

Barriers to Effective Implementation of Lean in Construction Engineering Projects

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ABSTRACT

Lean Construction have been shown to help improve effectiveness, efficiency, achieve standardization of workflows, and enhance performance of projects in engineering. But despite their benefits, adoption still remains limited due to many barriers at the organizational, technical, or behavioral level. The purpose of this research is to identify and investigate the barriers affecting the implementation of lean tools. This research utilized a quantitative descriptive-correlational design. A structured survey questionnaire was developed and distributed to office engineers, project managers, site engineers, and architects to collect data on their knowledge of lean tools and to assess the barriers they perceive that affect the use of these tools. The data was analyzed using mean, ranking, Pearson correlation analysis and regression analysis. Findings revealed that respondents generally demonstrate a high level of awareness of lean tools and perceive their implementation as evident, particularly in reducing errors, rework, and delays. Correlation analysis showed that lean awareness is positively associated with implementation, while organizational, technical, and behavioral barriers are negatively associated with it, with behavioral factors identified as the most influential. Regression results further confirmed that the combined barriers significantly predict lean implementation, with behavioral barriers emerging as the only significant predictor.

KEYWORDS: Lean Construction, Lean Engineering

INTRODUCTION

Construction engineering projects continue to experience persistent inefficiencies such as delays, waste generation, cost overruns, and productivity losses, which significantly affect the overall project performance. Lean construction has been introduced as a management philosophy meant to improve efficiency, minimize non-value-adding activities, and enhance workflow reliability in construction processes. There are empirical studies show that lean implementation can significantly improve project outcomes, including cost reduction, schedule adherence, and productivity enhancement [5][2]. Studies also show that lean practices contribute to improved productivity, reduced waste, better quality, and enhanced project performance [9][11]. Furthermore, the integration of lean construction with digital technologies such as Building Information Modeling (BIM) has strengthened its contribution to project success by improving coordination, visualization, and decision-making [7][18]. These developments indicate that lean construction is increasingly relevant in modern engineering.

Previous researches also shows that lean implementation is influenced by a combination of organizational [13][17], technical [10][3], and behavioral factors [1][9]. Moreover, evidence suggests that these barriers are interconnected rather than independent. Organizational weaknesses often lead to technical limitations, which then influence behavioral resistance within project teams [15][8]. In addition, multiple studies have

identified persistent barriers such as lack of awareness, lack of training and concept understanding, resistance to change, and weak management support as major constraints to effective lean adoption [19][14][5]. Also, differences in perception between management and operational staff further complicate implementation, as decision-makers may underestimate the actual challenges experienced on-site [6]. Despite the recognized benefits, the implementation of lean construction remains limited and inconsistent across the construction industry. Many construction professionals are still not fully aware of lean principles, while others apply lean tools without formal understanding or structured implementation (Shaqour, 2022; Ahmed et al., 2021) [2][4]

The importance of addressing these barriers is evident in the potential benefits of lean construction when properly implemented. This highlights the complexity of lean implementation in real construction environments and the need for a more integrated understanding of its barriers. Although several studies have studied lean construction barriers and its success factors, most researches tend to focus on isolated factors or specific contexts. There is still limited empirical research that simultaneously examines organizational, technical, and behavioral barriers within construction engineering projects in a single integrated framework. This gap limits the development of targeted strategies for improving lean adoption in practice.

Therefore, this study aims to identify and analyze the barriers to effective implementation of lean in construction engineering projects, focusing on organizational, technical, and behavioral dimensions. It also seeks to assess the level of awareness of lean tools among construction professionals, examine the relationship between awareness, barriers and lean implementation, examine whether lean awareness, organizational barriers, technical barriers, and behavioral barriers significantly predict lean implementation in construction engineering projects and propose strategies for improving lean implementation. By addressing these gaps, the study contributes to bridging the divide between lean theory and practice and supports more effective implementation of lean construction in engineering projects.

