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AN ANALYSIS OF THE EFFECT OF LEAN CONSTRUCTION TECHNIQUES ON CONSTRUCTION PROJECT PERFORMANCE IN NIGERIA

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ABSTRACT
The construction industry has been dotted with reoccurring issues of projects overrunning cost, and time or both, not meeting quality requirements, reduction in profit margin, fraudulent practices, and non-compliance to health and safety regulations which have led to the abandonment of projects. Studies have recommended lean construction as an innovative project management strategy to cope with these poor performance problems but there is not much research on lean construction in Nigeria as lean is still a relatively new concept in Nigeria. This research analysed the effect of lean construction techniques on project performance in Nigeria. The study adopted a quantitative approach. 350 questionnaires were distributed to professionals from 71 construction organisations practicing in Nigeria registered with the Federation of Construction Industry (FOCI), with a response rate of 84%. Data for the research was gathered using a structured questionnaire through a purposive sampling technique. Data collected was analysed using Mean Index Score (MIS), and Structural Equation Modelling estimated by Partial Least Square Method (SEM-PLS). The result revealed that lean techniques have a significant effect on cost, time, quality, health and safety, and stakeholders' satisfaction in enhancing the performance of construction projects in Nigeria. 5S techniques had more effects on the cost performance of construction projects, TPM had more effects on time, the last planner system had more effects on quality while root cause analysis had more effects on health and safety and stakeholders' satisfaction performance of Nigerian construction projects.

Keywords: Lean construction, lean techniques, construction, projects, performance

INTRODUCTION
The construction industry is the driving force behind the socio-economic development of any nation (Saidu and Shakantu, 2016). However, most of these developments are not void of performance problems that deplete resources (time and money). Hence, resource management for successful project performance is usually challenging (Abdul-Azis *et al.,* 2013; Saidu and Shakantu, 2016). In Nigeria, the construction industry has been dotted with reoccurring issues of projects overrunning cost, and time or both, all due to mismanagement; as a result, many projects take a while to complete and some are even abandoned (Nzekwe *et al.,* 2015).
The need for improved project performance has led to innovative techniques and concepts such as building information modelling (BIM), supply chain management, lean construction, total

quality management, and value management among others. Despite the perceived value of the application of some of these aforementioned techniques, there are some shortfalls (Saccardo, 2020). Other performance improvement techniques focus on individual construction processes and do not consider wastages due to non-value-adding activities. Lean construction has been identified as one of the most promising improved developments in the construction industry which is capable of solving the problems of poor performance in the Nigerian construction industry (Umar *et al.,* 2022). However, Oladiran (2017) posited that lean construction techniques are poorly used in Nigerian construction projects. Amade *et al.* (2019) also opined that the industry is faced with some risks and challenges that may hinder the successful implementation and readiness of the adoption of the LC approach. Incorporating lean tools, techniques, and principles into construction projects improves performance and gives clients better value for their money. The continuous poor performance of construction projects in Nigeria has given the Nigerian construction industry a negative image (Nwaki and Eze, 2020; Oluyemi-Ajibiowu *et al.,* 2021). Previous studies have made efforts to mitigate these underperformance issues of construction projects but there seems to have been minimal positive effect or improvement (Saidu and Shakantu, 2017; Oluwajana *et al.,* 2022). Studies have recommended a more innovative approach like lean construction to abate these negative trends (Nwaki and Eze, 2020). However, there is little research on lean construction techniques and their effect on construction performance in Nigeria as it is still as the lean concept is relatively new in Nigeria (Adamu *et al.,* 2012; Nwaki and Eze, 2020; Oladiran and Kilanko, 2022).

Countries like the United Kingdom, the United States of America, and Germany have used lean construction to ameliorate their underperformance problems reduce cost overrun in construction projects, and have delivered projects faster than earlier envisaged (Nwaki and Eze, 2020). Research in Nigeria suggested that the utilisation of the lean concept in the Nigerian construction industry will impact positively affect project performance in terms of cost, time, quality, and health and safety (Adamu and Abdulhamid, 2015; Nwaki and Eze, 2020). This is because, lean construction techniques give rise to high-quality project operations and output, enhance safety and reduce risk, cost control, and client satisfaction. However, current studies in Nigeria have centred on the benefits of lean construction (Adamu and Abdulhamid, 2015; Olamilokun and Okeowo, 2017), awareness of lean construction principles (Nwaki and Eze, 2020), factors, and barriers to lean implementation (Olamilokun and Okeowo, 2017; Ayinde, 2018), lean techniques for minimising material waste (Ango and Saidu, 2021). Ahiakwo and Sureh (2014) also reported the implementation of the last planner in the Nigerian construction industry. Despite the contribution of previous studies, a knowledge gap still exists in the aspect of how lean construction techniques affect construction performance in terms of time, cost, quality, health and safety, and stakeholders' satisfaction. It is against this background that this study carried out an analysis to enable the application of lean techniques which will help curb the risks of the construction project's poor performance. This study contributes to knowledge of lean construction globally and to current studies on lean construction approaches in Nigeria. The lean techniques will serve as a guide to construction organisations and other stakeholders in helping to reduce waste and generate profit and ROI for clients on their projects.

CONSTRUCTION PROJECT PERFORMANCE

Performance measures effectiveness (doing the right thing) and efficiency (doing the right thing right) (Idrus *et al.,* 2011). Performance can be considered as an evaluation of how well individuals, groups of individuals, organisations, or systems have done in pursuit of a specific objective. Appelbaum *et al.* (2015) defined performance as an achievement of assigned undertakings measured against pre-set known of recognised excellent accuracy, accomplishment, cost, and within the time. This is to say, for construction projects to be performed, certain indications or criteria need to be fulfilled. Project performance is an indispensable goal of every project where success is measured from innumerable parameters that are still conflicting, such as the most common time, cost, and quality (Yusof *et al.,* 2021).

The basic requirement for project performance is cost, time, and quality often referred to as 'the iron triangle' (Pheng and Chuan, 2006, Ayodeji *et al.,* 2017). Sweis *et al.* (2014) posit that cost, time, quality, client satisfaction, client changes, and health and safety are the main determinants of project performance. Yahya *et al.* (2019) state that the basic requirements for project performance are cost, time, quality, health and safety, client satisfaction, environmental factors, productivity factors, and contractor factors. A study by Unegbu *et al.* (2020) reported cost, time, quality, design requirements, and overall stakeholder satisfaction as key parameters for project performance.

