This achieves the 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 is a method that forms workflow and deals with project variability [50] [73] [22] [68].	In the collected literature, the authors did not find any evidence of the application of this tool.
Value stream mapping (VSM)	An information and material flow mapping tool that is used to graphically visualise the current value stream and design the future state of the construction process while reducing all sources of waste (overproduction, waiting, inventory, displacements, etc.) [14] [20] [75].	In the collected literature, the authors did not find any evidence of the application of this tool.
Continuous improvement (kaizen)	This technique supports the idea that every process can, and should, be continually measured, analysed, and improved in terms of resources used, time required, quality demanded by customers, and other performance criteria relevant to the construction [70] [27].	Yes, this tool is currently used in the South African construction industry. [7] [77]
Total productive maintenance (TPM)	This tool is an integrated approach to maintenance that focuses on proactive and preventative maintenance to maximise 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 [9] [23].	In the collected literature, the authors did not find any evidence of the application of this tool.
Total quality management (TQM)	Most of the substantial tools used to address construction performance issues are based on the concept of plan-do-act. Functions involve the identification and evaluation of the problem, developing and implementing solutions, and evaluating and measuring the results [46] [55].	In the collected literature, the authors did not find any evidence of the application of this tool.
Pareto analysis	The Pareto chart is a graph highlighting the most important causes that have an effect on the analysed system; it thus	In the collected literature, the authors did not find

Lean tool	Definition	Is the lean tool being applied in the South African industry?
	allows the development of innovative actions to improve the current situation [15] [53].	any evidence of the application of this tool.
Ishikawa diagram	This effective quality tool is used to identify the causes of an inherent problem. The Ishikawa diagram is considered a powerful tool for the root cause analysis (RCA) approach [31] [18] [60].	In the collected literature, the authors did not find any evidence of the application of this tool.
Waste elimination	This technique is the core of the lean construction concept. It aims at spreading a culture among employees to eliminate the various sources of waste (overproduction, quality defects, unnecessary transportation, over-processing, waiting, inventory, displacements, and unused employee creativity) [43] [47] [76].	Yes, this tool is currently used in the South African construction industry. [78] [81]
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 [4] [16] [60] [68].	In the collected literature, the authors did not find any evidence of the application of this tool.
Plan of conditions and work environment in the construction industry	This is a lean construction tool that assures occupational safety and health management. It manages safety requirements through the risk management cycle, consisting of continuous identification of risk, evaluation, and control [16] [60].	In the collected literature, the authors did not find any evidence of the application of this tool.
Pull 'kanban' system	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. Japanese word 'kanban' means 'card' or 'sign', and is the name given to the inventory control card used in a pull system [13] [37] [24].	In the collected literature, the authors did not find any evidence of the application of this tool.
Error proofing (poka-yoke)	Poka-yoke, a Japanese word, is a mechatronic device that works as error proofing, avoiding mistakes and preventing defects from flowing through the process. It increases the quality of the construction process and improves conditions of safety for the workers [2] [11] [20] [30].	In the collected literature, the authors did not find any evidence of the application of this tool.
Target value design (TVD)	This approach applies methods for the design to be developed in accordance with the constraints, especially cost (i.e., 'design-to-cost' or 'design-to-targets'). TVD considers the customer's vision to define restrictions and deliver the required target values [56].	In the collected literature, the authors did not find any evidence of the application of this tool.
Failure mode, effects and criticality analysis (FMECA)	Risk analysis is an essential step in construction project management. It is a method of qualitative analysis of reliability, which makes it possible to assess the risks of the appearance of failures, to evaluate their consequences, and to identify their root causes [11] [37].	Yes, this tool is currently used in the South African construction industry. [77] [78]

1.2 Benefits of lean construction

Lean construction has made significant improvements in terms of the timely completion of construction projects [5]. These improvements are facilitated by the way the construction site is managed and controlled, and are shown in Table 2 [1] [3] [7] [14] [29] [36] [41] [42] [45] [50] [52] [57] [58] [59] [69] [80] [81]. Applications of lean principles in construction have resulted in efficiency improvement of overall equipment effectiveness (OEE), as seen from Table 2. The main benefits of lean construction are reduction of waste, customer satisfaction, and overall project cost reduction. Lean construction helps construction companies to identify and analyse waste to improve productivity, reduce project duration, improve safety, improve quality, ensure customer satisfaction, and improve reliability.