LITERATURE REVIEW

Lean construction has been widely recognized as an effective approach for improving efficiency, reducing waste, and enhancing productivity in construction engineering projects. Across empirical studies, lean implementation has consistently demonstrated positive impacts on cost performance, schedule reduction, workflow optimization, and overall project success [5][9]. In addition, recent research highlights that lean construction is increasingly integrated with digital technologies such as Building Information Modeling (BIM), automation systems, and Industry 4.0 tools, which further enhance coordination, visualization, and decision-making in construction [7][18]. One research also examined that the key enablers that have an impact on the effective implementation of Lean are the skills and expertise, active work methods, and leadership style, it also stated the impact of digital technologies can enhance the integration of Lean practices [3]. While another researched found out that cooperation within work teams and participation in decision-making are one of the critical factors of a successful lean implementation [1].

Despite the benefits, the studies consistently shows that the implementation of lean construction remains limited and uneven across the construction industry due to the persistent barriers. Studies across different countries and project environments repeatedly identify lack of awareness, insufficient understanding of lean principles, resistance to change, inadequate training, and weak management support as the most dominant challenges affecting [5][19][14]. Similar findings are reported in developing construction contexts where traditional project management practices remain dominant, resulting in fragmented

communication, poor collaboration, and limited knowledge sharing [8][12]. The consistency of these barriers across diverse geographic and industrial contexts suggests that lean implementation challenges are not isolated but rather systemic in nature within the construction sector.

To better understand these challenges, the researches commonly categorize these barriers into three types. These are organizational, technical, and behavioral dimensions. Organizational barriers are often associated with weak leadership commitment, lack of strategic direction, and insufficient allocation of resources, all of which significantly affect lean adoption outcomes [13][17]. Technical barriers, on the other hand, include limited knowledge of lean tools, lack of training, and inadequate technological integration such as poor BIM adoption or lack of standardized processes [14][10]. It also includes the inadequate equipment and nonuse of modern techniques and technologies [4]. Behavioral barriers are strongly linked to human factors such as resistance to change, low engagement, and negative attitudes toward new construction methodologies [1][9].

Further synthesis of the studies revealed that these barrier categories are highly interrelated. Organizational weaknesses such as poor leadership and lack of commitment often result in insufficient training and technical resources, which subsequently contribute to behavioral resistance among employees [15][8]. Similarly, studies show that awareness plays a critical role in bridging this gap, as higher levels of lean awareness are associated with increased adoption rates and improved project outcomes [10][2]. Moreover, differences in perception across organizational levels further complicate implementation, as top management often perceives fewer barriers compared to operational staff who directly engage in lean processes [6].

Recent studies also emphasized that successful lean implementation depends heavily on human and organizational readiness rather than tools alone. Research indicates that people involvement, leadership commitment, and continuous improvement culture are among the strongest determinants of lean success [11][17]. Furthermore, a study stated that people directly influence the successful implementation of lean construction by individual level which are traits, motives, and leadership, then the corporate level which are working culture, capability, process, and change readiness. And lastly is the governance level namely its policies, codes, and regulations [5]. Additionally, in overcoming barriers, structural and managerial readiness, including clear implementation frameworks and strategic alignment, plays a significant role [16][3].

METHODOLOGY

This study employed a quantitative descriptive-correlational research design to examine the barriers affecting the implementation of lean tools in engineering projects. The descriptive component was used to determine the level of awareness and identify the extent of organizational, technical, and behavioral barriers. Meanwhile, the correlational approach was utilized to examine the relationship between these barriers and the level of lean tool implementation. The study was conducted across various engineering and construction project environments in a private company in the Philippines. Respondents were drawn from different project sites to capture diverse perspectives on lean implementation and barriers. The distributed nature of respondents reflects real-world project conditions where professionals operate in different locations and project setups. The target population of this study comprises of engineering professionals involved in project execution, including site engineers, architects, project managers, and office engineers. However, the exact population size could not be determined due to the absence of a centralized database and the dispersion of professionals across multiple project sites. Given this limitation,

