Adoption of Lean Approach to Enhance Performance of Fast-Track Construction Projects

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Abstract:

The construction industry in Egypt plays a pivotal role in the country's economy, however, inefficient project management practices have been identified as a significant challenge, impacting both the environment and the economy. Evidence showed that the integration of lean construction (LC) concepts and tools into construction management not only addresses challenges but also generates a synergistic impact on project performance. The study investigates the level of awareness, adoption, perceived benefits, and challenges of lean construction in Egypt. A questionnaire survey was used and was collected from 133 respondents from different levels among construction specialists. Additionally, the research explores the feasibility of a tailored framework for the adoption of lean principles, specifically targeting fast-track projects. The findings of this research contribute significantly to bridging the knowledge gap in the application and understanding of lean construction principles in the Egyptian construction industry. The study reveals a diverse landscape of awareness among respondents, emphasizing the importance of increasing knowledge levels for effective implementation. Participants with higher awareness demonstrated substantially higher adoption rates of lean methods, highlighting the interconnected relationship between awareness, adoption, and positive outcomes. This underscores the need for targeted educational programs and training initiatives to enhance professionals' knowledge and skills in effectively implementing lean principles in fast-track projects, especially in the face of current economic challenges. The proposed conceptual framework integrates insights from the literature review and questionnaire analysis, offering practical guidance for implementing lean construction principles. This will enhance the productivity of construction projects with best quality, limited waste, and on-time delivery. In conclusion, this research contributes to advancing knowledge and understanding of lean construction principles in the context of the construction industry in Egypt, providing a foundation for further research and practical strategies. It contributes to lean practices' effective adoption, promoting the industry's advancement and sustainability. Applying LC methods will enhance the implementation of fast-track projects with high quality, less cost and time. Future research considerations include contextual influences and regulatory support for lean construction in developing countries.

Keywords: Lean construction, fast track, projects, construction, adoption, survey

1. Introduction:

In Egypt, the construction industry has proven to be one of the most important sectors of the economy accounting for 14% of Egypt's GDP. Despite high inflation, currency depreciation, and rising energy and material costs, The Egypt Construction Market size is estimated at USD 50.78 billion in 2024 and is expected to reach USD 75.97 billion by 2029, growing at a CAGR of 8.39% during the forecast period (2024-2029). As reported in May 2022, about USD 93 billion worth of projects were being worked on in Egypt, while there are more than USD 425 billion worth of projects in various pre-execution stages [1].

However, several challenges are noticed through inefficient project management. It is recognized as a waste-producing sector that has a negative impact on both the environment and the economy. Incorporating lean construction; (LC) concepts/tools into construction management can overcome challenges in the construction industry [2].

Different ways were sought to explore the construction industry that provides architectural, engineering design, and construction services [AEC industry] through digitalization, innovative technology, and new construction methods to catalyze a technological, cultural, strategic, and economic shift in the industry [3]. Thus, the adoption of lean concepts has indeed increased over the years as organizations look for more efficient and effective ways to operate [4]. The hard work and dedication of the lean approach in implementing and developing these principles has led to a significant change in the manufacturing industry itself [5]. In Egypt, a similar type of shift in the AEC sector is dependent on the way these concepts and principles are understood, applied, and practiced in the construction sector.

Addressing the gap in knowledge and adoption of lean construction principles for promoting economic development in Egypt. The current study aimed to investigate the level of awareness and adoption of lean construction in Egypt, as well as to explore the perceived benefits and challenges among construction specialists and experts in Egypt. Furthermore, we explored the feasibility of devising a framework tailored to the adoption of lean principles specifically for fast-track projects. Such a framework aimed to optimize project performance by ensuring high quality, minimizing costs, and expediting project timelines.

2. Literature review:

This literature review explores key concepts, methodologies, and studies related to lean construction, shedding light on its evolution, principles, and implementation strategies. By synthesizing existing research findings, this review aims to identify trends, gaps, and opportunities

for further advancement in lean construction practices, ultimately contributing to the enhancement of project efficiency, quality, and overall performance within the construction sector.

2.1 Lean concepts and definition:

The term "Lean" is defined as an approach focused on minimizing waste to enhance the rate of production which is accomplished through a specific procedure [6]. This occurs through identifying the intended value of products, the ongoing flow of manufacturing processes, good documentation, and transparency of data before implementing a solution to improve the decision-making process. The lean approach has multiple objectives: reducing waste, improving time, making values-based approaches, enhancing improvements, and managing change as necessary [7].

Many firms around the world have employed lean principles to benefit from their positive effects on performance [8]. The Toyota production system is renowned for its innovative approach to manufacturing production [9]. It adheres to a philosophy that emphasizes the importance of establishing sound processes based on principles rather than relying solely on technology, with ongoing improvements driven by the collective efforts of individuals [10].

Lean construction includes five key principles supporting the efficiency of production in construction, which were initially stated by Womack and Jones as follows [11]:

- Identify Customer Value: to meet the needed specification and deliver the required value to the end customer.
- Map the value stream (the operations that generate the value): to deliver a product or service, and then evaluate the extent to which the customer's value is delivered. This shows the end-to-end process of delivering value to customers, which requires the reduction of all non-value-added activities.
- Make the product flow (keep product flowing): to maintain workflow by achieving optimal work sequencing. This minimizes waste and increases value for customers.
- Use pulls logistics: to produce according to or on demand of the customer (what the customer needs, when the customer needs it?).
- Striving for perfection (Seek perfection) in all operations: to implement appropriate methodologies for continuous improvement of the processes.

2.2 Lean tools:

Experts utilize the instruments to apply lean principles in industry and manufacturing. The general goals of these tools are to enhance quality, increase safety, decrease the project's time, reduce the effort and optimize resources. Lean methods and instruments were gathered from previous investigations and summarized in Table 1.

Table (1): Lean construction tools & definitions

Tools	Definition	Ref.
Last Planer System (LPS)	A system for scheduling and controlling project production, designed to create a workflow that ensures reliable execution, the LPS system is a collaborative commitment-based planning system integrating should-could-would planning: pull planning, prepared forward scheduling with constraint analysis, weekly or biweekly work activity based on PPC analysis and reasons for deviation	[12]
Building Information Model (BIM)	Is the process of a digital representation of a project that allows for coordination, collaboration, and integration of various aspects and stakeholders involved in the design, construction, and operation phases. It encompasses detailed information about the physical and functional characteristics of the project, including 3D models, facilitating better decision-making, and effectiveness throughout the project lifecycle in the project, it also includes (4D, 5D,….) which can simulate the project during the construction phase	[13]
Visual Management (VM)	Ensuring that tools, parts, production activities, plans, schedules, measures, and performance indicators are clearly visible allows everyone involved to easily grasp the status of the system. This, in turn, enables individuals to take appropriate actions in support of the system's objectives	[14]
Value Stream Mapping (VSM)	Is a manual tool that involves creating a visual representation of the entire process using a pen and paper. By meticulously drawing out the process map using a standardized set of icons, VSM allows for a comprehensive analysis of the process, enabling the identification of any weaknesses or sources of waste. Once these areas of improvement are pinpointed, changes are proposed and implemented, and the new process is thoroughly evaluated to assess its effectiveness.	[15]
Integrated Project Delivery (IPD)	This approach seamlessly integrates people, systems, business structures, and practices into a well-coordinated process. The beauty of this process lies in its ability to harness the talents and insights of all participants, resulting in a reduction of waste and an optimization of efficiency throughout every phase of the project. From the early design stages to the final project handover.	[16]
Target Value Design (TVD)	TVD has a unique perspective on AEC (Architecture, Engineering and Construction). They see it as a complex system that encompasses project definition, design, and construction stages. They turn it on its head by prioritizing costs over design. This means that the costs determine the design, rather than the other way around.	[17]
Linguistic Action Perspective (LAP)	This is essentially an application of Speech Act Theory to the field of organizational management. It suggests that conversations are not just a precursor to action, but rather they are actions in and of themselves. This is because conversations involve commitments that shape and define the actions that follow. Every conversation aimed at taking action can be broken down into four basic speech acts: 1) making a request or an offer, 2) making a promise or accepting one, 3) declaring compliance, and 4) declaring satisfaction.	[18]
Choosing by Advantages (CBA)	Is a tested and effective informed decision-making system designed to make the best decision possible by considering the benefits of each option?	[14]

