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Unveiling Effectiveness of Lean Construction Practices: A Comprehensive Study through Surveys and Case Studies

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Abstract

Construction projects frequently encounter challenges such as stagnant productivity, excessive waste, cost overruns, and delays, contributing to sustainability issues. In response to these issues, Lean Construction (LC) has emerged as a methodology aimed at eradicating inefficiencies and wasteful practices. However, the construction industry has been slow to embrace LC, primarily due to a lack of comprehensive evaluations regarding its real-world effectiveness. This study seeks to thoroughly assess the effectiveness of LC when implemented in construction projects in Pakistan. The research involved conducting a survey among experts in the construction industry, utilizing a comprehensive questionnaire to evaluate the extent of LC adoption and its impact on construction project performance. The collected data underwent rigorous statistical analysis to ascertain the influence of LC practices on project outcomes. To validate the survey results, the study selected five case study projects for in-depth analysis. These case studies assessed how well the projects adhered to LC principles and examined the resulting effects on project delays, cost overruns, quality issues, rework, and health-related concerns. The findings consistently confirmed that a higher level of adherence to LC principles led to significant reductions in project delays, cost overruns, quality issues, and health-related problems. This analysis strongly supports the notion that a more extensive adoption of LC practices results in substantial improvements in project performance. By presenting these compelling results, this study offers valuable insights to the construction industry, providing a clearer path for the effective integration of LC practices.

Keywords: Lean Construction; Waste; Construction Management; Lean Principles; Quality Management.

1. Introduction

The construction industry has grappled with persistent issues of waste, occurring throughout the construction process, material management, and design and planning phases. These wasteful practices significantly contribute to cost overruns and, at times, lead to project delays due to disrupted cash flows [1, 2]. Furthermore, the construction sector has been slow to embrace effective change management approaches, exacerbating the issue [3, 4]. In response to these challenges, some developed and a few developing countries have adopted innovative technologies, sustainable methods, and environmentally friendly materials to curtail waste. Strategies such as Total Quality Management [5], Just-In-Time [6], Lean Construction [7], and value engineering [8] have collectively contributed to reducing wasteful practices. Lean management principles, renowned for fostering sustainable development in industries, have proven effective in enhancing coordination, waste reduction, sustainability, cost and time efficiency, quality, productivity, and resource utilization [9, 10]. The success story of Toyota serves as a testament to the positive effects of lean management principles [11].

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Despite numerous reports citing significant benefits from implementing Lean Construction (LC) principles, its adoption rate remains relatively low, with many firms hesitating to implement LC practices [12–14]. Lack of awareness has been identified as one of the top barriers to LC adoption by many researchers [15–19]. Similarly, fear of failure or uncertainty associated with LC has prevented the construction industry from embracing Lean practices [20–22]. The true potential and efficacy of existing LC practices are questioned, as the industry lacks awareness of the tangible benefits LC can offer in real-world projects [23]. Additionally, theoretical concerns have led some researchers to oppose the utilization of LC practices [24, 25]. These challenges are compounded by insufficient support from industry stakeholders, limiting the full realization of LC's potential and rendering it seemingly unnecessary [10]. Confidence in the implementation of Lean Construction (LC) within the construction industry would significantly benefit from a thorough comparison and evaluation of LC's efficacy in actual projects. Currently, there is a scarcity of case studies measuring the practical benefits of LC in contemporary research, with much of the existing literature relying on theoretical comparisons to assess LC efficacy and potential [26]. Moreover, while many case studies focus on time and cost overruns, there is a limited exploration of the impact of LC on quality, safety, and health issues [27]. Evaluating the effectiveness of LC practices can play a pivotal role in educating industry stakeholders about the value of lean practices.