a non-probability convenience sampling technique was adopted, whereby respondents were selected based on accessibility and relevance to the research objectives. Convenience sampling is widely utilized in applied research contexts where sampling frames are difficult to establish, particularly in construction and engineering environments characterized by fragmented populations. A total of 30 respondents were surveyed, which is commonly regarded as a minimum threshold for preliminary statistical analysis. This is supported by the Central Limit Theorem, which states that the sampling distribution of the mean tends toward normality as sample size increases. In practice, a sample size of $n \geq 30$ is often considered sufficient for approximating normality and enabling the use of parametric statistical techniques such as mean estimation and correlation analysis.

The primary data collection tool used in this study was a structured survey questionnaire designed to assess awareness and barriers related to lean implementation. A self-made research questionnaire using a four-point (4 point) Likert scale (4 – Strongly Agree to 1 – Strongly Disagree) was formulated based on established studies on lean construction and adapted to suit the context of engineering projects. Reliability of the instrument can be assessed using Cronbach’s alpha, which measures the internal consistency of survey items. A Cronbach’s alpha value of 0.70 or higher is generally considered acceptable for research purposes. The results confirmed that the scale possessed excellent realizability, with reliability coefficients of 0.933 for awareness of lean, 0.935 for organizational barriers, 0.951 for technical barrier and 0.908 for Lean Implementation. These values indicated that the items consistently measured their respective constructions and were adequate for data collection. Respondents were informed of the purpose of the study and were assured that their responses would remain confidential and used solely for academic purposes. Participation was voluntary, and respondents had the right to withdraw at any time without consequence.

The collected data were analyzed using both descriptive and inferential statistical methods. Mean was used to measure awareness levels, barriers and level of implementation. Ranking was used to identify the most significant barriers Pearson Product-Moment Correlation Coefficient (r) was used to determine the relationship between barriers (organizational, technical, behavioral) and the level of lean implementation as well as the relationship of awareness and level of lean implementation. The level of significance was set at 0.05, where: $p < 0.05$, Reject H0 (significant relationship) and $p > 0.05$, Fail to reject H0 (no significant relationship). Lastly, Multiple Linear Regression Analysis was used to determine whether organizational, technical, and behavioral barriers significantly predict the level of lean implementation among construction engineering projects. The level of significance was set at 0.05, where: $p < 0.05$, Reject H0 (barriers significantly predict lean implementation) and $p > 0.05$, Fail to reject H0 (barriers do not significantly predict lean implementation).

RESULTS

Awareness Indicators	W M	SD	Rankin g	Interpretatio n
I am familiar with lean construction principles.	2.77	0.7 7	1	High
I understand the purpose and benefits of Lean and Lean tools.	2.67	0.9 6	3	High
I am confident in applying lean tools in engineering projects.	2.73	0.8	2	High

		3		
I actively update my knowledge on lean.	2.43	0.82	5	Low
I can select the appropriate lean tool for a given project situation.	2.63	0.85	4	High
Overall	2.65	0.85		

Table 1. Awareness of Lean in Construction

Scoring Range: 3.26 – 4.00 (Very High); 2.51 – 3.25 (High); 1.76 – 2.50 (Low); 1.00 – 1.75 (Very Low)

Table 1 indicates that the respondents generally demonstrated a high level of awareness regarding lean construction principles and lean tools, with an overall mean of 2.65 and a standard deviation of 0.85. This suggests that, on average, respondents have adequate knowledge and understanding of lean concepts and their application in engineering projects.

Among the indicators, “I am familiar with lean construction principles” obtained the highest mean score (M = 2.77, SD = 0.77), ranking first and interpreted as High Awareness. This indicates that most respondents are generally knowledgeable about the basic principles of lean construction. However, the statement “I actively update my knowledge on lean” obtained the lowest mean score (M = 2.43, SD = 0.82) and was interpreted as Low Awareness.