Table 2: Lean construction benefits

Benefits	Project type	Has the South African industry benefitted from this benefit?
Reducing total project duration	Industrial projects Residential building projects Housing estate projects/units	According to Akinradewo, Oke, Aigbavboa & Ndalamba [7], the South African construction industry benefits from this.
Quick turnover and low cost of construction projects	Construction & civil engineering infrastructure projects	In the collected literature, the authors did not find any evidence of this benefit.
Improving quality of work	Infrastructure projects Commercial buildings	In the collected literature, the authors did not find any evidence of this benefit.
Improving environmental performance	Housing estate projects Residential, institutional, and commercial	In the collected literature, the authors did not find any evidence of this benefit.
Improving the safety of workers	Residential, institutional, and commercial	According to Akinradewo <i>et al.</i> [7] and Emuze & Ungerer [80], the South African construction industry benefits from this.
Improved project delivery methods	Construction & civil engineering	In the collected literature, the authors did not find any evidence of this benefit.
Managing uncertainties in supply	Hospital construction Housing estate projects	In the collected literature, the authors did not find any evidence of this benefit.
Supporting the development of team work, and transferring the responsibility in the supply chain	Renovation projects	In the collected literature, the authors did not find any evidence of this benefit.
Continuous improvement in projects	Residential building projects	According to Monyane, Awuzie & Emuze [81], lean construction implementation enhances continuous improvement within projects.
Minimisation of conflicts that can dramatically change budget and schedule	Infrastructure projects	In the collected literature, the authors did not find any evidence of this benefit.
Delivery of custom products instantly without waste	Residential, institutional and commercial	In the collected literature, the authors did not find any evidence of this benefit.
Delivery of products and services on time and within budget	Residential, institutional and commercial	In the collected literature, the authors did not find any evidence of this benefit.
Reduction of direct cost and time in transportation and communication	Residential building projects	In the collected literature, the authors did not find any evidence of this benefit.
Reduced waste	Road construction projects	According to Akinradewo <i>et al.</i> [7] and Monyane <i>et al.</i> [81], lean construction implementation in South Africa reduces waste and increases productivity.
Improved overall equipment effectiveness (OEE)	Residential, institutional, and commercial	In the collected literature, the authors did not find any evidence of this benefit.
Improved quality control and minimisation of risks	Infrastructure projects	In the collected literature, the authors did not find any evidence of this benefit.
Improved employee satisfaction and supplier relationships	Residential building projects	Yes, lean construction enhances motivation [80].

1.3 Gap analysis

From the brief analysis of the literature on lean construction, it has been observed that there are limited frameworks for the implementation of lean construction for different construction projects in the South African construction industry. The authors observed that there is limited application of lean construction in the electrical and mechanical services (wet, fire, and heating, ventilation and air conditioning (HVAC) projects), which are also key components of the construction industry. Hence the aim of this study is to develop a lean construction implementation framework that can be used to implement lean principles in mechanical and electrical services projects.

2 METHODOLOGY

The research design employed for this study was a systematic literature review of published literature. A systematic literature review is an important scientific research approach that can be used to appraise, summarise, and communicate the findings and implications of a large number of research publications on a particular subject [39]. Second, evidence in the literature shows that previous authors [32] [35] [54] [67] have adopted a similar approach with their respective studies. A systematic literature review is used to gather and study a huge number of research studies and publications relating to a specific subject to answer predefined questions, by incorporating the practical evidence from all relevant studies [25].