This research based its project performance parameters on cost, time, quality, health and safety, and stakeholder satisfaction which are the major elements acceptable in evaluating project performance.

THE CONCEPT OF LEAN CONSTRUCTION

Lean Construction is a philosophy based on the concepts of lean manufacturing. It is about managing and improving the construction process to profitably deliver what the customer needs. It is a management philosophy focused on identifying and eliminating waste throughout a product's entire value stream, extending not only within the organisation but also along with the company's supply chain network (Scherrer-Rathje *et al.,* 2009).

Lean Construction is achieved through a set of mutually reinforcing practices like Just-in-Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), continuous improvement, Design for Manufacturing and Assembly (DFMA), Employee Involvement, Continuous improvement, Benchmarking, Timebase competition, Concurrent Engineering, Value-based Strategy (or management), Visual Management, supplier management, and effective human resource management (Bajjou, *et al.,* 2019).

The concepts and principles of lean are generally based on making the construction process leaner by eliminating waste which is regarded as a non-value-adding activity and ensuring continuous flow (Koskela, 2000). Six Sigma concept application has been suggested by Abdelhamid (2003). Six Sigma is an organised and efficient process of strategic process improvement and new product and service development that relies on statistical methods and scientific methods to make significant reductions in customer-defined defect rates (Linderman *et al.,* 2003). Environmental Management System (ESM) also shared similar goals as a lean concept which is waste reduction. ESM will maximise the customer's satisfaction as well as minimise waste.

It is noted that most of these concepts are interconnected and it is important to understand all the key concepts of LC, which may improve performance while minimising waste (Marhani *et al.,* 2013). Figure 2. 1 shows the inter-relationship of the lean concept.

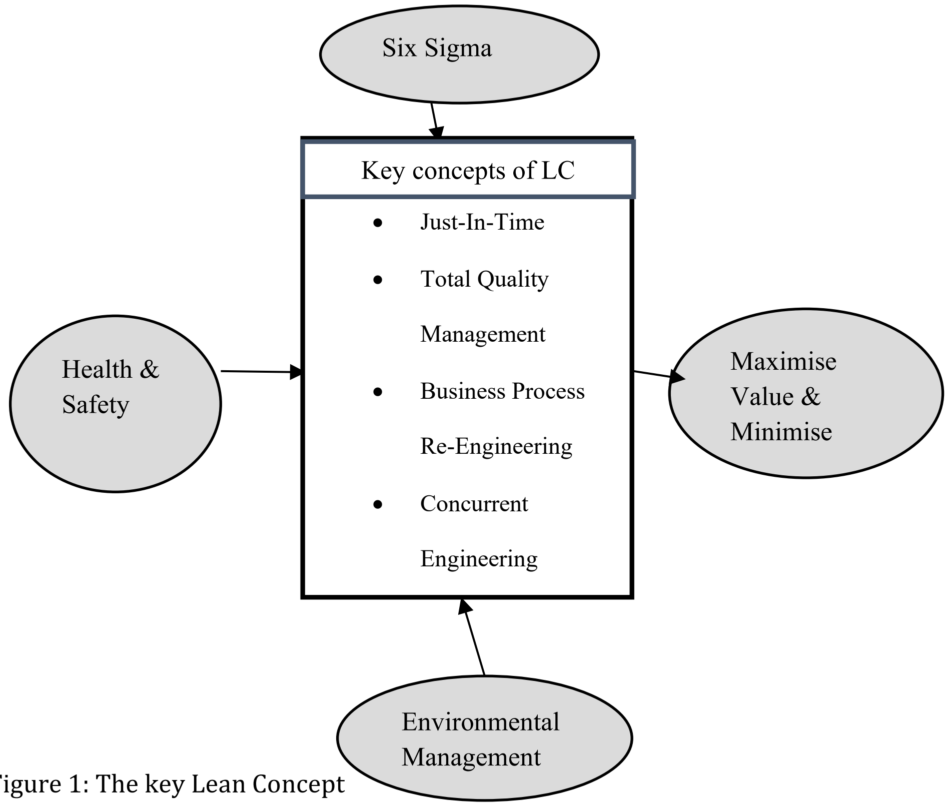

Figure 1: The key Lean Concept
Source: Adapted from Marhani *et al.* (2013)

Lean construction does not differ from current construction practices which focus on pursuing customers' needs and eliminating waste of every resource but the difference between current practices and lean construction is that lean construction is based on production management principles, and it has better results in complex, uncertain, and quick result projections (Ogunbiyi, 2013). Studies throughout the globe have shown that lean construction principles when applied, prove to have an enormous potential positive impact on the construction process and the industry as a whole (Small *et al.,* 2017). However, widespread implementation has not yet been realised. The adoption and application of some of the lean techniques are not without challenges as is common to a construction project due to its nature. For instance, Howell (1999) reported that the United States' implementation of lean construction has faced a limitation of lack of investment in research from the construction industry. Due to the uniqueness of the construction on the above premises, some of the techniques cannot be directly used as adopted from manufacturing, simple modifications are done. The Last Planner developed by Glenn Ballard in 1992 has gained wide usage and emphasises the relationship between scheduling and production control, is the most completely developed lean construction technique (Ballard, 1999).

LEAN CONSTRUCTION TECHNIQUES

Lean Construction does not imply the imposition of lean manufacturing techniques on the construction process but rather, the development of techniques and tools that conform to lean construction principles and applying them to improve project performance (Abdelhamid *et al.,* 2008). These techniques can be applied at different stages of the construction process with different set goals and areas of work. These lean techniques have a significant impact on improving construction project performance if used appropriately:

i. It delivers more value to the client with less waste of time and resources;
ii. It reduces cost, accelerates delivery, and improves both quality and safety;
iii. It delivers products or services on time and within budget;
iv. It helps contractors improve processes and overall project delivery;
v. It promotes continuous improvement in project delivery methods through lessons learned;
vi. It improves productivity by improving planning;
vii. It injects reliability, accountability, certainty, and honesty into the project environment;
viii. It helps in accommodating the change and;
ix. It reduces system noise.
x. communicate between the different project participants in the best manner to reduce the time lag and look for possible clashes rather than undergo them;
xi. measure and control key performance indicators

Table 1 shows the summary of lean construction techniques with their definitions at a glance from the literature.