Tools	Definition	Ref.
Gemba Walk	Gemba is Japanese for 'actual place'. This concept has been further developed into the practice of site walking as part of Lean Manufacturing. It is important to understand the importance of 'looking and seeing' during the construction process	[19]
5S	Originated in Japan and is divided into five actions designed to organize and standardize work as follows: • Sort, • Set in order, • Shine, • Standardize, • Sustain	[15]
Just in time (JIT)	A system for delivering the correct quantity of products (row material) when needed for production/construction	[20]
Kanban	Japanese term meaning tasks are represented as cards or sticky notes on a board, categorized into different columns representing different stages of the workflow. The goal is to move cards from one column to another, signaling progress and encouraging continuous flow, while limiting work in progress to maintain efficiency "a signboard." A communication tool used in JIT production systems. The signal tells workers to pull parts or refill material to a certain quantity used in production"	[21]
A3 Report	A report sheet that has a summary of the project, including the obstacles to the problem-solving proposed action and the expected results	[14]
Jidoka	Is a quality control method that originated in the Toyota Production System. It refers to the concept of building quality into the production process to prevent the production of defective products and ensure that quality is maintained throughout the manufacturing process. Jidoka emphasizes the importance of human intervention and automation working hand in hand to improve efficiency and product quality	[22]

2.3 Benefits of implementing Lean construction:

Lean's methods, techniques, instruments, and ideas could be challenged by the value problem in construction and provide a solution to the efficiency-based issue in the construction industry. Many items associated with projects could be improved by using LC methods like timesaving, material waste reduction, labor waste reduction, and cost saving. Previous research/studies discussed the advantages of LC, and classified benefits according to the 3 bottom lines: environmental, economic, and social components as shown in Table 2.

Table (2): Summary Table of Lean Benefits

Environmental		**Economic**		**Social**	
Benefits	Ref	Benefits	Ref	Benefits	Ref
Safety control improvements	[23]	Time reduction	[23,29]	Customer satisfaction	[23]
Time, cost, and material waste reduction	[24,25]	Cost reduction	[23,25,30]	Employee satisfaction	[23]
Material waste reduction	[25,26]	Improve quality	[26,30]	Minimization of conflicts	[23,25]
Improve the quality of the environment	[27]	Increase productivity	[23]	Improve communication between project stakeholders	[25]
Preventing pollution and emissions	[28]	Rework minimization	[29]	Enhancing transparency	[26]
Material storage control (access and inventor)	[23]	Improve prediction of risks	[29,31]	Improving decision making	[25]
Labor cost reduction	[31]	Continues improvements	[25]		
Value achievement	[31]	Enhancing teamwork	[25]		
Improving life-cycle cost	[31]	Valuing relationships	[31]		
Reduction of rework	[31]				

2.4 Adoption of LC in Egypt:

Egyptian researchers investigated "lean Construction" from various perspectives and used various approaches. The aims and main findings of these studies are summarized in Table 3.

Table (3): Lean construction studies in Egypt

Year	Summary of the past works	Reference
2007	This article aimed to improve Egypt's construction labor productivity by implementing two lean construction principles: reducing variability and benchmarking. It is based on information from eleven structures' masonry activity. Based on the findings of this research, there is a link between the quality performance of construction projects and the variability in daily labor productivity	[32]
2008	This research explores the advantages and principles of implementing lean concepts in highway construction. The main objective is to provide guidelines for a smooth implementation of lean management.	[33]
2012	The goal of this study was to come up with a method for evaluating the influence of lean principles in the design process at construction consultancy firms. In addition, a simulation model for the design process was created and subsequently tested in a case study. When measured in terms of activity rates, the results demonstrate a 40% improvement in performance after implementing the lean method.	[34]
2013	By applying lean construction principles, this study proposed a new technique for minimizing the effect of risk variables on time. Furthermore, limiting the execution of industrial structures in Egypt to control variables risk results in time overruns. According to the study, the use of the lean process reduced the duration of industrial processes by 15.57 percent.	[35]
2013	This study recommended using LC to increase productivity and found that lean-based solutions had been successfully adopted in construction management, resulting in reduced construction times, improved safety, and improved quality.	[36]
2014	The implementation of Lean Principles in the Egyptian construction industry was explored in this study. The initial survey questionnaire, background, and a case study were conducted. According to the findings of this study, 58 percent of respondents said they use Lean principles in their projects to create value and remove waste without even realizing it. It is called lean during the design and construction phases.	[37]
2018	This research aimed to look into the function of LC as an innovative waste-reduction strategy in the Egyptian construction industry. Finally, it proposed a strategy for facilitating Lean Construction implementation in construction projects in Egypt.	[38]
2020	This paper addressed the obstacles facing the last planner system [LPS] adoption in the Egyptian construction industry and proposed a framework for LPS implementation in Egypt.	[39]
2021	The thesis' primary goal was to enhance Egypt's construction building projects' performance by incorporating lean principles into the process. The Framework finding showed the effect of the V.A., N.V.A., and E.N.V.A [value-added, non-value-added, and essential non-value-added] activities on the overall process duration and the overall reduction in the process duration. The factors influencing [project constraints] the used lean technique or tool were discovered to have a significant impact on process length improvement.	[40]
2021	According to the findings, adopting lean construction methods is critical for decreasing waste and improving the performance of the Egyptian construction industry. The respondents assessed a total of 31 benefits. The main advantages are economic-related. The following are the significant advantages of using Lean Construction "L.C." tools: improved planning, improved material storage control, improved process control, and time reduction	[41]
2022	The thesis' primary goal: Eighteen key drivers were identified and ranked, with a clear definition of customer needs generally having the greatest global weight among these factors, with case studies showing that over 60% of lean drivers are implemented in Egypt. Daily observation and standardization of work are two of the most commonly used lean practices in Egypt	[42]

However, its implementation can face challenges and gaps in different regions. Here are some potential gaps in the context of lean construction in Egypt:

- Awareness and Education: lack of awareness among construction professionals and stakeholders about the principles and benefits of lean construction. Insufficient educational programs and training opportunities focusing on lean construction practices in Egyptian universities and training institutions.
- Cultural and Organizational Challenges: resistance to change within the construction industry, as lean construction often requires a cultural shift in the way projects are planned and executed. Limited adoption of collaborative and integrated project delivery methods, which are essential for lean construction success.
- Regulatory and Legal Framework: lack of supportive regulatory frameworks and policies that encourage and facilitate the implementation of lean construction practices. Challenges related to legal aspects, contracts, and procurement processes that may hinder the adoption of lean principles.
- Supply Chain Issues: limited emphasis on the standardization of construction materials and components, which can contribute to waste reduction.
- Metrics and Performance Measurement: inadequate metrics and performance measurement systems to evaluate the success and effectiveness of lean construction projects. Limited use of key performance indicators (KPIs) tailored to the specific needs and challenges of the Egyptian construction industry.