A systematic literature review is a part of research in its own right and, by its nature, is able to address much wider questions than single empirical studies ever can. Without doubt, a systematic review is at the top of the ‘hierarchy of evidence’ compared with other research designs, because it has the potential to deliver the most important practical implications [25]. Thus the systematic literature review focused on reviewing available studies in the construction industry through different search engines. The study was conducted in six steps, as shown in Table 3.

Table 3: Research methodology steps

Steps	Reason for that step	Where it is presented
1. Developing search terms	To develop appropriate terms that will assist to identify relevant literature for the study.	Section 3.1
2. Identifying data sources	To identify the appropriate search engines; this study used Web of Science, Google Scholar, and Science Direct.	Section 3.1
3. Selecting relevant publications	The papers were screened to see whether they were relevant to the objective of the study.	Section 3.2
4. Analysing the studies	This step was important, as it helped to understand the lean construction concepts in the literature.	Section 4.1 & Section 4.2
5. Developing a framework	To develop a framework in the context of the South African mechanical and electrical services industries.	Section 5
6. Evaluating the framework	To evaluate the framework in the context of the South African mechanical and electrical services industries.	Section 6

3 CONDUCTING THE REVIEW

3.1 Data sources and data collection

To identify studies on lean construction, the authors used ‘lean in construction industry’ and ‘lean construction’ as search terms as shown in Table 4. The search fields used were article title, abstract, and keywords. The search engines used were Web of Science, Google Scholar, and Science Direct. The initial search yield is displayed in Table 4.

Table 4: Initial Search Results

Search terms	Search field	Web of Science	Google Scholar	Science Direct
Lean in construction industry and lean construction	Article title, abstract, and keywords	312	134	90

3.2 Selection criteria

Out of 536 publications found on the primary search, an extensive review was done to establish whether each publication was fit for the systematic literature review. The first screening criterion was to check whether or not the publication was related to the topic of lean construction implementation. The second vetting process was to check whether or not the publication was relevant to the scope of the study. A total of 343 publications were found to be unrelated to the topic of study. Of the 193 publications that were related to the topic, only 33 papers were relevant to the current study. Of the 33 papers found, only nine papers focused on lean construction in the South African construction industry. Figure 1 shows the document selection.

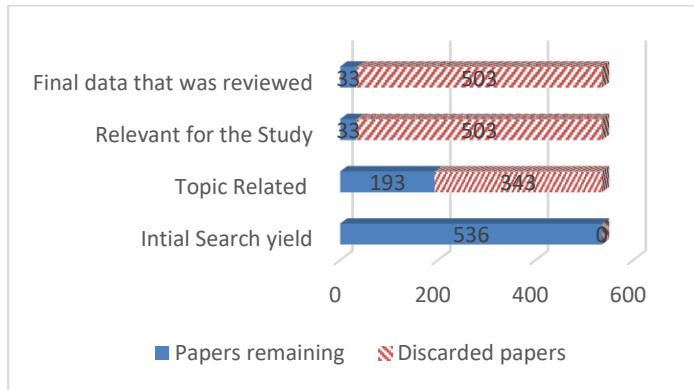


Figure 1: Document selection (see online version for colour)

4 OUTCOMES OF THE SYSTEMATIC REVIEW

This section is divided into two sub-sections: descriptive statistics and conceptual aspects.

4.1 Descriptive statistics

From the systematic literature review, it was found that documents that related to lean construction were in the form of journal articles, conference papers, industry research reports, and book chapters. The review focused on lean implementation in the construction industry, the authors selected material with a rich content of empirical data on lean construction implementation. A total of 33 publications were relevant to the current study of lean construction implementation. These were published from 2012 to 2019. Of these publications, 58 per cent were journal articles, 39 per cent conference papers, and three per cent book chapters, as shown in Figure 2. From these papers, the next step was to read the whole paper to understand the study objective, the research approach used, key concepts, and the lean tools used in each paper.