Table 1: Lean construction techniques summary

S/N	Reference	Techniques	Definition
1	Alireza and Sorooshian (2014), Ango and Saidu*.* (2021)	**5S**	A process of waste removal from the workplace through visual controls
2	Aziz and Hafez (2013)	Concurrent Engineering	Parallel execution of tasks by multi-disciplinary teams
3	Ansah *et al.* (2012), Karthik (2020)	Check Sheet	It is a structured form prepared for collecting and analysing data
4	Alireza and Sorooshian (2014), Mourya *et al.* (2020)	Six Sigma	It is a tool for improving quality through the identification and removal of defects and reduction of variability in the process
5	Patel and Patel (2021), Kourriche and Aboutafail (2023).	Pareto Analysis	A bar graph that is used for analysing data about the frequency of the causes of problems in the process
6	Alireza and Sorooshian (2014), Ansah *et al.* (2016)	Check Points and Control Points	mechanisms that regulate managers' activities improvement at different levels
7	Bas (2022), Albasyouni *et al.* (2023)	FMEA	Step-by-step approach for identifying potential failures in product or services

8	Aziz and Hafe, (2013), Albalkhy and Sweis (2021)	Continuous Flow	Uninterrupted steps in the production/construction process
9	Alireza and Sorooshian (2014), Rauch *et al.* (2020)	FIFO line (First In, First Out)	An approach of handling work requests in order of flow
10	Alireza and Sorooshian (2014), Shedge *et al.* (2022	Jidoka/Automation	Automation of quality into a production process
11	Alireza and Sorooshian (2014), Ahmed *et al.* (2020)	Kanban (Pull System)	Billboards or signboards that regulates movements or flow of resources
12	Alireza and Sorooshian (2014), Vieira *et al.* (2022).	Kaizen	Continuous improvement of working practice, personal efficiency, etc.
13	Ballard (2000), Umar *et al.* (2022)	The Last Planner	It is a person or group of people with the task to control the production unit
14	Alireza and Sorooshian (2014), Boutbagha and El Abbadi (2024)	Heijunka (Level Scheduling)	Achieving a perfect supply and demand balance
15	Salem *et al.* (2005), Kalubovila and Kawmudi (2023). (2013)	Poka-Yoke (Error Proofing)	A mechanism design to detect and prevent errors
16	Alireza and Sorooshian (2014), Prakash *et al.* (2020)	First Run Studies	Used to design and improve work methods through field observations.
17	LeanProduction.Com (2015), Ghatorha and Sharma (2019)	Time and Motion Study	A procedure for evaluating efficiency based on the time taken or needed
18	Alireza and Sorooshian (2014), Xiang and Feng (2021)	Bottleneck Analysis	Identification of the part of the process that puts a limitation on the overall process
19	Tezel *et al.* (2017), Umar *et al.* (2022)	Total Productive Maintenance (TPM)	A holistic maintenance approach for equipment to maximize the operational time of the equipment
20	Alireza and Sorooshian (2014), Mortada and Soulhi (2023)	Visual Management	Use of visual signs to improve communication
21	Tsao *et al.* (2004), Garcia-Lopez *et al.* (2019)	Synchronize/Line Balancing	Leveling of workload across all process in a value stream
22	Ballard (2000), Umar *et al.* (2022)	Work Structuring	Work Structuring can be described as a path taken from chaotic work to optimized work

23	Alireza and Sorooshian (2014), Ansah *et al.* (2016)	Multi-Process Handling	It involves assigning operators tasks in multiple processes in an oriented layout of product flow
24	Muhammad *et al.* (2013), (Umar *et al.* (2022)	5 Whys	Why should be asked five times to get the root cause of the problems
25	Salem *et al.* (2005)	Fail-Safe for Quality	This relies on the generation of ideas that alert for potential defects
26	Salem *et al*. (2005), Wandahl *et al.* (2023)	Daily Huddle Meetings	Daily start-up meeting to update workers on daily tasks and previous efforts
27	Alireza and Sorooshian (2014), Xiang and Feng (2021)	Preventive Maintenance	Regular maintenance on equipment to reduce its failure
28	Alireza and Sorooshian (2014), Erdil and Arani (2018)	Quality Function Development (QFD)	Use of a customer's voices and different organisational functions and units for final engineering specification of a product.
29	Leanproduction.Com (2015), Islam *et al.* (2019)	SMART Goals	Project goals should be Specific, Measurable, Attainable, Relevant, and Time-Specific
30	Leanproduction.Com (2015), Rajab (2022)	PDCA (Plan, Do, Check, Act)	set up the plan and expect a result, do execute the plan, check anticipated result achieved and act (evaluate; do it again)
31	Alireza and Sorooshian (2014), Rafeal *et al.* (2022)	Setup Reduction	Changeover technique use to speedily change tools and fixtures for multiple products to be run on the same machine
32	Aslam *et al.* (2020), Medynski *et al.* (2023)	Work Standardisation	Documented procedures that capture best practices
33	Alireza and Sorooshian (2014), Charles and Chucks (2012)	Suggestion schemes	A formal mechanism that encourages employees to contribute actively to the process
34	Alireza and Sorooshian (2014), Haddad (2021)	Statistical Process Control	It is a quality control tool that monitors and controls process to ensure that the output variable(s) operates to its full potential through periodic measurement.
35	Aziz and Hafez (2013), Alireza and Sorooshian (2014), Patel and Solanki (2020)	Just-in-Time (JIT)	It is aimed at minimising flow time between the suppliers and end-users. Whatever is needed should be made available when due without a buffer

36	Ansah *et al.* (2016), Rajab (2022)	Muda Walk	Identification of waste through observation
37	Rahman *et al.* (2012), Leanproduction.Com (2015), Morshidi *et al.* (2022)	Value Stream Mapping	Visually analysing, documenting, and improving the flow of a process
38	Ansah *et al.* (2016), Groot (2021	Root Cause Analysis	Discovering and resolving the real problem instead of quick-fix applications
39	Alireza and Sorooshian (2014), Ansah *et al.* (2016)	Team Preparation	Training on waste, continuous flow, and standardise work for the lean team
40	Ansah *et al.* (2016), (Lauble *et al.* (2023).	Construction Process Analysis	Process chart describing the flow of the production process

Source: Researcher's construct (2023)

EFFECTS OF LEAN CONSTRUCTION TECHNIQUES ON CONSTRUCTION PROJECTS PERFORMANCE

Conventional construction project management is constantly facing problems of cost, time, quality, and safety (Wong *et al.,* 2018). For this reason, the construction industry needs a radical change rather than a step-by-step change to overcome the problems and challenges it is facing. Projects are becoming more complex and dynamic and most times the available performance improvement measures are no longer adequate to meet the current challenges (Tunji-olayemi *et al.,* 2016). The adversary nature of administering construction contracts and vertical communication systems needs to be abated to a friendlier, open-book accounting system and lineate contract administration present in other methods such as lean construction. The traditional construction projects' performance improvement measures are termed obsolete and overemphasise contractors' profitability while oftentimes compromising quality and time (Ayibiowu *et al.,* 2019).