To address this gap, this study primarily aims to assess the efficacy of LC practices through real-world projects. The hypothesis, examining whether LC delivers benefits to the construction industry and to what extent, will be rigorously tested. A literature review will be conducted to identify LC principles, and their percentage conformance within the construction industry of Pakistan will be assessed using a questionnaire survey. Case studies will then be undertaken to investigate the efficacy of LC in projects with higher percentage conformance compared to those with lower adherence to LC principles, thereby evaluating the impact of LC implementation. Through this comprehensive investigation, the team aims to provide insights into the utility of LC and contribute to boosting the confidence of the construction industry in its adoption. The main objectives of this study include:

- To assess the percentage adherence of Lean Construction (LC) practices within the construction industry of Pakistan.
- To compare the performance (in terms of time, cost, safety, health, and quality) of projects where the maximum LC principles are implemented with those where the least LC principles are implemented.

2. Literature Review

2.1. Problems in Construction

Construction projects are widely recognized for their inherent uncertainty and volatility, primarily arising from the diverse and collaborative nature of the environments in which they take place. These projects involve multiple specialized teams working together to achieve common objectives [28]. The resulting uncertainty leads to significant waste generation, both in the final product and throughout various processes, often considered inherent to the nature of construction projects. According to Babalola et al. [29], the construction industry grapples with numerous non-value-adding activities, which have emerged as a primary source of waste. Lauri Koskela, along with Watson et al. [30], identify non-value-adding activities such as waiting, rework, inspection, overproduction, large inventories, and movement as significant contributors to waste generation [30].

Substantial research, including assessments by the Construction Industry Institute, emphasizes the severity of this issue, concluding that non-value-added efforts or waste account for an average of 50% in construction projects [31]. Similarly, Mossman [21] reveals that an astounding 55-65% of construction efforts are wasted, significantly undermining construction productivity. The sheer volume of waste production exerts a profound impact on the performance of the construction industry, accentuating inefficiencies [32, 33].

In the United Kingdom, concerning statistics indicate up to 30% rework, 40-60% labor inefficiency, and a minimum of 10% material wastage, with time wastage reaching a staggering 57% [32]. Furthermore, research conducted by Love et al. [34, 35] in Australia, involving an analysis of 346 construction projects, exposes that rework events account for 34% of total costs, with owners contributing 50%, and contractors 43% of these rework occurrences [35].

The extensive prevalence of waste in both materials and effort underscores a pivotal factor responsible for the lackluster performance and inefficiencies in the construction industry. Urgent measures are imperative to mitigate waste generation, enhance efficiency, and drive meaningful improvements within the construction sector.

2.2. Emergence of Lean Construction

The construction industry drew inspiration from the Toyota Production System (TPS) and began integrating TPS tools and techniques to enhance construction efficiency and address operational challenges. This approach, known as Lean Construction (LC), has been shaped by influential researchers such as James P. Womack, Glenn Ballard, Lauri Koskela, Diekmann, and others [36, 37]. James P. Womack and his co-authors made significant contributions by introducing lean principles in their seminal work, "The Machine That Changed the World." This book conducted a comparative analysis of lean practices within the automotive industry, specifically focusing on Toyota, General Motors, and Ford. This thorough examination underscored the effectiveness and advantages of lean production principles, leading to the global spread of the concept.

Lauri Koskela is credited with laying the theoretical foundation for LC in 1992. He introduced the Transformation-Flow-Value (TFV) theory in 2000 and played a crucial role in developing lean principles tailored for the construction industry [37]. Koskela identified a fundamental set of LC principles critical for lean production in construction. These principles encompass meeting customer requirements, minimizing non-value-added activities, reducing variability, shortening cycle times, enhancing transparency and flexibility, continuous improvement, process simplification, optimizing flow and conversion, benchmarking, and concentrating on process control [38, 39].

Diekmann further refined this framework by categorizing Lean Construction (LC) principles into five key areas: customer focus, cultural/people factors, workplace standardization, waste elimination, and continuous improvement/built-in quality [31]. Case study outcomes have yielded a comprehensive set of sub-principles supporting each major lean principle, as outlined in Table 1. Institutions such as the LC Institute (LCI) and the International Group for LC (IGLC) have played pivotal roles in promoting and endorsing lean principles and practices within the construction sector.