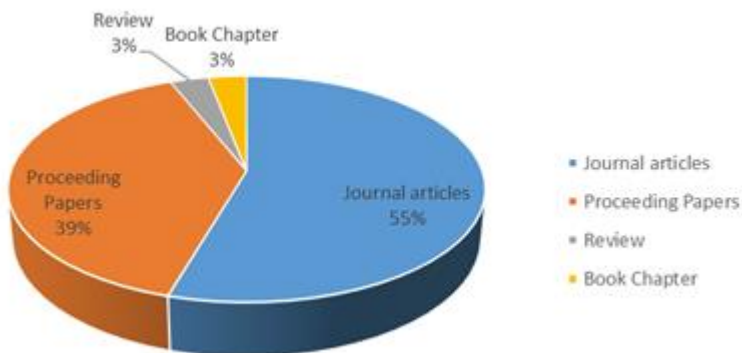


Figure 2: Paper types (see online version for colour)

Out of the 33 papers that were relevant to the current study, only nine focused on the South African construction industry. Figure 3 shows the sub-sectors in which lean construction has been applied in the South African construction industry. From these results it is evident that there is limited application of lean construction, particularly in the electrical and mechanical services (wet, fire, and heating, ventilation and air conditioning (HVAC)) in the South African construction industry. Construction and civil engineering projects involve the management of infrastructure such as roads, tunnels, bridges, airports, railroads, dams, and sewerage. Commercial buildings are those construction projects that involve building projects that can be leased or sold in the private sector. These spaces can be anything from offices and retail shopping centres to medical centres.

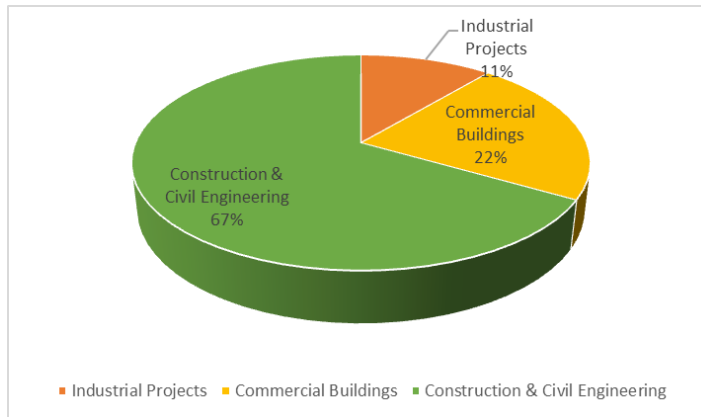


Figure 3: Project types (see online version for colour)

4.2 Conceptual aspects

Different concepts were identified from the systematic literature review, and were grouped into four categories, as shown in Table 5. Category 1 consists of the following concepts: understanding customer needs, identifying the value stream, and identifying value-adding and non-value-adding activities [7] [10] [21]. Category 2 focuses on investigating the current state of lean construction, identifying lean construction barriers, identifying lean construction implementation drivers, and implementing lean construction tools [2] [3] [62]. Lean implementing barriers include cultural barriers, resistance to change, and lack of knowledge about the lean construction philosophy. Category 3 highlights managerial support for the successful implementation of lean construction, government support, mind-set change, and change management of organisational culture and perception [15] [16] [17]. When the paradigm shifts, everything changes [54]. Training programmes should be made available to workforces at different levels to spread the required skills and techniques for minimising waste, such as cost and time control, scheduling, and risk analysis [54] [58] [72]. Category 4 consists of performance management, lean construction plan, lean project delivery system, project planning, and continuous improvement. There are nine lean construction key performance indicators. These are time, costs, quality, client satisfaction, environmental impact, waste, speed, value, and health and safety [36] [40] [75].