The lean approach has been implemented in many sectors and has resulted in cost-saving, especially in manufacturing and construction. An example is the Department for Work and Pensions Jobcentre Plus project, launched in October 2002, is one of the largest government construction programs undertaken in the UK, in recent years this ambitious £750 million program aimed to redesign, rebrand, and refurbish more than 1000 former Jobcentre and Social Security offices in Great Britain by the Bovis procurement consultants. The project adopted a Lean approach in executing the project which yielded the following impressive results:

i. 12% saving on construction costs against target cost (estimated total of £80 million);
ii. reduced component prices by 25% on average (estimated total £40 million).
iii. 89% of all projects achieved target costs;
iv. 86% of projects completed on Programme;
v. accident statistics are 10 times better than HSE-published construction statistics;
vi. supply chain performance improvement – average 5% quarter on quarter;
vii. no contractual disputes.

Mahrani *et al.* (2013) stated that lean thinking has attained great success in reducing cost-related waste in manufacturing with a rate of 12%. Also, in case studies of using lean techniques in executing projects Wen (2014) reports cost savings of 64,000 USD from the J2-5 project of Pearl River New City in China. This agreed with previous studies that state cost saving as a benefit of lean construction (Kulkarni and Mhetar, 2017; Jose *et al.,* 2018; Wong *et al.,* 2018).

RESEARCH METHODOLOGY

Quantitative research approach was adopted for this study. The purposive sampling technique was employed in sampling data while the questionnaire was the research instrument used in the collection of data. This is because the study wanted to elicit the views of professionals who have specific expertise on Lean Construction and the researcher relied on the fact that lean construction is still not widely practiced in Nigeria (Adamu, 2017; Olamilokun and Okeowo, 2017). The Sample Size was drawn from the population of FOCI with 71-member organisations. The sample was taken from Project managers, Site managers, Quality assurance managers, Safety managers, and Equipment managers of the seventy-one (71) organisations who are usually involved in applying or implementing the lean approach in the organisations. Table 2 shows the numbers of these professionals in the 71 members of FOCI. The total population is 1875professionals. To obtain the sample size, it was calculated using Yamane (1967) formula illustrated below;

$n = \frac{N}{1+N(e)^2)}$

Where n is the sample size, N = 1875, e (margin of error) = 0.05, Confidence level = 95%,

$$n = \frac{1875}{1 + 1875(0.05)^2}$$

$$n = 329.67$$

$$n = 330$$

The sample size for this research is derived as shown in Table 2

Table 2: Determination of the Sample Size

POSITIONS	Project Managers	Site managers	Quality assurance managers	Safety managers	Equipment managers	TOTAL
No. of professionals	347	496	339	342	351	1875

Source: Researcher's construct (2023)

The total population is 1875 while the calculated sample size is 330. An additional 20 respondents are added to cover for non-response number. Therefore, the adjusted Sample Size used for this study was 350 for the questionnaire.

A hypothesis was formulated for the study which is given below;

H_{O1}: There is no significant relationship between lean construction techniques and improved project performance (Cost, time, quality, health and safety, and stakeholders; satisfaction).

RESULTS AND DISCUSSION

A total number of three hundred and fifty (350) questionnaires were distributed based on the sample size calculated. Two hundred and ninety-four were retrieved (294) and were all responsive. This showed a response rate of 84% which is adequate for this research. Similar studies by Bashir (2013) had a response rate of 17%. Nwaki *et al.* (2021), had a response rate of 81.73%. This demonstrates that the response rate of 84% for this study is adequate

Descriptive Analysis of Respondent's Profile

The result in Table 3 shows the analysis of the general profile of the respondents as addressed by Section A of the questionnaire. The results showed that 43% of the respondents are project managers, 27% are Site Managers, 16% are Quality Assurance Managers, 8% are Equipment Managers, 6% are Safety Managers. This showed that most organisation prefer project managers to respond to the questions indicating more experience in understanding the lean concept.

The results also showed that 58% of the respondents had either HND or BSC, and 33% had a Master's degree which implied that the respondents had adequate academic qualifications to understand the questions and give responsive answers. Table 3 also revealed that 38% of the respondents are Quantity Surveyors, 26% are Engineers, 18% are Builders and 14% are Architects. This implied that the respondent had the required background knowledge to provide appropriate data for the research.

The results in Table 3 showed that 37% of respondents are in the building sector, 14% in civil engineering works, 3% in heavy engineering works, 30% are involved both in building and civil works and 16% are in all sectors. This result implied that the respondents have an understanding of the Lean approach which validated their responses. It is also shown that 52% of the respondents had 10 years and above years of working experience. This shows that the data provided for the study is reliable and valid for the research.

Table 3: Demography of Respondents

Demographic Variables	Frequency	P percentage	Cumulative Percentage
Position in the organisation			
Project Manager	126	43.00	43.00
Site Manager	79	27.00	70.00
Quality Assurance Manager	47	16.00	86.00
Safety Manager	18	6.00	82.00
Equipment manager	24	8.00	100.00
Academic Qualification			
OND	21	7.00	7.00
HND/BSC	171	58.00	65.00
Masters	97	33.00	98.00
PhD	5	2.00	100.00
Professional Qualification			
MNIQS	*94*	32.00	32.00
FNIQS	*18*	6.00	38.00
MNIA	*35*	12.00	50.00
FNIA	*6*	2.00	52.00
MNIOB	*47*	16.00	68.00
FNIOB	*6*	2.00	70.00
MNSE	*70*	24.00	94.00

FNSE	*6*	2.00	96.00
PMP	*3*	1.00	97.00
NEBOSH	*6*	2.00	99.00
GMICE	*3*	1.00	100.00
Type of organisation			
Building	*109*	37.00	37.00
Civil	*41*	14.00	51.00
Heavy Engineering	*9*	3.00	54.00
Building and civil	*88*	30.00	84.00
Building, civil, and heavy engineering	*47*	16.00	100.00
Years of Experience			
1 – 3years	35	12.00	12.00
4 – 6years	62	21.00	33.00
7 – 9years	44	15.00	48.00
10years and above	153	52.00	100.00

Source: Researcher's construct (2023)

Effects of lean techniques on the performance of construction projects

For a project to perform certain criteria need to be fulfilled which are usually cost, time, and quality. It is usually referred to as the Iron Triangle. Some studies have referred to these three criteria as inadequate. In some cases, Health and safety, and stakeholders' satisfaction need to be fulfilled.