Table 2. Organizational Barriers

Organizational Barriers	WM	SD	Rank	Interpretation
Management do not actively support lean implementation.	2.17	0.91	1	Low Barrier
Project policies do not clearly promote lean practices.	2.17	0.87	1	Low Barrier
Coordination between teams is not sufficient to implement lean.	2.13	0.86	4	Low Barrier
Leadership do not communicate the importance of lean tools effectively.	1.97	0.89	6	Low Barrier
There are no adequate resources (time, personnel, tools) are provided for lean implementation.	2.03	0.93	5	Low Barrier
There are no recognition and incentives to encourage the use of lean tools.	2.17	0.87	1	Low Barrier
Organizational culture does not support continuous improvement and change.	1.90	0.84	7	Low Barrier
Overall	2.08	0.88		Low Barrier

Scoring Range: 3.26 – 4.00 (Very High); 2.51 – 3.25 (High); 1.76 – 2.50 (Low); 1.00 – 1.75 (Very Low)

In Table 2, among the indicators, “Organizational culture does not support continuous improvement and change.” obtained the lowest mean score of 1.90 (SD = 0.84), ranking last among the organizational barriers. Meanwhile, “Management do not actively support lean implementation.,” “Project policies do not clearly promote lean practices.,” and “There are no recognition and incentives to encourage the use of lean tools.” obtained the highest mean score of 2.17, although it is still interpreted as Low Barrier.

Table 3. Technical Barriers

Technical Barriers	WM	SD	Rank	Interpretation
There is no sufficient training is provided for lean tools.	2.20	1.03	3	Low Barrier
Necessary tools and technology are not available for lean implementation.	2.30	0.88	1	Low Barrier
Standardized procedures do not exist for using lean tools effectively.	2.23	0.86	2	Low Barrier
Project management software does not support lean practices.	1.97	0.89	6	Low Barrier
Technical support is not available when challenges arise.	2.07	0.87	5	Low Barrier
Documentation for lean processes is incomplete and inaccessible.	2.20	0.92	3	Low Barrier
Overall	2.16	0.91		

Scoring Range: 3.26 – 4.00 (Very High); 2.51 – 3.25 (High); 1.76 – 2.50 (Low); 1.00 – 1.75 (Very Low)

Table 3 represents the technical barriers affecting Lean Construction implementation in engineering projects. It shows that respondents generally perceived technical barriers to lean implementation as a low barrier, with an overall weighted mean of 2.16 and a standard deviation of 0.91. Among the indicators, “Necessary tools and technology are not available for lean implementation” obtained the highest weighted mean (WM = 2.30, SD = 0.88), ranking first and indicating that this was the most perceived technical barrier among the respondents. In contrast, “Project management software does not support lean practices” obtained the lowest weighted mean (WM = 1.97, SD = 0.89).

Table 4. Behavioral Barriers

Behavioral Barriers	Mean	SD	Rank	Interpretation
Employees do not willingly apply lean in projects.	2.17	0.75	3	Low Barrier
Workers are not motivated to learn and use lean tools.	2.23	0.77	2	Low Barrier
Teamwork is not effective in implementing lean practices.	1.83	0.87	7	Low Barrier
Peer influence does not encourage proper use of lean tools.	1.97	0.81	6	Low Barrier
Employees are discouraged by additional workload when using lean tools	2.30	0.65	1	Low Barrier
Employees do not seek to improve processes using lean tools.	2.07	0.64	4	Low Barrier
Collaboration across teams is not sufficient to implement lean practices.	2.00	0.69	5	Low Barrier
Overall	2.08	0.74		

Scoring Range: 3.26 – 4.00 (Very High); 2.51 – 3.25 (High); 1.76 – 2.50 (Low); 1.00 – 1.75 (Very Low)