2.5 Lean Constructions and Fast-Track Projects:

Fast-track projects are defined as time-driven projects that essentially necessitate a sensitive degree of balancing between engineering, procurement and construction, intensive planning, and coordination concerning the quality, time frame, and cost [43]. It has become essential in the construction sector and is increasingly adopted in the Gulf Area and Middle East. However, barriers may face fast-track projects and can be categorized into 4 groups: a] Design and Coordination, b] Scope or order changes, c] Material, and Equipment, and d] Contractual. Such challenges can be overcome by providing all needed information to the project team on time and the early involvement of all stakeholders will significantly improve and eliminate the factors impacting the projects, [44]. Empirical evidence was provided regarding the synergistic effect of LC principles and tools on a fast-track construction project's success, this is still to be more validated and deeply analyzed [45].

3. Research Methodology:

To gather the necessary data, a review of the literature was done and a designed questionnaire was distributed to construction professionals from various companies to achieve the study's objectives. The questionnaire was divided into 4 parts: 1) respondents' profile; like years of experience, level of education, position, and field of work, to validate the respondents' capability to answer the questions, 2) measuring the awareness level of lean construction through 35 items collected from previous studies, 3) measuring the adoption, barriers, and benefits of lean construction that constituted of 21 items, 4) fast-track projects and how it is impacted by the implementation of lean construction.

Sample size justification:

The sample size was calculated to achieve a power of (80%) to detect moderate correlations ($r \geq 0.3$) between both awareness and adoption with the different composite scores of the dependent variables.

Equation (1) is used to calculate the sample size (1).

$$N = \left[\frac{Z\alpha + Z\beta}{C}\right]^2 + 3 \; Eq.(1)$$

where: N is the sample size, Z_α is the standard normal deviate for α and was set to 1.96 to correspond to the desired significance level of 0.05, Z_β is the standard normal deviate for β and was set to 0.8416 to correspond to β error rate of 20%. C is the Fisher z-transformed value of the correlation coefficient *(r)*. This transformation is applied to correlation coefficients to stabilize the variance to allow precise sample size calculation. The transformation is particularly useful because the distribution of the correlation coefficient r becomes more skewed as it approaches its boundaries of -1 and 1. The transformed value was calculated using Eq. 2.

$$C = 0.5 \times \ln\left(\frac{1-r}{1+r}\right) Eq.(2)$$

Setting the hypothesized correlations between the dependent and independent variables of the study to a minimum of 0.3, the sample size was estimated to be 85 respondents. Considering additional 25% to account for incomplete responses or missing data, the final sample size was estimated to include at least 107 respondents.

Of the 149 surveys distributed, 133 participants responded (characteristics of the study group were shown in Table 4), so it is acceptable to analyze the data.

Table (4): Demographic characteristics of the study group [N=133]

Characteristic	N = 133[1]
Field of Work	
Contractor	62 [46.6%]
Consultant	42 [31.6%]
Owner	29 [21.8%]
Educational Qualification	
Bachelor	74 [55.6%]
Master	35 [26.3%]
Ph.D.	24 [18.0%]
Years of Experience	
Less than 10 years	13 [9.8%]
10 to 15 years	21 [15.8%]
15 to 25 years	62 [46.6%]
Over 25	37 [27.8%]

Statistical methodology:

The collected data were analyzed using a statistical package for social sciences (SPSS) Ver.26.0 software. Data visualization was adopted using R software (Version 4.3.1, R Foundation for Statistical Computing, Vienna, Austria). A two-sided $P<0.05$ was considered statistically significant for all analyses.

Participant demographics were summarized using descriptive statistics including frequencies and percentages for categorical variables, median and interquartile range (IQR) for continuous non-normally distributed data or mean ± standard deviation (SD) for normally distributed data. The normality of continuous variables was checked using Shapiro-Wilk tests. The items of lean construction awareness and adoption levels were compared by participant characteristics using chi-squared tests for categorical outcomes and Wilcoxon rank sum tests for continuous composite score variables. The composite score of awareness was calculated as the sum of scores of individual Likert scale items of awareness principles (questions from 2-6 if the participant was aware of the concept of lean construction (question 1), otherwise participants were assigned an awareness score of 0.

The following formula summarizes the calculation of awareness scores:

$$Total\ awareness = (Question1[0,1]) \times \sum Question\ 2{:}\ 6 \quad \text{Eq. 3}$$

Based on the calculated total awareness scores, each participant was classified as aware if the total score of awareness ≥ 80% of the maximum domain total (maximum score of awareness is 5×5=25), if the total score < 80% of the maximum total, participant the was classified as non-aware.

A similar method was utilized to categorize participants' adoption levels. The composite score of adoption was similarly calculated as follows:

$$Total\ adoption = (Question1[0,1]) \times \sum Question\ 2{:}\ 35 \quad \text{Eq. 4}$$

Where Q2:Q35 are the items describing the principles and techniques of lean adoption. Participants with composite adoption scores ≥80% of the maximum total (3×34) were classified as a high adoption group, otherwise they were classified with low adoption.

4. Results

The results of the questionnaire distributed among engineers to assess awareness of lean principles, as well as the benefits and challenges associated with its implementation, revealed several key findings. Firstly, there was a varying degree of awareness regarding lean construction principles among the respondents, with some demonstrating a thorough understanding while others exhibited limited knowledge. Secondly, the survey highlighted numerous perceived benefits of implementing lean principles in construction projects, including improved project efficiency, enhanced quality, and better resource utilization. Additionally, respondents identified several challenges hindering the effective implementation of lean practices, such as resistance to change, lack of management support, and cultural barriers within organizations.

4.1 Awareness of Lean Construction

The majority (88%) of respondents indicated familiarity with the overarching definition of lean construction, a closer examination of awareness levels concerning the five key lean principles revealed lower levels of understanding. None of the respondents reported being "Very Aware" of the principles of "Identify Customer Value", “Create Flow”, “Map the Value Stream", and "Seek Perfection", suggesting a lack of in-depth knowledge in these areas. The highest level of awareness was observed for "Identify Customer Value", with 48.1% expressing moderate awareness. Conversely, "Create Flow" and "Establish Pull" exhibited higher rates of respondents reporting being "Not at All Aware" - 27.8% and 30.8% respectively. The median total awareness score stood at 10 out of 15, indicating a moderate level of awareness overall, as outlined in Table 5.