Cost effects of lean techniques on the performance of construction projects

The cost performance of a project is essential for project delivery. A lot of projects have suffered cost underperformance which is referred to as cost overrun in most cases in Nigeria's construction industry. Literature has shown that lean techniques practiced benefit construction activities in improving cost performance. Delivery projects at a reduced budget and better quality. Table 4 shows the result of the cost effects of lean techniques in construction project performance. The results ranked 5S (Sort, Straighten, Shine, Standardise, and Sustain) with a mean score of 4.02 as the first. Team Preparation and Total Productive Maintenance (TPM) with a mean score of 3.99 was ranked 2nd technique to have more effects on the performance of construction projects. Concurrent Engineering lean techniques were ranked 3rd with a mean score of 3.98. The Lean techniques that have the least cost effects on the performance of construction projects in Nigeria are; Heijunka (Level Scheduling), Kanban (Pull System), and Fail-Safe for Quality with mean scores of 3.77 and 3.80 respectively.

Table 4: The cost effect of lean techniques in construction projects

LCT	Lean Construction Techniques/Tools	Mean	Std. Deviation	Rank
LCT1	**5S** (Sort, Straighten, Shine, Standardise, and Sustain)	4.02	0.93	1
LCT2	Concurrent Engineering	3.98	0.93	3
LCT3	Construction Process Analysis	3.95	0.99	5
LCT4	Check Sheet	3.85	1.01	15

LCT5	Six Sigma	3.96	0.98	4
LCT6	Pareto Analysis	3.93	1.00	6
LCT7	Check Points and Control Points	3.83	0.99	17
LCT8	Failure Mode and Effects Analysis (FMEA)	3.89	1.02	10
LCT9	Continuous Flow	3.85	1.01	15
LCT10	FIFO line (First In, First Out)	3.86	0.99	14
LCT11	Jidoka/Automation	3.84	1.02	16
LCT12	Kanban (Pull System)	3.80	1.07	20
LCT13	Kaizen	3.80	1.04	20
LCT14	The Last Planner	3.84	1.04	16
LCT15	Heijunka (Level Scheduling)	3.77	1.03	21
LCT16	Poka-Yoke (Error Proofing)	3.92	1.04	7
LCT17	First Run Studies	3.85	1.01	15
LCT18	Time and Motion Study	3.85	0.96	15
LCT19	Bottleneck Analysis	3.87	1.01	13
LCT20	Total Productive Maintenance (TPM)	3.99	0.93	2
LCT21	Visual Management	3.86	1.01	14
LCT22	Synchronize/Line Balancing	3.88	0.98	11
LCT23	Work Structuring	3.92	1.01	7
LCT24	Multi-Process Handling	3.81	0.98	19
LCT25	5 Whys (Why, what, where, who, when)	3.85	0.95	15
LCT26	Fail-Safe for Quality	3.80	0.93	20
LCT27	Daily Huddle Meetings	3.82	1.01	18
LCT28	Preventive Maintenance	3.90	0.92	9
LCT29	Quality Function Development (QFD)	3.83	1.05	17
LCT30	SMART Goals	3.90	1.04	9
LCT31	PDCA (Plan, Do, Check, Act)	3.91	0.99	8
LCT32	Setup Reduction	3.87	0.97	12
LCT33	Work Standardisation	3.93	0.96	6
LCT34	Suggestion schemes	3.89	0.96	10
LCT35	Statistical Process Control	3.87	0.97	12
LCT36	Just-in-Time (JIT)	3.90	1.01	9
LCT37	Team Preparation	3.99	0.95	2
LCT38	Muda Walk	3.89	0.98	10
LCT39	Value Stream Mapping	3.88	0.99	11
LCT40	Root Cause Analysis	3.96	1.02	4

Source: Researcher's Analysis of Data (2023)

Time effects of lean techniques on the performance of construction projects

Time performance is of great importance in construction projects, especially on commercial projects where the facility or building is to be subjected to let or rent to generate income for the client (Chan, 2003). A successful project in terms of time performance is completed as specified in the contract or ahead of a predetermined schedule (Enshassi *et al.,* 2010). The result in Table 5 showed that Total Productive Maintenance (TPM), Daily Huddle Meetings, Heijunka (Level Scheduling), Failure Mode, and Effects Analysis (FMEA) are the top three ranked lean techniques with time effects in the performance of construction projects with a mean score of 3.96, 3.93, 3.97 respectively. The result also revealed that Kaizen and Muda Walk have the lowest time effects with a mean score of 3.73 and 3.76 respectively.