Table 4 presents the behavioral barriers affecting Lean Construction implementation in engineering projects. The findings revealed that respondents generally perceived behavioral barriers as a low barrier, with an overall mean of 2.08 and a standard deviation of 0.74. Although all indicators were interpreted as low barriers, the results suggest that certain behavioral challenges affecting lean implementation still exist within engineering projects. Among the indicators, “Employees are discouraged by additional workload when using lean tools” obtained the highest mean ($M = 2.30$, $SD = 0.65$), ranking first and indicating that workload concerns were the most perceived behavioral barrier affecting lean implementation. In contrast, “Teamwork is not effective in implementing lean practices” obtained the lowest mean ($M = 1.83$, $SD = 0.87$), suggesting that ineffective teamwork was the least perceived behavioral barrier.

Table 5. Level of Lean Implementation among Construction Engineering Projects

Lean Implementation	Mean	SD	Rank	Interpretation
Lean Construction are applied consistently in projects.	2.70	0.88	6	Implementation is Evident
Lean tools improve workflow efficiency in my project.	3.03	0.76	5	Implementation is Evident
Use of lean tools reduces errors, rework, and delays.	3.23	0.73	1	Implementation is Evident
Lean tools help projects meet deadlines and deliverables.	3.13	0.73	2	Implementation is Evident
Communication among teams improves due to lean tool adoption.	3.07	0.69	4	Implementation is Evident
Standardization of processes is enhanced through lean tool usage.	3.10	0.71	3	Implementation is Evident
Overall	3.04	0.75		

Scoring Range: 3.26 – 4.00 (Highly Evident); 2.51 – 3.25 (Evident); 1.76 – 2.50 (Slightly Evident); 1.00 – 1.75 (Not Evident)

The results in Table 5 indicate that the level of lean implementation among construction engineering projects is generally evident, with an overall mean of 3.04 ($SD = 0.75$). In terms of the highest-rated indicator, “Use of lean tools reduces errors, rework, and delays” obtained the highest mean score of 3.23 ($SD = 0.73$, Rank = 1). On the other hand, the lowest-rated indicator is “Lean Construction are applied consistently in projects” with a mean of 2.70 ($SD = 0.88$, Rank = 6). This suggests that while lean tools are recognized and their benefits are evident, their application is not yet consistently practiced across all construction projects.

Table 6. Relationship Between Lean Awareness, Organizational, Technical, and Behavioral Barriers, and Lean Implementation

Independent	Dependent	Pearson r	p-value	Decision (H_0)	Interpretation
Awareness	Implementation	0.683	3.1555E-05	Reject H_0	Strong
Organizational Barriers	Implementation	-0.703	1.4556E-05	Reject H_0	Strong

Technical Barriers	Implementation	-0.680	3.6210E-05	Reject Ho	Strong
Behavioral Barriers	Implementation	-0.844	4.8022E-09	Reject Ho	Very strong

Note. ^aCorrelation: 0.00 – 0.19 (very weak); 0.20 – 0.39 (weak); 0.40 – 0.59 (moderate); 0.60 – 0.79 (strong); 0.80 – 1.00 (very strong). ^bSignificant at <.05.

The results in Table 6 indicate that there is a statistically significant relationship between lean awareness, organizational barriers, technical barriers, behavioral barriers, and lean construction implementation, as all variables yielded p-values below 0.05, leading to the rejection of the null hypothesis. This confirms that both awareness and barrier-related factors are significantly associated with the level of lean implementation in construction engineering projects. The findings show that lean awareness has a strong positive correlation with lean implementation ($r = 0.683$), suggesting that higher awareness and understanding of lean principles are associated with better implementation outcomes. On the other hand, all identified barriers exhibit a negative relationship with lean implementation, meaning that as barriers increase, the level of implementation decreases. Specifically, organizational barriers ($r = -0.703$) and technical barriers ($r = -0.680$) both show strong negative correlations. The most influential factor, however, is behavioral barriers ($r = -0.844$), which shows a very strong negative relationship with lean implementation.