Table (5): Description of the items of awareness domain (N=133)

Characteristic	**N = 133**[1]
Lean construction definition awareness	117 (88.0%)
Identify Customer Value	
Not all aware	1 (0.8%)
Slightly aware	8 (6.0%)
Somewhat aware	60 (45.1%)
Moderately aware	64 (48.1%)
Very aware	0 (0.0%)
Create Flow	
Not all aware	37 (27.8%)
Slightly aware	2 (1.5%)
Somewhat aware	69 (51.9%)
Moderately aware	25 (18.8%)
Very aware	0 (0.0%)
Map the Value Stream	
Not all aware	24 (18.0%)
Slightly aware	6 (4.5%)
Somewhat aware	63 (47.4%)
Moderately aware	40 (30.1%)
Very aware	0 (0.0%)
Establish Pull	
Not all aware	41 (30.8%)
Slightly aware	1 (0.8%)
Somewhat aware	67 (50.4%)
Moderately aware	24 (18.0%)
Very aware	0 (0.0%)
Seek Perfection	
Not all aware	2 (1.5%)
Slightly aware	22 (16.5%)
Somewhat aware	67 (50.4%)
Moderately aware	42 (31.6%)
Very aware	0 (0.0%)
Awareness Category	
Not aware	74 (55.6%)
Aware	59 (44.4%)
Total awareness	10.0 (7.0, 12.0)

[1]n (%); Median (IQR)

4.1 Awareness and Adoption

Regarding principles and techniques, aware participants of LC concepts [n=59] showed substantially higher adoption rates of lean methods compared to those not aware [n= 74] [72.9% vs 40.5%, $p<0.001$] as shown in Figure 1.

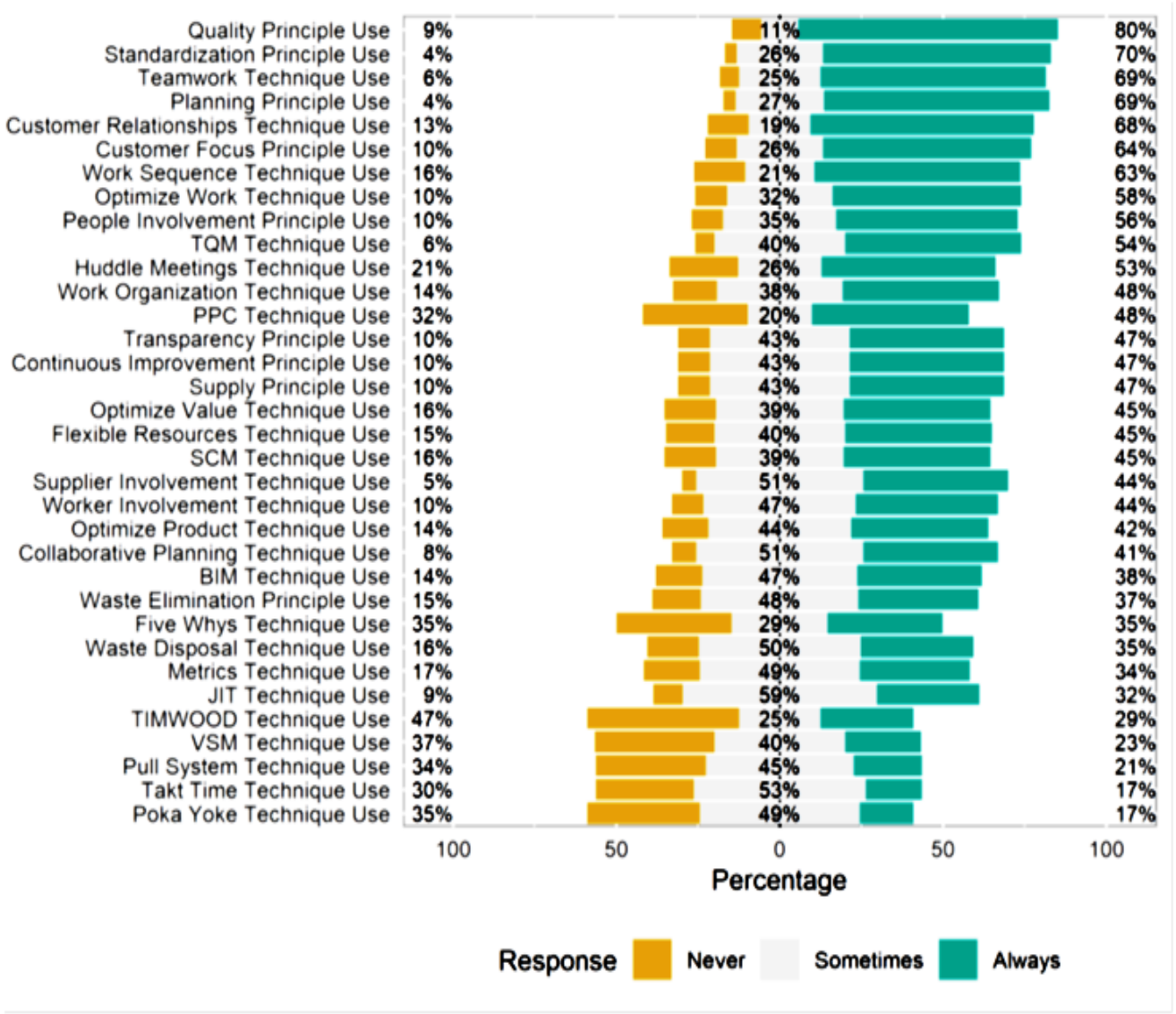

Figure (1): A Likert plot illustrates the trends in adopting lean construction principles and techniques, with items sorted from the highest positive trend at the top to the lowest positive trend at the bottom.

4.2 Barriers

The aware group demonstrated a higher level of agreement in recognizing barriers, with 40.7% strongly agreeing, compared to 20.3% in the unaware group [$p<0.001$]. The aware participants showed significant agreement regarding the time barrier compared to the non-aware participants [88.1% versus 41.9%, $p<0.001$]. Additionally, other barriers exhibited significantly higher agreement in the aware group, as shown in Figure 2.

This outcome aligns with a logical sequence, as awareness led to adoption, and thus increases the likelihood of encountering barriers with lean implementation in construction projects.