Table 5: The time effect of lean techniques in construction projects

LCT	Lean Construction Techniques/Tools	Mean	Std. Deviation	Rank
LCT1	**5S** (Sort, Straighten, Shine, Standardise, and Sustain)	3.85	1.02	9
LCT2	Concurrent Engineering	3.84	0.95	10
LCT3	Construction Process Analysis	3.86	0.99	8
LCT4	Check Sheet	3.83	1.01	11
LCT5	Six Sigma	3.80	0.99	13
LCT6	Pareto Analysis	3.80	1.00	13
LCT7	Check Points and Control Points	3.82	0.99	12
LCT8	Failure Mode and Effects Analysis (FMEA)	3.77	1.01	15
LCT9	Continuous Flow	3.89	0.97	6
LCT10	FIFO line (First In, First Out)	3.87	0.97	7
LCT11	Jidoka/Automation	3.83	1.00	11
LCT12	Kanban (Pull System)	3.79	0.98	14
LCT13	Kaizen	3.73	1.03	17
LCT14	The Last Planner	3.85	1.02	9
LCT15	Heijunka (Level Scheduling)	3.93	1.02	2
LCT16	Poka-Yoke (Error Proofing)	3.85	1.05	9
LCT17	First Run Studies	3.85	0.94	9
LCT18	Time and Motion Study	3.91	0.96	4
LCT19	Bottleneck Analysis	3.90	0.95	5
LCT20	Total Productive Maintenance (TPM)	3.96	0.96	1
LCT21	Visual Management	3.80	1.00	13
LCT22	Synchronize/Line Balancing	3.86	0.98	8
LCT23	Work Structuring	3.86	0.97	8
LCT24	Multi-Process Handling	3.92	0.98	3
LCT25	5 Whys (Why, what, where, who, when)	3.87	0.98	7
LCT26	Fail-Safe for Quality	3.90	0.97	5
LCT27	Daily Huddle Meetings	3.93	1.00	2
LCT28	Preventive Maintenance	3.85	0.94	9
LCT29	Quality Function Development (QFD)	3.90	0.97	5
LCT30	SMART Goals	3.90	0.99	5
LCT31	PDCA (Plan, Do, Check, Act)	3.89	0.96	6
LCT32	Setup Reduction	3.84	1.01	10
LCT33	Work Standardisation	3.82	1.00	12
LCT34	Suggestion schemes	3.87	0.96	7
LCT35	Statistical Process Control	3.85	1.00	9
LCT36	Just-in-Time (JIT)	3.90	1.07	5
LCT37	Team Preparation	3.83	1.05	11
LCT38	Muda Walk	3.76	1.07	16

LCT39	Value Stream Mapping	3.79	1.02	14
LCT40	Root Cause Analysis	3.89	1.00	6

Source: Researcher's Analysis of Data (2023).

Quality effects of lean techniques on the performance of construction projects

In conjunction with cost and time, quality becomes the third member of the three most important factors for construction project performance usually referred to as the 'iron triangle' or 'golden triangle'. The measurement of the quality performance of a construction project is subjective (Chan, 2003). Lean Construction views quality from the view of the client (Customer). Table 6 shows the quality effects of lean techniques in improving construction project performance in Nigeria. The results indicate that the Last Planner, Heijunka (Level Scheduling), 5S (Sort, Straighten, Shine, Standardise, and Sustain), check Sheet, and FIFO line (First In, First Out) Lean techniques have the most critical quality effect on the performance of construction projects in Nigeria with a mean score of 3.99, 3.98, 3.97 respectively. Fail-Safe for Quality and Daily Huddle Meetings have the lowest quality effects with a mean score of 3.79.

Table 6: The Quality effect of lean techniques in construction projects

LCT	Lean construction Techniques/Tools	Mean	Std. Deviation	Rank
LCT1	**5S** (Sort, Straighten, Shine, Standardise, and Sustain)	3.98	0.94	2
LCT2	Concurrent Engineering	3.91	0.98	9
LCT3	Construction Process Analysis	3.94	0.94	6
LCT4	Check Sheet	3.97	0.99	3
LCT5	Six Sigma	3.91	0.96	9
LCT6	Pareto Analysis	3.96	0.97	4
LCT7	Check Points and Control Points	3.88	0.94	11
LCT8	Failure Mode and Effects Analysis (FMEA)	3.94	1.00	6
LCT9	Continuous Flow	3.95	0.94	5
LCT10	FIFO line (First In, First Out)	3.97	0.95	3
LCT11	Jidoka/Automation	3.91	0.96	9
LCT12	Kanban (Pull System)	3.85	0.99	14
LCT13	Kaizen	3.84	1.02	15
LCT14	The Last Planner	3.99	0.93	1
LCT15	Heijunka (Level Scheduling)	3.98	0.91	2
LCT16	Poka-Yoke (Error Proofing)	3.93	1.07	7
LCT17	First Run Studies	3.85	1.04	14
LCT18	Time and Motion Study	3.85	0.99	14
LCT19	Bottleneck Analysis	3.94	0.98	6
LCT20	Total Productive Maintenance (TPM)	3.87	0.98	12
LCT21	Visual Management	3.86	1.00	13
LCT22	Synchronize/Line Balancing	3.87	0.91	12
LCT23	Work Structuring	3.88	0.96	11
LCT24	Multi-Process Handling	3.86	0.88	13
LCT25	5 Whys (Why, what, where, who, when)	3.93	0.93	7
LCT26	Fail-Safe for Quality	3.79	0.96	18

LCT27	Daily Huddle Meetings	3.79	1.04	18
LCT28	Preventive Maintenance	3.86	0.95	13
LCT29	Quality Function Development (QFD)	3.82	0.98	17
LCT30	SMART Goals	3.87	0.98	12
LCT31	PDCA (Plan, Do, Check, Act)	3.88	0.94	11
LCT32	Setup Reduction	3.83	0.98	16
LCT33	Work Standardisation	3.89	0.94	10
LCT34	Suggestion schemes	3.88	0.92	11
LCT35	Statistical Process Control	3.89	0.97	10
LCT36	Just-in-Time (JIT)	3.93	0.95	7
LCT37	Team Preparation	3.93	0.99	7
LCT38	Muda Walk	3.83	1.02	16
LCT39	Value Stream Mapping	3.91	0.92	9
LCT40	Root Cause Analysis	3.92	0.96	8

Source: Researcher's Analysis of Data (2023)

Health and safety effects of lean techniques on the performance of construction projects

Compliance with Health and Safety Regulations, Safety-Committee Policy, Risk Management, and availability of Safety Equipment/ Posters/ Displays is important to construction project performance. Table 7 shows that Root Cause Analysis is ranked 1st with a mean score of 3.92 as the lean technique that has the most effects in terms of health and safety on the performance of construction projects. This is followed by Team Preparation, the last planner, Heijunka (Level Scheduling), and Statistical Process Control with mean scores of 3.90. Continuous Flow techniques are the lowest with a mean score of 3.75 followed by 5 Whys (Why, what, where, who, when) and Muda Walk with mean scores of 3.77.