Table 5: Concepts identified

Category 1 Understand customer needs Identify value stream Identify value-adding processes Identify non-value-adding processes Identify waste and sources of waste	Category 2 Investigate current state of lean construction or other waste reduction processes Identify lean construction barriers Identify lean implementation drivers Implement lean construction tools
Category 3 Managerial support for successful implementation Mind-set change Change management of organisation culture and preparation	Category 4 Performance management Lean construction plan Lean project delivery system Project planning Focus on continuous improvement

5 DEVELOPING THE FRAMEWORK

From the systematic literature review, the authors developed a framework that can be used in the mechanical and electrical services industries. Lean construction focuses on getting things right, in the right place, at the desired time, and in the desired quantity [23] [32]. The framework consists of seven steps, as shown in Figure 6. The first step is to identify waste practices on site. This will enable the person tasked to implement lean construction to determine the level of comprehension of construction waste among the contractors involved in the project. The second step, as shown in Table 6, is to educate project managers and team leaders about lean construction and its benefits. This step is crucial to get support from all teams involved in the project. The third step is to identify value from the customer's perspective. The fourth stage is to identify the value stream; this is made out of all the activities that create customer value and satisfy the demands and expectations of the

customer. In this stage, value-adding activities should be distinguished from non-value-adding activities. This will lead to the discovery of the sources of waste. The fifth step is to establish flow by minimising waste – unnecessary waiting time, storage of material, unnecessary processes, unnecessary transportation of material, movement of labour workforces, etc. – and focusing on value-adding activities only. Maintaining a continuous flow of work on site, contractors can make use of different tools (such as plan-do-check-act) where everything is documented and responsibility is taken for each and every action. Contractors can identify possible sources of waste when they do their risk assessment on site. The sixth step will be to share with other workmates on site the waste likely to be encountered, and how to reduce this waste so that everyone on site is aware of lean construction. This will cultivate continuous learning on the construction site. The seventh step is to seek perfection; this is achieved by repeating steps one to six. It is through repeating these steps that Kaizen (continuous improvement) is achieved.

Table 6: Developed lean construction implementation framework

Step	Phase	Objective(s) for this step	Possible tools that can be used for the stage	References
1.	Understand current waste reduction practices at the targeted construction site	- To assess and determine the level of awareness of construction waste among contractors on site	Questionnaires, daily huddle meetings	
2.	Educate all contractors taking part in the project about lean construction and its benefits	- To ensure that top management and everyone else understands lean principles and is on-board for successful implementation of lean.	Daily huddle meetings Toolbox talks	[16] [17] [18] [58]
3	Specify value	- To outline value from the project viewpoint and from the customer’s own definition and needs	Value analysis mapping Process analysis	[49] [45] [21] [23]
4	Identify value stream	- To identify the activities that deliver customer value - To distinguish between value-adding activities, essential non-value-adding activities, and non-essential value-adding activities - To identify actual and potential sources of waste	Process mapping Value stream mapping Process flow chart 5 Whys	[10] [19] [20] [22] [59]
5	Establish flow of products	- To create a continuous flow of work by revising Gantt chart where necessary - To standardise	Poka-yoke 5S process Visual controls 5Whys Plan-do-check-act Last planner system	[7] [13] [16] [26] [27]
6	Pull production	- To produce exactly what the customer wants at the exact time given by the customer - To be guided by drawings received from the customer	JIT Kanban system	[66] [69] [70] [71]
7	Seek perfection	- To provide a perfect solution without defects or mistakes, and do continuous improvements - To have close communication with the customer	Kaizen	[70] [72] [73] [75]

6 EVALUATING THE FRAMEWORK

6.1 Case description

This framework was evaluated using a project for the refurbishment of government offices in South Africa. One of the authors had participated in this project. The scope of the project was as follows:

- Demolition of some walls to extend offices
- Renovation and replacement of the roof

- Mechanical engineering services: Installation of new air conditioning units, installation of new fire fighting equipment, and new plumbing pipes.
- Electrical engineering services: Installation of new lighting inside and outside the building, upgrading of the existing distribution board, installation of access control, installation of new small power, and installation of a generator and an automatic transfer switch linked to the generator
- Installation of new ceiling
- Internal plastering and internal painting
- External paving
- Construction of a covered outdoor waiting area.