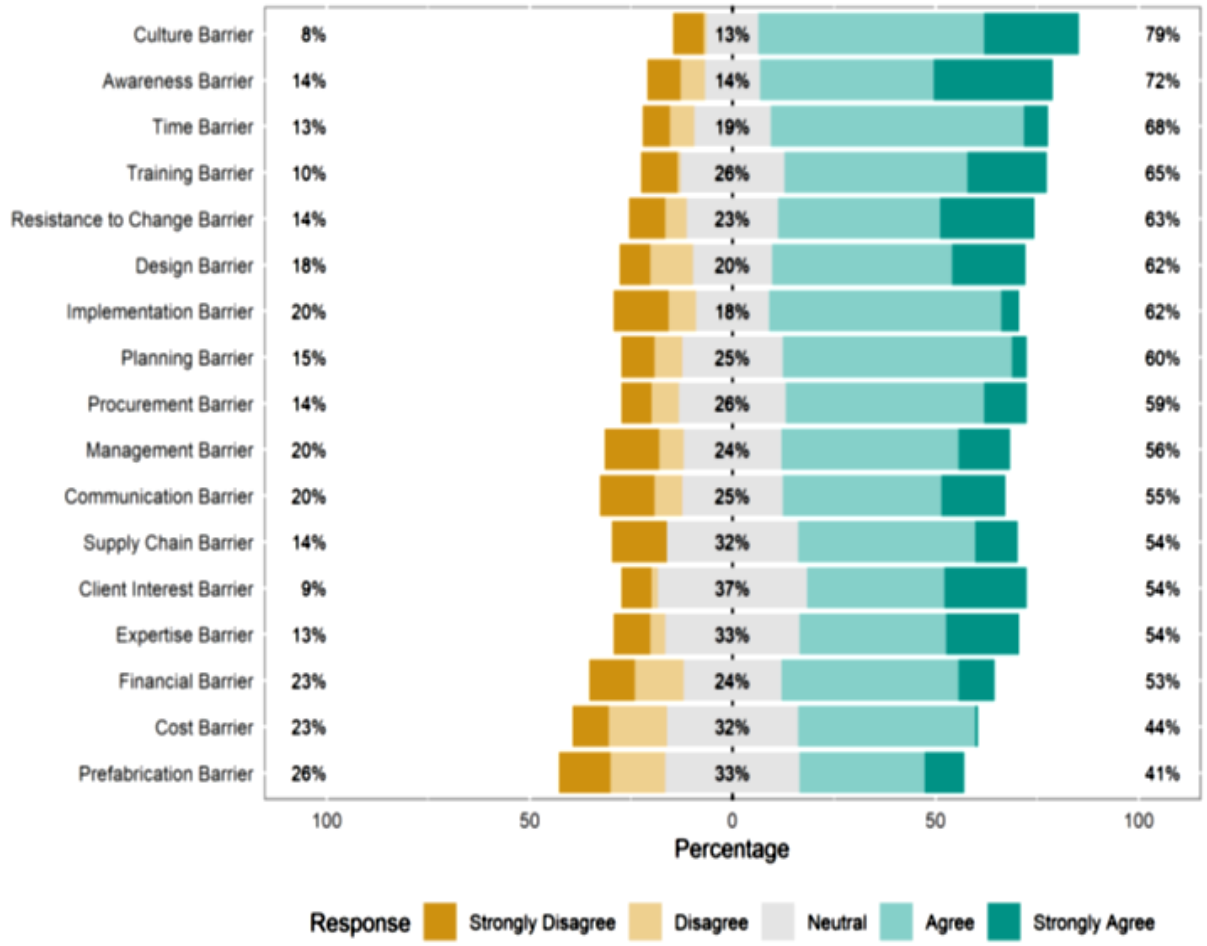

Figure (2): Likert plot illustrates trends in barriers to adopting lean construction, with items sorted from highest to lowest positive trend.

4.3 Environmental Benefits

Participants who were aware of lean construction practices demonstrated a greater recognition of environmental benefits across various domains. Specifically, a larger percentage of aware participants identified the following as highly beneficial when compared to non-aware group: time and material waste benefit [81.4% vs. 60.8%, p=0.005], material waste benefit [54.2% vs. 37.8%, p=0.009], quality benefit [62.7% vs. 59.5%, p=0.032], energy benefit [66.1% vs. 37.8%, p<0.001], and work environment benefit [64.4% vs. 43.2%, p=0.006]. Furthermore, none of the aware participants rated any domain as offering "no benefit." In contrast, among non-aware participants, only 6%-10% expressed no benefits across different environmental domains, as illustrated in Figure 3. These findings support existing research on the benefits of lean construction and underscore the correlation between awareness, adoption, and the perception of lean construction implementation benefits.

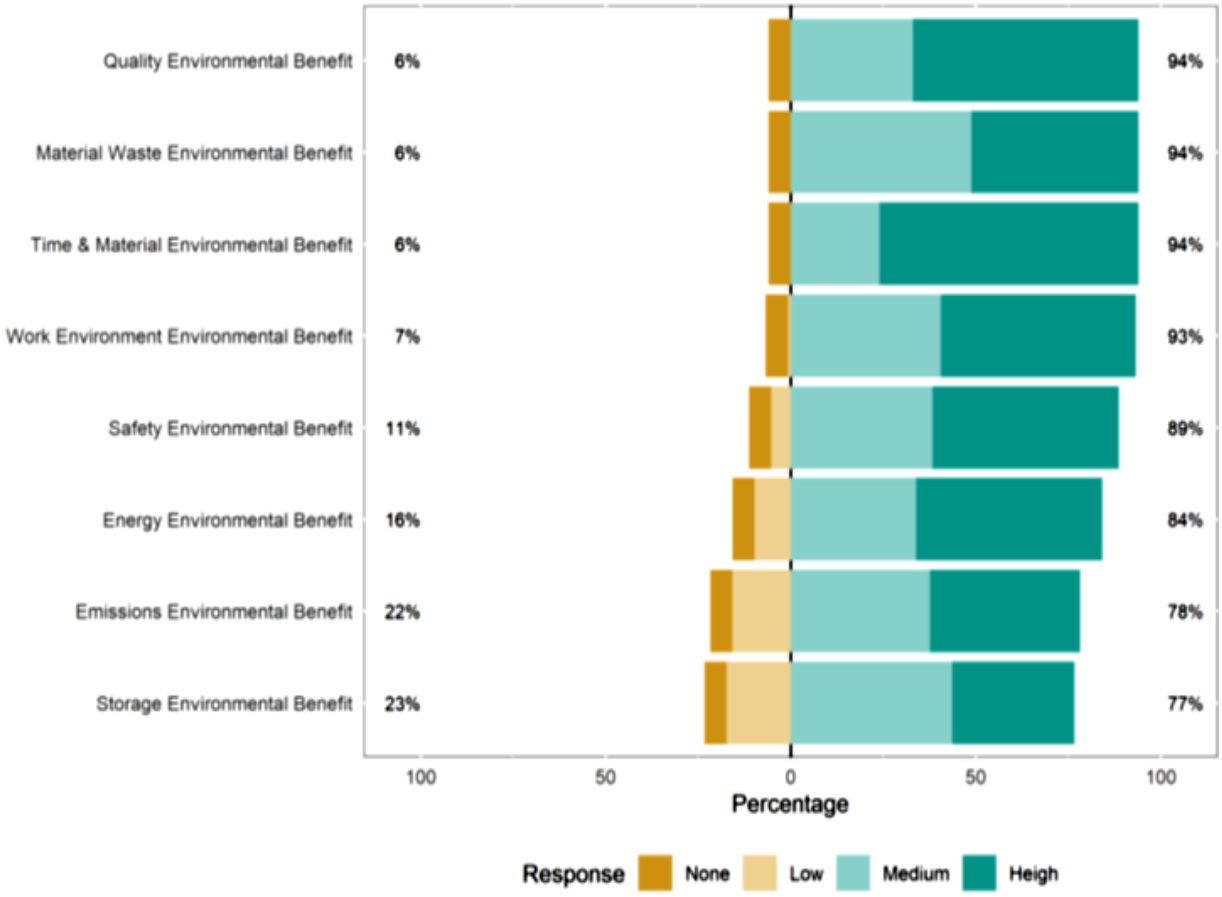

Figure (3): Likert plot shows trends in environmental benefits of lean construction, with items sorted from highest to lowest positive trend.