Table 7. Model Summary of the Combined Predictive Power of Organizational, Technical, and Behavioral Barriers on the Level of Lean Implementation in Construction Engineering Projects

Model	R ²	Adj. R ²	F	df	p-value	Interpretation
1	0.727	0.696	23.127	(3, 26)	1.659E-07	p-value is < .001, Significant

Note: Barriers (Constant) Organizational, Technical, Behavioral; *Dependent Variable:* Lean Implementation

The results in Table 7 shows that the combined organizational, technical, and behavioral barriers significantly predict the level of lean implementation in construction engineering projects. The regression model is statistically significant, with an F-value of 23.127 and a p-value of 1.659×10^{-7} ($p < .001$), indicating that the model provides a good fit for explaining variations in lean implementation. The R² value of 0.727 suggests that approximately 72.7% of the variation in lean implementation is explained by the combined effect of the three barrier categories, while the adjusted R² of 0.696 confirms that the model remains strong even after adjusting for the number of predictors. This indicates that organizational, technical, and behavioral factors collectively have substantial explanatory power over lean implementation outcomes.

Table 8. Predictive Power of Organizational, Technical, and Behavioral Barriers on the Level of Lean Implementation in Construction Engineering Projects

Predictors	B	SE	Beta (β)	p-value	Decision	Interpretation
Organizational	-0.227	0.191	-1.192	0.244	Fail to	Not Significant

Barriers					Reject Ho	
Technical Barriers	0.112	0.188	0.596	0.556	Fail to Reject Ho	Not Significant
Behavioral Barriers	-0.87	0.193	-4.502	0.0001	Reject Ho	Significant

Note: Barriers (Constant) Organizational, Technical, Behavioral; *Dependent Variable: Lean Implementation*

Table 8 further presents the individual contribution of each predictor. The results show that behavioral barriers are the only statistically significant predictor of lean implementation, with a coefficient of $B = -0.87$, $\beta = -4.502$, and $p = 0.0001$, indicating a strong negative effect. This means that increases in behavioral barriers such as resistance to change, low engagement, and negative attitudes significantly reduce the level of lean implementation in construction projects. While, organizational barriers ($B = -0.227$, $p = 0.244$) and technical barriers ($B = 0.112$, $p = 0.556$) were found to be statistically insignificant predictors.

DISCUSSION

Table 1 suggests that although respondents are generally aware of lean principles and tools, they may not consistently engage in continuous learning or professional development related to lean practices. Overall, the findings imply that respondents possess a high awareness and understanding of lean construction concepts, there is still a need to encourage continuous learning and knowledge updating to further strengthen lean implementation competencies. Similarly, a study emphasized that while construction professionals may apply lean tools, their knowledge and understanding of lean concepts often remain limited, indicating the need for continuous education and training [2].

In Table 2, findings suggest that while organizational support is generally evident, certain areas such as management commitment, policy integration, and incentive systems may still require improvement to strengthen Lean Implementation in construction projects. The findings of the study are consistent with previous literature emphasizing the importance of organizational factors in Lean Construction implementation. Previous study identified lack of top management support, weak organizational commitment as one of the major barriers affecting Lean implementation in construction projects. It also states that policies, codes, and regulations directly influence the successful implementation of lean construction [5]. Similarly, this also aligns with the findings of other studies that insufficient leadership commitment, was also recognized as a significant barrier to Lean implementation [15][19]. Overall, the findings imply that although organizational conditions generally support Lean Construction, improvements in management support, policy enforcement, coordination, and incentive systems are still necessary to achieve more effective Lean Construction implementation.