Table 1. Lean Principles and Sub-Principles (Adapted from Diekmann et al. [31])

	Principles	Subprinciples
Lean Construction	Standardization	Visual management
		Workplace organization
		Defined work process
	Cultural/people	People involvement
		Organizational commitment
		Training
	Eliminate Waste	Reduce Process cycle
		Supply chain management
		Optimize work content
		Optimize production system
	Continuous Improvement/ Build in Quality	Error proofing
		Organizational learning
		Response to defects
	Customer Focus	Flexible resource
		Optimize value

Over three decades, the construction industry has witnessed successful implementations of LC, particularly in developed countries. Recent instances of effective LC applications have resulted in significant improvements in cost and time efficiency, as well as increased productivity [22, 40, 41]. These achievements underscore the potential of LC to enhance construction performance and alleviate inefficiencies.

2.3. Why lean Construction not Taking off

Despite well-established theories and several successful case studies, Lean Construction (LC) has faced challenges in gaining widespread acceptance in the expansive construction industry [42]. According to Ballard et al. [43], significant barriers hindering the adoption of LC include strong resistance to change among various stakeholders and a lack of commitment and leadership. Jorgensen (2006) [44] adds that the construction sector has not been as exposed to the principles of LC as the manufacturing industry, resulting in a limited understanding of its core concepts. To address this issue, it is essential to enhance awareness and knowledge of LC. Ballard et al. [43] suggest that increasing government-sponsored events and programs that promote LC would raise industry awareness.

Sarhan & Fox [15] conducted a questionnaire survey, revealing a lack of sufficient awareness and understanding of lean concepts as the primary barrier to implementing LC. The authors advocate for a more impactful approach to promotion, emphasizing the importance of discussing practical lean implementation stories rather than presenting abstract, metrics-based improvements. Similarly, Simonsen et al. [6] echo this sentiment, suggesting strategies such as showcasing LC success stories through media, organizing meetings and conferences, and allocating funds for LC research. Aslam et al. [45] further emphasize the importance of sharing success stories related to LC implementations to raise industry-wide awareness.

In response to these challenges, this research takes a pragmatic approach by evaluating different projects based on their adherence to LC principles. This study aims to provide concrete insights into the impact of implementing LC principles on project performance. Through this approach, the research aims to contribute to a clearer understanding of how LC can positively influence construction projects and potentially pave the way for its broader adoption in the industry.

3. Research Methodology

Analyzing the effectiveness of implementing Lean Construction (LC) in the construction industry is challenging due to the complex nature of lean principles and variations in these fundamental concepts proposed by different scholars [36]. To address this challenge, this research selected the lean principles and sub-principles introduced by Diekmann as the foundation for developing a questionnaire (see Table 1) [31]. Diekmann's principles and sub-principles are notably comprehensive and cover nearly all the essential principles discussed by other researchers, such as Sacks et al. [46] and Ballard et al. [47].

This study tests four main alternative hypotheses against a single null hypothesis (H_0) that LC practices have no significant reduction in project delays, cost overruns, quality issues/reworks, and health issues. The four alternative hypotheses are as follows:

H_1: LC practices enhance project performance by mitigating delays.

H_2: LC practices enhance project performance by mitigating cost overruns.

H_3: LC practices diminish quality-related issues and prevent reworks.

H_4: LC practices mitigate health-related issues otherwise faced on construction sites.

Our research methodology, depicted in Figure 1, adopts a two-stage approach that encompasses both quantitative analysis and case studies. In the initial stage, the research team conducted a questionnaire survey using a 5-point Likert scale. The decision to employ a 5-point scale was based on its comparable validity to other scales while optimizing efficiency in data collection and analysis [48]. The questionnaire comprised 31 questions, including 27 questions to assess lean conformance based on LC principles/sub-principles and 4 questions related to project outcomes (delays, cost overruns, quality/reworks, and health/safety issues). A total of 220 questionnaires were distributed via email, and 72 complete responses were received, resulting in a response rate of 32.72%. Such response rates are typical and have been observed in previous research [49-51].