4.4 Economic Benefits

Among all participants, the top recognized economic benefits included quality improvement (71.4%), improved decision-making (70.7%), rework reduction (64.7%), time reduction (63.9%), and lifecycle cost reduction (61.7%). Moreover, more than half of the surveyed professionals, regardless of awareness level, identified high economic benefits for risk mitigation (62.4%), process improvement (61.7%), cost reduction (58.6%), value optimization (57.1%) and increased productivity (56.4%). These findings were consistent when comparing aware and non-aware participants regarding economic benefits. Remarkably, only 1.5% of participants perceived any economic domain to offer low or no benefit, as shown in Figure 4. This reflects the value added by lean construction, which not only saves time but also enhances quality.

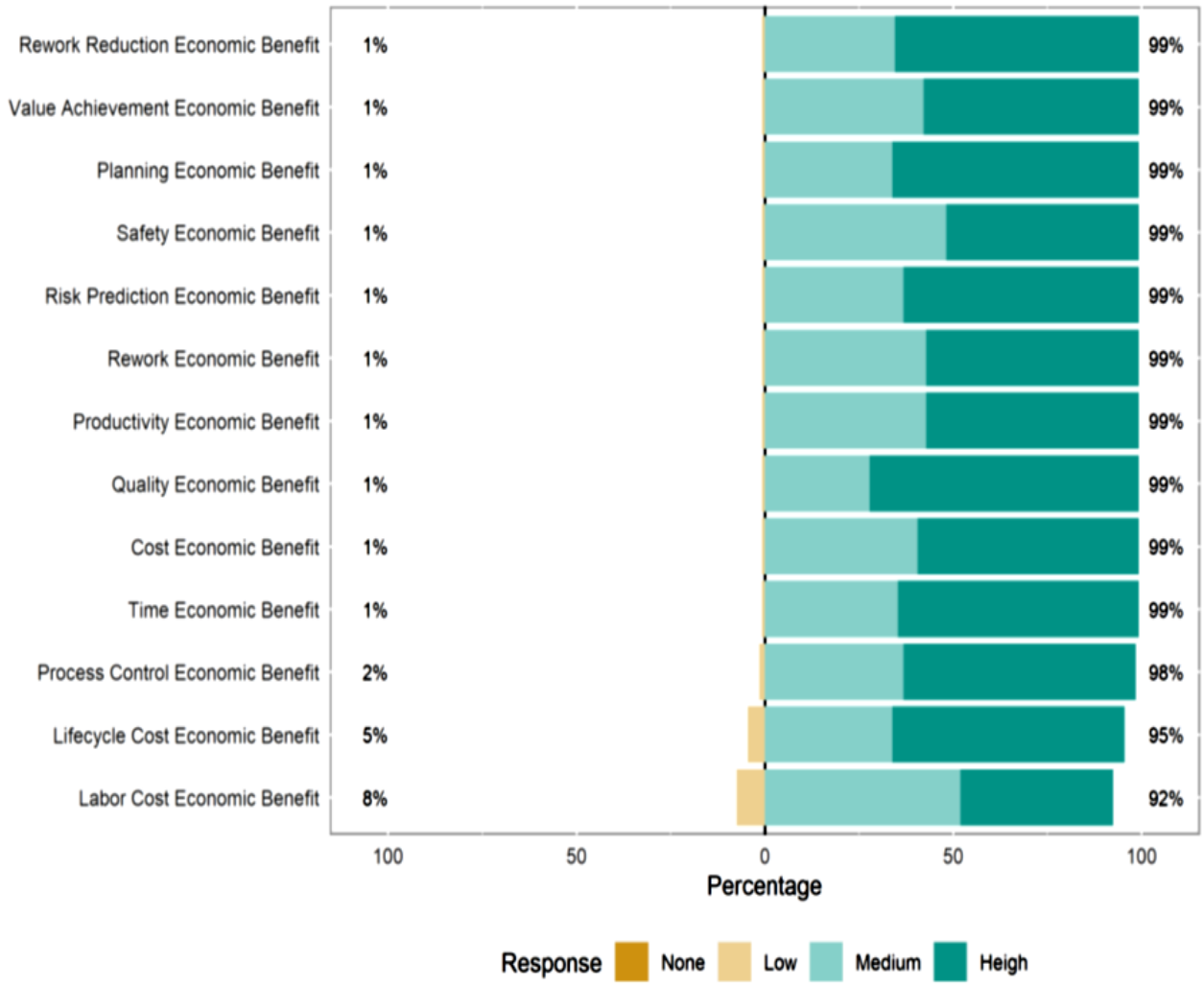

Figure (4): Likert plot illustrated trends in economic benefits of lean construction, with items sorted from highest to lowest positive trend.

4.5 Social Benefits

The application of Lean Construction (LC) concepts yields significant social benefits, including enhanced decision-making (70.7%), teamwork (65.4%), improved communication (60.9%), increased continuous improvement (57.9%) and greater customer satisfaction (56.4%). Moreover, a notable percentage of respondents recognized high benefits for employee satisfaction (43.6%), relationship building (42.1%), enhanced relationships (42.1%), and conflict reduction (45.1%). As shown in Figure 5, 1.5% of participants cited low or no social benefit, underscoring the consensus regarding the positive impact of lean construction on team dynamics and stakeholder engagement. Lean construction emphasizes social collaboration, particularly in the early phases of preparation and design.