In Table 3, among the indicators, “Necessary tools and technology are not available for lean implementation” obtained the highest weighted mean and ranking first. Which means that was the most perceived technical barrier among the respondents. This finding aligns with the study, which identified that one of the top-ranked challenges to implementing lean construction are inadequate resources and the nonuse of modern techniques and technologies [4]. In contrast, “Project management software does not support lean practices” obtained the lowest weighted mean, suggesting that software limitations were the least perceived technical barrier. This result aligns with the findings of a study in which stated that skills,

expertise, and digital technologies positively impact lean implementation [3]. Overall, the findings suggest that while some technical challenges exist, respondents generally do not consider technical factors as major barriers to lean tool implementation.

In Table 4, among the indicators, “Employees are discouraged by additional workload when using lean tools” obtained the highest mean, ranking first and indicating that workload concerns were the most perceived behavioral barrier affecting lean implementation. This finding is supported by a study that identified resistance to change and human-related factors as significant barriers influencing Lean Construction adoption and implementation [5]. In contrast, “Teamwork is not effective in implementing lean practices” obtained the lowest mean, suggesting that ineffective teamwork was the least perceived behavioral barrier affecting lean implementation. This finding aligns with the study which emphasized that cooperation within work teams and participation in decision-making contribute to the successful implementation of Lean Construction practices [1]. Overall, the findings indicate that while behavioral barriers were generally rated low by the respondents, challenges related to employee workload, motivation, and collaboration still exist and may influence the effective implementation of lean practices in engineering projects.

The results in Table 5 suggests that lean construction practices are already being applied in engineering projects and are perceived to contribute positively to project performance, particularly in improving efficiency and workflow processes. In terms of the highest-rated indicator, “Use of lean tools reduces errors, rework, and delays” obtained the highest mean score, this reflects that respondents strongly recognize the effectiveness of lean implementation in improving construction outcomes by minimizing inefficiencies such as rework and project delays. This finding aligns with previous studies which emphasize that lean construction significantly enhances efficiency, reduces waste, and improves overall project performance in terms of cost, schedule, and workflow optimization [5][9]. On the other hand, the lowest-rated indicator is “Lean Construction are applied consistently in projects”. This suggests that while lean tools are recognized and their benefits are evident, their application is not yet consistently practiced across all construction projects. This result is consistent with literature indicating that lean implementation remains limited and uneven in practice due to various challenges such as resistance to change, lack of awareness, and insufficient organizational support [5][19][14]. It also reflects the broader gap between theoretical benefits and actual implementation in real construction settings, where traditional practices often remain dominant [8][12]. Overall, the findings imply that although lean construction is already evident and provides clear benefits in reducing errors, rework, and delays, the inconsistent application across projects are still evident.

The results in Table 6, confirms that both awareness and barrier-related factors are significantly associated with the level of lean implementation in construction engineering projects. The findings show that higher awareness and understanding of lean principles are associated with better implementation outcomes. This supports the idea that knowledge and familiarity with lean concepts enhance their practical application in construction settings [10][2]. Also, all identified barriers exhibit a negative relationship with lean implementation, meaning that as barriers increase, the level of implementation decreases. Specifically, organizational barriers and technical barriers both show a strong negative correlation, indicating that issues such as weak leadership support, insufficient resources, lack of training, and limited technical integration significantly hinder lean adoption [13][14]. The most influential factor, however, is behavioral barriers, which shows a very strong negative relationship with lean implementation. This suggests that human-related factors such as resistance to change, low engagement, and negative attitudes have the greatest