To calculate the lean conformance percentage, the following formula was utilized:

$$\text{Lean Conformance (\%)} = \frac{\text{Sum of all the actual answers} \times 100}{\text{Sum of highest answer scores}} \quad (1)$$

For data analysis, the latest version of SPSS was utilized. Additionally, skewness and kurtosis tests were employed to assess data symmetry and distribution tails. The Shapiro-Wilk test was used to determine data normality, following the methodology of [52]. The results of the normality test assist in determining the nature of the data and the suitable analysis tool for that type of data. For a dataset to be considered normally distributed, the p-value of the Shapiro-Wilk normality test should be greater than 0.05 when tested for a 95% confidence level [53].

To rank and prioritize lean principles and sub-principles based on their significance, the Relative Importance Index (RII) was employed as recommended by Naji et al. [54]. The RII is recognized for its utility in ranking factors based on expert perceptions, as highlighted by Baig et al. [55]. RII not only helps in ranking factors but also assists in shortlisting important factors based on the RII score. A threshold of 0.50 is used, below which factors are considered less important and hence discarded [56].

To examine correlations between lean principal categories, Pearson chi-square tests were conducted, following the approach of [57]. The Pearson chi-square value and its p-value help in understanding statistically significant associations among variables being analyzed. A p-value less than 0.05 indicates that observed frequencies in the data are significantly different from what would be expected if there were no associations [58]. Given the non-parametric nature of the data, Kruskal-Wallis tests were employed to assess association-independence among groups, as suggested by Wei et al. [59]. A p-value of less than 0.05 shows that a strong association exists among LC practices and individual project outcomes, hence rejecting the null hypothesis that the factors have no association with each other [59].