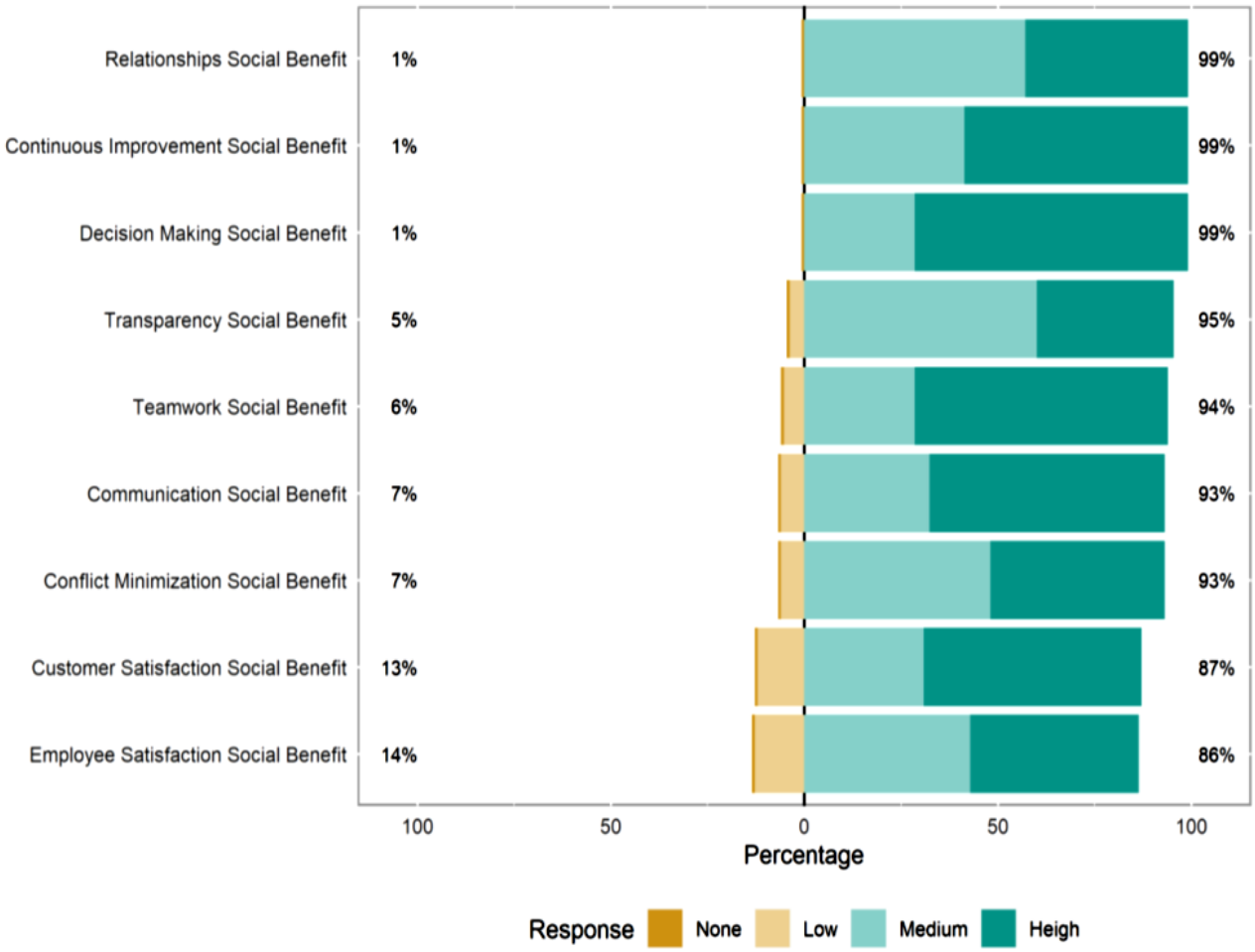

Figure (5): Likert plot illustrated trends in social benefits of lean construction, with items sorted from highest to lowest positive trend.

4.6 Fast-Track Projects:

Despite the potential benefits recognized by a considerable percentage of respondents (37.6%) strongly agreeing that lean construction tools and techniques can enhance fast-track project performance. A substantial portion (56.4%) did not strongly agree, suggesting uncertainties or lack of confidence in the efficacy of lean construction methodologies. This highlights a notable gap in understanding and perception. Thus, the need for enhanced education, training, and awareness initiatives to equip construction professionals with the knowledge and skills, also development of standardized framework to effectively implement lean principles in fast-track projects. Especially with the deflation affecting the economy, the timely execution of infrastructure and development projects becomes crucial. Lean methodologies streamline processes, minimize waste, and optimize resource utilization, enabling project teams to meet accelerated deadlines while maintaining quality standards. Therefore, enhance overall project performance and contribute to the sustainable development of projects which will eventually reflect on stimulating the economic growth of Egypt.

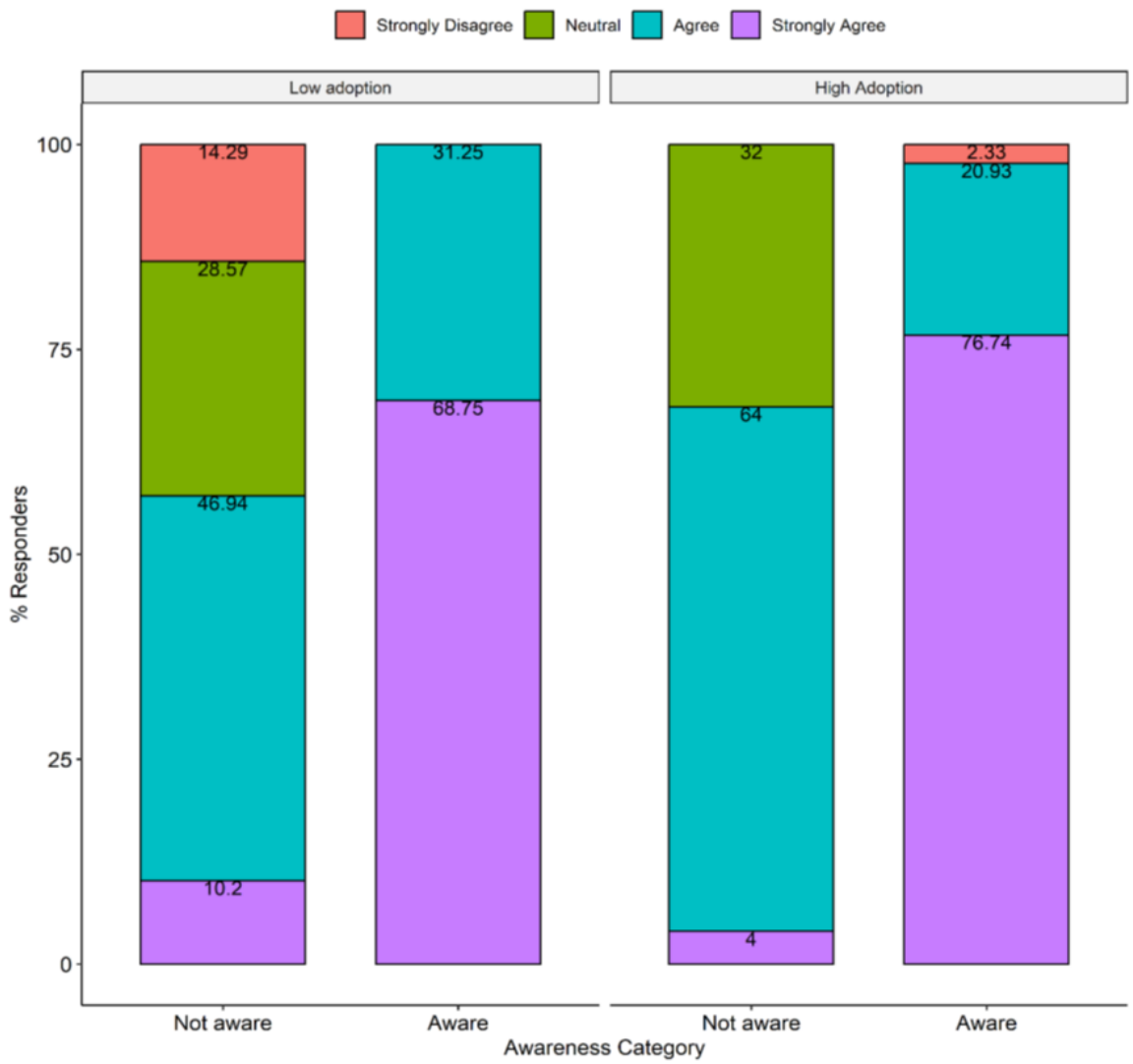

Figure (6): Comparing perception of fast-track improvement based on the perceived adoption level and the awareness level.

4.7 Reliability analysis:

Reliability is defined as the level to which quantities are duplicable when individuals implement the same process under various circumstances and various conditions but using the same research instrument [46]. For simplicity, reliability can be measured using Cronbach's coefficient alpha. This shows the average correlation of all items that make up the scale. Cronbach's coefficient alpha mainly depends on the number of items presented in the questionnaire, the fewer the items, the lower the value of Cronbach's alpha. Cronbach's alpha values above 0.7 are considered acceptable [47]. Therefore, based on Cronbach's alpha values, the study concludes that the questionnaire employed was reliable, with all assessed objectives exhibiting alpha values ranging from 0.86 to 0.97 as shown in Table 6.