impact in limiting the successful implementation of lean construction, consistent with findings emphasizing the importance of behavioral and cultural readiness in lean adoption [1][9]. Overall, the results imply that while increasing awareness can significantly enhance lean implementation, the presence of organizational, technical, and especially behavioral barriers can substantially reduce its effectiveness. Table 8 means that increases in behavioral barriers such as resistance to change, low engagement, and negative attitudes significantly reduce the level of lean implementation in construction projects. This finding is consistent with literature emphasizing that human-related factors are among the most critical determinants of lean success, as behavioral resistance often undermines even well-structured implementation effort [1][9]. In contrast, organizational barriers and technical barriers were found to be statistically insignificant predictors. This suggests that although these factors may influence lean implementation in practice, their individual impact is not strong enough to significantly predict implementation levels when combined with other variables in the model. Organizational factors such as leadership support and resource allocation, as well as technical aspects such as training and tool integration, may still play indirect roles but are overshadowed by behavioral factors in this analysis [13][14]. Overall, the regression results indicate that while the combined barriers significantly explain lean implementation levels, behavioral barriers are the most critical influencing factor, highlighting the role of human behavior in determining the success of lean construction implementation in engineering projects.

Several recommendations can be drawn to enhance lean construction implementation in engineering projects. Since behavioral barriers were identified as the most influential factor affecting implementation, construction organizations should prioritize strategies that strengthen employee engagement, motivation, and willingness to adopt lean practices. This may be achieved through structured change management initiatives, active involvement of employees in decision-making, and fostering teamwork and collaboration across project teams to reduce resistance to change and improve acceptance of lean methods [1][9].

In addition, although respondents demonstrated a generally high level of awareness of lean construction, the results suggest that continuous learning remains limited. Therefore, organizations should implement regular training programs, workshops, and continuous professional development activities focused on lean tools and principles. Strengthening knowledge updating practices will help ensure that awareness is translated into more consistent and effective application of lean methods in actual construction settings [2].

Furthermore, to address the issue of inconsistent implementation across projects, it is recommended that construction firms develop standardized lean implementation frameworks and guidelines. This will help ensure uniform application of lean practices regardless of project type or team composition. At the same time, management should reinforce leadership commitment by integrating lean principles into organizational policies, providing adequate resources, and recognizing teams that successfully apply lean practices, thereby strengthening organizational support systems [5]. Finally, even though technical barriers were generally rated low, improving access to appropriate tools, technologies, and training support remains significant for lean implementation. Enhancing technical readiness, combined with strengthening organizational commitment and behavioral engagement, will support a more rounded and effective implementation of lean construction across engineering projects.

CONCLUSIONS/RECOMMENDATIONS

Based on the findings of the study, it can be concluded that lean construction awareness, implementation, and barrier levels are all present but vary in strength and influence across construction engineering projects.

First, the respondents demonstrated a generally high level of awareness of lean construction principles (Overall WM = 2.65). This indicates that most participants are familiar with lean concepts and have a good understanding of their purpose and application. However, the lower score in continuous learning suggests that while awareness is sufficient, it is not consistently developed through ongoing professional growth.

Second, the results show that organizational, technical, and behavioral barriers are all rated as low (Overall WM = 2.11), meaning they are not considered major obstacles in general. Among these, technical barriers were slightly more evident, although still low, indicating minor limitations in training, tools, and system support.

Third, the level of lean implementation is generally evident (Overall WM = 3.04), particularly in reducing errors, rework, and delays, and in improving deadlines, communication, and standardization. However, the lowest-rated indicator shows that lean is not consistently applied across all projects, indicating variability in implementation practices.

In terms of relationships using Pearson's analysis, the study found out that lean awareness has a strong positive relationship with lean implementation, while all three barriers have a negative relationship with lean implementation. Among them, behavioral barriers show the strongest negative influence, meaning human factors such as resistance to change and motivation are the most critical limitations to successful lean implementation. Regression results further confirm this, showing that behavioral barriers are the only significant predictor of lean implementation, while organizational and technical barriers are not statistically significant on their own. However, the combined model explains a substantial portion of variation in lean implementation ($R^2 = 0.727$), confirming that these factors collectively still matter.

Overall, the study concludes that lean construction is already understood and partially implemented in construction engineering projects, but its effectiveness is mainly constrained by behavioral factors and inconsistent application across projects.

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