6.2 Understanding current waste reduction practices at the targeted construction site

Semi-structured interviews were conducted to determine the level of understanding of lean construction from the site foremen, site manager, and project manager. Each interviewee was briefed about lean thinking and different waste types based on the work of Liker & Meier [51] and Womack & Jones [74]. During the interviews, these team leaders were requested to provide waste examples from their experience.

6.3 Educating all contractors taking part in the project about lean construction and its benefits

The author made a presentation on lean construction and its benefits to all contractors on-site during the daily toolbox talks. The objective was to ensure that everyone on site understands lean construction principles and is on board for successful implementation of lean.

6.4 Specify value

'Value' stands for what the customer agrees to pay in return. The value in this construction project was to achieve heating, cooling, fresh air supply, ventilation, fire detection systems, fire protection systems, lighting, and power supply.

6.5 Identify value stream

A Gantt chart was used to help identify the value stream. Activities on the Gantt chart were shared on noticeboards on-site so that everyone had a chance to appreciate the value stream. The importance of finishing the project on time and of religiously following the Gantt chart was emphasised to everyone. Identification of sources of waste and of potential sources of waste was done on-site. Demonstration of value-adding, non-value-adding, and unnecessary activities for each construction process was done. Value-adding activities were defined as those activities that directly affect the final product of the construction process, increase the economic worth of the process, and are valued by the customer.

6.6 Establish flow of products

A continuous flow of work was created by revising the Gantt chart when necessary. Waste in construction is assumed to be physical – for example, waste of materials in the construction process – but in reality there are multiple activities that do not add any value and should be regarded as waste in this industry. The flow of products was defined as the movement of materials, information, and equipment through a system. This step is necessary, as it enhances the flow of materials and information in a construction process.

6.7 Pull production

Pull production aims to ensure just-in-time coordination between upstream and downstream tasks. The author was on site twice a week to ensure that everything was delivered just in time to avoid any delays. Materials and information were delivered to the next station at the right time, at the right place, and without delay or unnecessary storage. Architectural drawings and design drawings were delivered in time by the designing team to the contractor. The Kanban system was also used to achieve pull production. This helps in controlling and balancing the resources required in order to achieve project completion.

6.8 Seeking perfection

Continuous improvement (Kaizen) was done to provide a perfect solution without mistakes. The project deadline should be met, and the client's needs satisfied, saving on project costs and reducing project duration.

6.9 Improved lean implementation framework

The improved lean implementation framework is developed after the evaluation phase. This framework can be used in lean construction for electrical and mechanical engineering services.

Table 7: Improved lean construction implementation framework

Step	Phase	Lean tools to be used	Responsible people
1	Understand current waste reduction practices at the targeted construction site	Semi-structured interviews	Site foreman, site manager, project manager
2	Educate contractors about lean benefits, and focus on mind-set change	Toolbox talk and daily huddle meeting	Construction team (employees) on site
3	a) Specify value (electrical engineering) b) Specify value (mechanical engineering)	Value analysis mapping	Technicians, site foremen (mechanical & electrical), site manager, project manager
4	Identify value stream	Process flow chart Gantt chart	Site foreman, site manager, project manager
5	Establish work flow	5 whys for waste elimination	Site foreman, site manager, project manager
6	Pull production	Kanban	Project manager, architects, quantity surveyor, engineers
7	Seek perfection	Kaizen	

7 CONCLUSION

In this paper, a lean implementation framework has been developed and evaluated in the context of electrical and mechanical engineering services in the construction industry in South Africa. The benefits of adopting lean construction as highlighted in the paper are immense, and will make the industry more resource-efficient. From the systematic literature review done, it was evident that lean construction techniques have not been practised and implemented in the mechanical (HVAC) and electrical construction services. The study contributes to covering that gap by developing a lean construction framework. The next step in this study is to implement this framework fully, and further resynthesize and improve the framework. The authors also seek to refine the implementation of the high level tools of lean construction, such as JIT, in a project setting.

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