Alpha (α) can be mathematically represented as [48]:

$$\alpha = \frac{k * r}{1 + [k - 1]r} \quad Eq. 5$$

Where: α = Symbol for Cronbach's coefficient alpha

k = Items (variables) in the scale;

r =Average of the inter-item correlations

Table (6): Assessment of the reliability of different domains of the survey

Domain	No. of items	Cronbach's Alpha	Reliability accepted
Awareness	6	0.86	Yes
Adoption	35	0.97	Yes
Barriers	17	0.96	Yes
Environmental benefits	8	0.95	Yes
Economic benefits	13	0.92	Yes
Social benefits	9	0.88	Yes
Benefits (All domains)	30	0.95	Yes

5- Conceptual Framework

The proposed framework as illustrated in Figure 7, was established after research in several directions based on the literature review and the analysis data from the questionnaire.

The first step in implementing the lean construction framework is to identify value-adding activities in the construction process. This involves understanding the needs and expectations of the client and focusing on delivering features that contribute to meeting those needs. Project teams should engage with the client and stakeholders to clearly define what aspects of the project are essential to delivering value.

Once the value-adding activities are identified, the next step is to identify and eliminate waste in the construction process. This involves reducing unnecessary movement of materials, optimizing workflow, and minimizing waiting times. Lean construction encourages project teams to regularly assess processes and identify areas where waste can be minimized or eliminated.

Continuous improvement is an integral part in lean construction. Establish a system for continuous improvement by fostering a culture of learning and innovation. This may involve conducting regular meetings to discuss challenges and brainstorm solutions.

Implement visual management techniques to make the status of the project and the flow of work visible to all stakeholders to enhance transparency and communication. By making the project's progress and potential issues visible, project teams can respond quickly and effectively.

Encourage open communication and collaboration among all project stakeholders. Foster a team environment where everyone is engaged in problem-solving and decision-making to drive project success.

Explore and adopt innovative technologies and best practices to streamline processes to enhance project efficiency and precision. This includes digital tools for project management, 3D modeling, and advanced construction methodologies.

Invest in the training and development of the workforce to equip them with the skills and knowledge necessary for identifying and addressing inefficiencies in real-time.

Implement pull planning techniques to create a detailed schedule based on the actual needs of the project. Embrace just-in-time delivery to minimize excess inventory and optimize resource utilization. This ensures that materials and resources are utilized efficiently without unnecessary delays or hoarding.

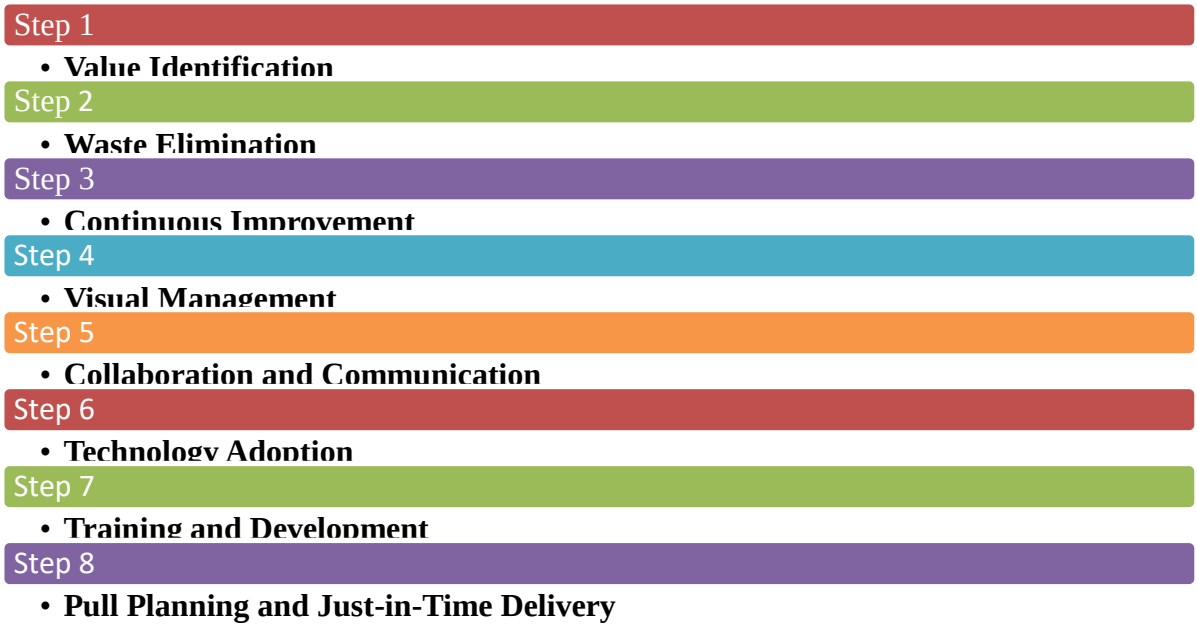

Figure (7): Proposed Framework

6. Conclusion

This research has significantly contributed to bridging the knowledge gap in the application and understanding of lean construction principles. It provides a comprehensive understanding of the awareness, adoption, benefits, and challenges associated with lean construction principles in the Egyptian construction industry.

The findings reflect the diverse landscape of awareness among respondents, revealing a spectrum ranging from a thorough understanding to limited knowledge of lean construction principles.

The observed link between awareness and adoption further emphasizes the importance of increasing knowledge levels for effective implementation. Notably, the study revealed that participants with higher awareness demonstrated substantially higher adoption rates of lean methods compared to those with limited awareness. The barriers identified by the aware group align

logically with the sequence of awareness leading to adoption, reinforcing the potential challenges faced during lean implementation in construction projects.

Regarding environmental, economic, and social benefits associated with lean construction. Participants with higher awareness recognized and acknowledged a broader spectrum of benefits, reinforcing the interconnected relationship between awareness, adoption, and perceived positive outcomes.

The study also shed light on the notable gap in understanding and perception concerning the application of lean principles in fast-track projects. The findings highlight the need for targeted educational programs, training initiatives, and the development of standardized frameworks to enhance professionals' knowledge and skills in effectively implementing lean principles in the fast-track project context, especially given the current economic challenges.

Finally, the proposed conceptual framework integrates insights from the literature review and questionnaire analysis, offering practical guidance for implementing lean construction principles in construction projects. The framework outlines key steps for identifying value-adding activities, eliminating waste, fostering continuous improvement, implementing visual management techniques, encouraging open communication and collaboration, adopting innovative technologies, investing in workforce development, and implementing pull planning techniques.

In summary, this research contributes to advancing knowledge and understanding of lean construction principles in the context of the construction industry in Egypt. Furthermore, the findings provide a foundation for further research, educational initiatives, and practical implementation strategies, ultimately promoting the effective adoption of lean construction practices and contributing to the advancement and sustainability of the construction sector in Egypt. The study also raised some questions that can be recommendations for future studies:

- To what extent do contextual differences (e.g., working culture, regulations) influence the adoption and implementation of Lean Construction?
- What types of support from regulatory agencies in developing countries could facilitate wider adoption of lean construction?

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