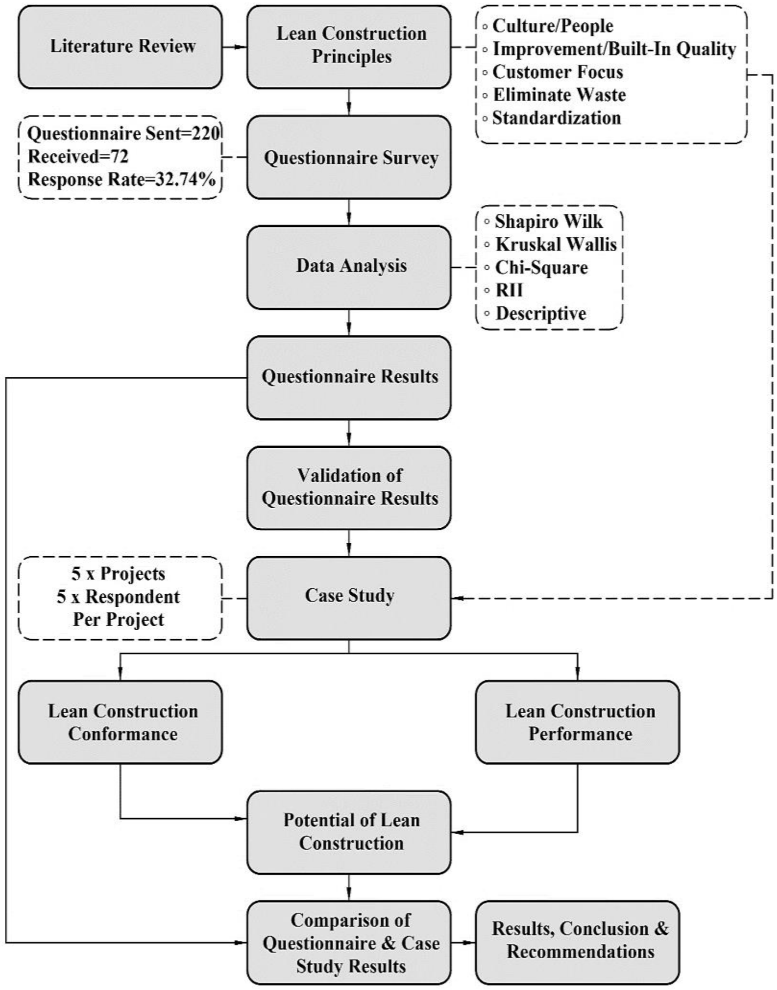

Figure 1. Research Methodology

To validate the survey findings, face-to-face interviews were conducted with 25 experts, drawn from five distinct case study projects. These experts represented a diverse range of project performance levels, including cost overruns, delays, and on-time/on-cost completion. The structured interviews consisted of 16 questions, with 12 focused on Lean Construction (LC) principles and 4 centered on real-time project outputs. Detailed information about the selected case study projects is presented in Table 2. Participants responded to LC principle-based questions using a score scale ranging from -10 to +10. A positive +5 score indicated a 50% adoption of a specific LC principle, while a negative score of -5 implied opposition to the principle up to 50%, following the approach of Rogers [60]. A sample question and the scale are shown in Table 3. Additionally, Table 4 provides sample questions related to real-time output assessment, aimed at comparing project outcomes based on LC principles adoption.

Table 2. Case Study Projects for Lean Practices Assessment

Sr. #	Project Name	Project Type and Detail
01	Infectious Treatment Centre, Hospital (ITCH)	During the COVID-19 pandemic, a prefabricated steel structure hospital was built in just 40 days at a cost of 980 million. The hospital, known as ITCH, encompasses 250 beds and is spread over 40 kanals of land. The project exhibited excellent performance, with no significant delays or budget overruns.
02	Building of Tunnelling Institute (BTI)	This building is a prefabricated steel structure that was completed in six months. The project was executed smoothly, and there were no significant delays or cost overruns.
03	High-Rise Residential Building (HRB)	This is a high-rise apartment building constructed with an RCC frame structure. Originally scheduled for completion in 2 years, the project encountered a delay of 9 months. Additionally, there was a minor cost overrun of 0.03%. The main cause of this delay was a 6-month period of extensive rework required to address quality issues.
04	Approach Roads and Roundabout (ARR)	The project was initiated to improve the traffic flow in Rawalpindi city. It was completed without any significant delays or cost overruns, and the project's performance met expectations in most cases.
05	Road in Hilly Terrain (RHT)	This project involves the rehabilitation and widening of a 164 km hilly road. While the original plan aimed for completion within 3 years, it faced a delay of 13 months and an approximate 10% cost overrun. The primary reasons for these challenges include the harsh environment and rugged terrain in the area.

Table 3. Sample Question of Interview along with used along with used Scale

Was coordination and cooperation among all the departments, like mechanical, electrical, architectural, civil, design, etc., given enough importance to minimize the internal conflicts?																				
Score																				
-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	+9	+10

Table 4. Sample Interview Question for Project Output Investigation

Were there any cost overruns?
If yes, then: -
Initially planned cost of the project:
Actual cost of the project:
Percentage of cost overrun:

4. Results

4.1. Questionnaire Survey

The team conducted statistical analysis and RII analysis for all five principles and fifteen sub-principles, in addition to the four output-based questions included in the Likert scale questionnaire. The results are presented in Table 5. The mean scores of all Lean Construction (LC) sub-principles indicate that certain sub-principles, including response to defects, error-proofing, flexible resources, visual management, and defined work processes, are widely adopted within the construction industry. While other LC principles are also followed to some extent, there is no standardized method employed by the construction industry for planning the adoption of LC principles to achieve better results. Results in Table 5 show that the sub-principles with the highest mean score in each category are people involvement (3.875), error proofing (4.083), flexible resources (4.028), reduced process cycle time (3.889), and defined work processes (3.986). Meanwhile, the sub-principles with the least mean score in each category are organizational commitment (3.653), response to defects (3.583), optimize value (3.667), supply chain management (3.625), and workplace organization (3.764), respectively.