Table 7: The health and safety effect of lean techniques in construction projects

LCT	Lean Construction Techniques/Tools	Mean	Std. Deviation	Rank
LCT1	**5S** (Sort, Straighten, Shine, Standardise, and Sustain)	3.85	0.93	7
LCT2	Concurrent Engineering	3.85	0.98	7
LCT3	Construction Process Analysis	3.86	0.99	6
LCT4	Check Sheet	3.85	1.05	7
LCT5	Six Sigma	3.84	1.01	8
LCT6	Pareto Analysis	3.88	1.03	4
LCT7	Check Points and Control Points	3.81	1.02	11
LCT8	Failure Mode and Effects Analysis (FMEA)	3.83	1.04	9
LCT9	Continuous Flow	3.75	1.01	15
LCT10	FIFO line (First In, First Out)	3.80	0.99	12
LCT11	Jidoka/Automation	3.82	0.95	10
LCT12	Kanban (Pull System)	3.80	1.00	12
LCT13	Kaizen	3.84	0.98	8
LCT14	The Last Planner	3.90	0.92	2
LCT15	Heijunka (Level Scheduling)	3.90	0.97	2
LCT16	Poka-Yoke (Error Proofing)	3.86	0.94	6

LCT17	First Run Studies	3.82	1.00	10
LCT18	Time and Motion Study	3.80	0.95	12
LCT19	Bottleneck Analysis	3.87	0.98	5
LCT20	Total Productive Maintenance (TPM)	3.87	0.93	5
LCT21	Visual Management	3.84	0.96	8
LCT22	Synchronize/Line Balancing	3.83	0.92	9
LCT23	Work Structuring	3.83	0.92	9
LCT24	Multi-Process Handling	3.79	0.92	13
LCT25	5 Whys (Why, what, where, who, when)	3.77	0.94	14
LCT26	Fail-Safe for Quality	3.79	0.99	13
LCT27	Daily Huddle Meetings	3.81	0.96	11
LCT28	Preventive Maintenance	3.82	0.99	10
LCT29	Quality Function Development (QFD)	3.82	0.97	10
LCT30	SMART Goals	3.83	0.96	9
LCT31	PDCA (Plan, Do, Check, Act)	3.81	1.02	11
LCT32	Setup Reduction	3.89	0.95	3
LCT33	Work Standardisation	3.82	0.97	10
LCT34	Suggestion schemes	3.85	0.92	7
LCT35	Statistical Process Control	3.90	0.94	2
LCT36	Just-in-Time (JIT)	3.87	0.96	5
LCT37	Team Preparation	3.90	0.97	2
LCT38	Muda Walk	3.77	0.98	14
LCT39	Value Stream Mapping	3.83	0.95	9
LCT40	Root Cause Analysis	3.92	1.01	1

Source: Researcher's Analysis of Data (2023)

Stakeholders' satisfaction effects of lean techniques on the performance of construction projects

The ability of the project to fulfil the client's requirements is essential for project performance. The Lean approach is primarily to ensure clients have value for money, and that the stakeholders are satisfied with the end product. The results in Table 8 showed that Root Cause Analysis is ranked 1st with a mean score of 3.89 as the lean technique that has the most effects in terms of health and safety on the performance of construction projects. Work Structuring, Total Productive Maintenance (TPM), visual management, and the last planner were also among the top lean techniques that have effects on the performance of construction projects in terms of stakeholders' satisfaction with a mean score of 3.88, 3.86, 3.85, and 3.84 respectively. Fail-Safe for quality, Pareto analysis, and work standardisation were the lowest effect techniques with mean scores of 3.68, 3.71, and 3.73 respectively.

Table 8: The stakeholder satisfaction effect of lean techniques in construction projects

LCT	**Lean Construction Techniques/Tools**	**Mean**	**Std. Deviation**	**Rank**
LCT1	**5S** (Sort, Straighten, Shine, Standardise, and Sustain)	3.73	0.99	18
LCT2	Concurrent Engineering	3.82	0.92	7
LCT3	Construction Process Analysis	3.75	1.00	16
LCT4	Check Sheet	3.73	1.00	18
LCT5	Six Sigma	3.73	1.01	18
LCT6	Pareto Analysis	3.71	1.01	19

LCT7	Check Points and Control Points	3.76	0.97	15
LCT8	Failure Mode and Effects Analysis (FMEA)	3.76	1.01	15
LCT9	Continuous Flow	3.80	1.00	9
LCT10	FIFO line (First In, First Out)	3.77	0.97	14
LCT11	Jidoka/Automation	3.78	1.03	12
LCT12	Kanban (Pull System)	3.73	1.02	18
LCT13	Kaizen	3.81	0.97	8
LCT14	The Last Planner	3.84	0.99	5
LCT15	Heijunka (Level Scheduling)	3.81	0.98	8
LCT16	Poka-Yoke (Error Proofing)	3.82	1.03	7
LCT17	First Run Studies	3.83	1.02	6
LCT18	Time and Motion Study	3.78	0.97	13
LCT19	Bottleneck Analysis	3.83	1.01	6
LCT20	Total Productive Maintenance (TPM)	3.86	0.98	3
LCT21	Visual Management	3.85	0.99	4
LCT22	Synchronize/Line Balancing	3.84	0.96	5
LCT23	Work Structuring	3.88	1.05	2
LCT24	Multi-Process Handling	3.77	1.03	14
LCT25	5 Whys (Why, what, where, who, when)	3.77	1.01	14
LCT26	Fail-Safe for Quality	3.68	1.08	20
LCT27	Daily Huddle Meetings	3.73	1.09	18
LCT28	Preventive Maintenance	3.80	0.99	9
LCT29	Quality Function Development (QFD)	3.78	1.05	13
LCT30	SMART Goals	3.82	1.00	7
LCT31	PDCA (Plan, Do, Check, Act)	3.79	1.02	10
LCT32	Setup Reduction	3.74	1.00	17
LCT33	Work Standardisation	3.73	1.06	18
LCT34	Suggestion schemes	3.79	1.02	10
LCT35	Statistical Process Control	3.79	1.03	10
LCT36	Just-in-Time (JIT)	3.78	1.01	11
LCT37	Team Preparation	3.81	1.10	8
LCT38	Muda Walk	3.76	0.99	15
LCT39	Value Stream Mapping	3.80	1.00	9
LCT40	Root Cause Analysis	3.89	1.04	1

Source: Researcher's Analysis of Data (2023).

Inferential Analysis Result

To test for the relationship between Lean construction techniques and improved project performance (Cost, time, quality, health and safety, and stakeholders; satisfaction), factor analysis was carried out on the constructs. Sixteen (16) lean techniques met the threshold of ≥ 0.70 and those below it was discarded in the model. Table 10 shows the retained lean techniques in the factor loadings. PLS-SEM analysis was conducted to find out the degree of effect on the dependent variable.

Factor Loadings

Factor loading indicates the correlation coefficient for indicators/items. High factor loadings indicate a strong convergent validity, suggesting that the indicators effectively measure the underlying constructs and at least it should be ≥ 0.70 for strong convergent validity (Hair *et al.,* 2022). These indicators/items are presented in Table 9.

Table 9: Lean techniques retained in factor loadings

LCT	Description
LCT 5	Six Sigma
LCT 6	Pareto Analysis
LCT 7	Check Points and Control Points
LCT 8	Failure Mode and Effects Analysis (FMEA)
LCT 14	The Last Planner
LCT 15	Heijunka (Level Scheduling)
LCT 16	Poka-Yoke (Error Proofing)
LCT 17	First Run Studies
LCT 18	Time and Motion Study
LCT 20	Total Productive Maintenance (TPM)
LCT 31	PDCA (Plan, Do, Check, Act)
LCT 32	Setup Reduction
LCT 33	Work Standardization
LCT 34	Suggestion schemes
LCT 35	Statistical Process Control
LCT 39	Value Stream Mapping

Source: Researcher's Analysis of Data (2023).

Structural model path coefficient (Hypotheses testing)

PLS-SEM provides a path coefficient among the constructs that represent the hypothesized relationship of the constructs in the model. The specific hypothesised relationships of the constructs in the model are given as:

H01: Lean construction techniques → improved Project performance;

The standardized values provided by the path coefficient are approximately between −1 to +1. The path coefficient values close to +1 usually signify a positive relationship between the constructs. However, path coefficient values relative to −1 are usually insignificant (Purwanto *et al.*, 2021). On the other hand, the t-value or p-value signifies the level of relationships (Ahmed *et al.*, 2017). Where, t-values 1.65, 1.96, and 2.57 are concluded to be statistically significant at $p \leq 0.10$, $p \leq 0.05$, and $p \leq 0.01$ (Lai, *et al.,* 2022; Ponomareva, *et al.,* 2022). The result of the path coefficient in Table 10 shows the relationship between lean construction techniques and improved project performance is 0.521 (beta value) with a t-value of 8.983 at a p-value of 0.000, which signifies a positive relationship between them and supports H1.

Table 10: Path coefficient (Hypothesis testing)

Hypothesis/ Path	Original Sample(O)	Sample Mean (M)	Standard Deviation (STDEV)	T-Value (|O/STDEV|)	P Values	Remark
HI: Lean Construction Techniques → Improved Projects Performance	0.521	0.519	0.058	8.983	0.000	Supported

The assessment of the coefficient of determination (R^2) which measures the structural model was determined. According to Hair *et al.* (2022), R^2 values considered are 0.25, 0.50, or 0.75 and are described as weak prediction, reasonable prediction, and substantial prediction. This is regarded as the rule of thumb for R^2 values in all areas of study (Hair *et al.*, 2022;). R^2 value estimated for the effect of lean techniques on the performance of construction projects is 0.203 derived from Lean construction techniques, which explains 20.3 percent variance and is considered as a weak prediction.

The assessment of the effect size (f^2) was also determined. The f^2 technique investigates the changes in R^2 values when a specified construct is excluded from the model to examine the impact of the excluded exogenous construct on the endogenous constructs. According to Hair *et al.* (2022), the recommended values for f^2 are 0.02, 0.15, and 0.35, representing a small, medium, and significant effect, respectively. There is no effect if the value of f^2 is less than 0.02.

In this study, as shown in Table 11, Lean Construction techniques have a high effect on improved project performance.

Table 11: Effect size (f^2)

Constructs	F^2	Decision
Lean Construction Techniques → Improved Project Performance	0.415	Supported

Predictive relevance (Q^2)

The assessment of the predictive relevance (Q^2) of the model was also determined. For assessing the Q^2 for all the endogenous constructs, a PLS predict procedure was used to determine the value of Q^2. Hair *et al.* (2022) suggest that the model demonstrates good Predictive relevance when its Q^2 value is more significant than zero, and the value obtained can be categorised if is 0.02 as (small), 0.15 as (medium), and 0.35 as (significant). In contrast, the Q^2 value of zero or below (negative value) demonstrates the absence of predictive relevance. Table 12 shows that all Q^2 values are above zero. Therefore, the model can be said to be good or have an excellent predictive value.

Table 12: Predictive Relevance (Q^2)

Constructs	Q^2predict	RMSE	MAE
Improved Project Performance (IPP)	0.245	0.880	0.677
Lean Construction Techniques (LCT)	0.189	0.909	0.726

The result also showed how each construct had the power to predict the validation of structural models and the significance of each path coefficient in the model. Findings from the R^2 result showed that 42.9%, and 20.3% of improved project performance and lean construction techniques, in the Lean construction model were influenced by improved project performance (Cost, time, quality, health and safety, and stakeholders' satisfaction). According to Elbanna *et al.* (2016), a level of 10% is acceptable, therefore, the R^2 values in the model are in line with this assertion.

The result also showed that Lean construction techniques exhibit a positive relationship with improved project performance at a 43% significance level. Findings from the study also revealed that the R^2 value (20.3%) of Lean techniques is influenced by all the reflective constructs in the model. The reflective indicators of improved project performance were cost, time, quality, health and safety, and stakeholders' satisfaction which positively linked to lean techniques and ways of applying the Lean approach (path = 0.24; t = 5.62, at $p < 0.00$). This supports the findings of Akinola *et al.* (2020), and Ango and Saidu (2021) that lean techniques affect construction project success in terms of cost, time, quality, health and safety, and stakeholders' satisfaction by reducing or eliminating non-value-adding activities.

Conclusion

Lean techniques have effects on the performance of constructions in Nigeria in terms of cost, time, quality, health and safety, and stakeholder satisfaction. The analysis of the SEM revealed that Lean techniques have a significant effect on the performance of construction projects. This indicated that if construction organisations in Nigeria take these lean techniques seriously it will improve their projects' performance significantly. The SEM analysis also revealed a positive statistically significant relationship between lean techniques and improved project performance metrics (Cost, time, quality, health and safety, and stakeholder satisfaction).

The study also recommends the use of cost, time, quality, health and safety, and stakeholder satisfaction as metrics for ascertaining the performance of construction projects in Nigeria's construction industry using the lean approach.

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