Table 5. Results (Mean Score, Normality, RII)

Principle	Sub Principle	Statement	Mean	Shapiro Wilk P Value	RII	Rank
Culture/ People	People involvement	Employees are considered an integral part of the organization, and their viewpoint is given consideration by top management.	3.875	<0.001	0.775	8
	Organizational Commitment	Management at all levels have developed a mechanism to keep themselves updated with new developments.	3.653	<0.001	0.73	24
	Training	Firm focuses on incorporating new skills in employees that are considered necessary to fulfil changing demands.	3.708	<0.001	0.741	18
Continuous Improvement/ Built in Quality	Response to defects	During defects identification process, quality plans are prepared which assign responsibilities to concerned members.	3.667	<0.001	0.733	21
		Defects are identified and remedial actions are recorded for future use.	3.917	<0.001	0.783	5
		Every team is quite responsible in ensuring quality in the product by their own.	3.583	<0.001	0.716	26
	Error proofing	Supervisors always plan their work methodologies through due consultation with team members on a regular basis.	4.083	<0.001	0.816	1
	Organization learning	Information related to techniques and changes are always communicated timely with concerned departments.	3.514	<0.001	0.702	27
Customer Focus	Flexible Resources	Firm is flexible and can cope with changes while utilizing the minimum number of resources.	3.944	<0.001	0.788	4
		Firms do depend on actual resources but change directions with changing customer needs without losing much time or money.	3.681	<0.001	0.736	19
		All changes are passed immediately via telephone call first, and then through the proper channel.	4.028	<0.001	0.805	2
	Optimize Value	The project value is defined with the customer and known to everyone.	3.667	<0.001	0.733	22
		Customer needs are studied throughout the project rather than initially only.	3.75	<0.001	0.75	16

Eliminate Waste	Supply Chain Management	Materials predominantly reach at site just before their usage and minimum inventory is required.	3.625	<0.001	0.725	25
		Firms select reliable suppliers who meet requirements in time. Changing suppliers is never planned.	3.819	<0.001	0.763	12
	Optimize Production System	Employees are multi-skilled and can utilize diverse activities.	3.722	<0.001	0.744	17
		Detailed sequencing, flow charts, and scheduling are carried out regularly and consultation is performed before and after activities execution.	3.847	<0.001	0.769	9
		Coordination and cooperation among all departments is given enough importance.	3.819	<0.001	0.763	13
	Reduce Process Cycle Time	Risk management is carried out and planned. Risk register is also maintained regularly.	3.889	<0.001	0.777	7
		Master schedule, Back-schedule and look-ahead plans are maintained through input of foremen and key workers.	3.83	<0.001	0.766	11
	Optimize Work Content	Standard, prefabricated, preassembled, repetitive construction elements are preferred.	3.681	<0.001	0.736	20
		Non-value-added activities and identified and efforts to eliminate their resource utilization are made.	3.667	<0.001	0.733	23
Standardization	Visual Management	Jobsite uses visual devices showing requirements of schedule, quality, safety, and productivity.	3.903	<0.001	0.78	6
	Workplace Organization	Firms give due emphasis to organization and structuring of resources, materials, tools.	3.764	<0.001	0.752	15
		Firms pay enough attention to housekeeping in administration blocks as well as jobsite.	3.792	<0.001	0.758	14
	Defined Work Processes	Processes are identified and continuously monitored.	3.986	<0.001	0.797	3
		Regular meetings are carried out instead of inspections only	3.847	<0.001	0.769	10

When comparing the adoption rate of all LC principles with project outcomes, the team observed an inverse relationship between LC practices and negative outcomes, such as delays, cost overruns, quality issues, and health problems, as depicted in Figure 2. This clearly indicates that an increase in the adoption rate of LC practices reduces the occurrences of cost overruns, delays, quality issues, and health problems. For example, on projects with a 20% lean principles adoption rate, the probability of delays is 73%, cost overrun is 74%, quality issues are 75%, and health issues are 71%. As the LC adoption rate increases to 81%, the chance of delays is reduced to 20%, cost overrun to 26%, quality issues to 15%, and health issues to 24%, respectively. Hence, the trend shows the inverse relation between LC practice adoption rate and negative project outcomes. The most improvement with an increase in LC adoption is visible in quality, followed by delays, health issues, and cost overrun.

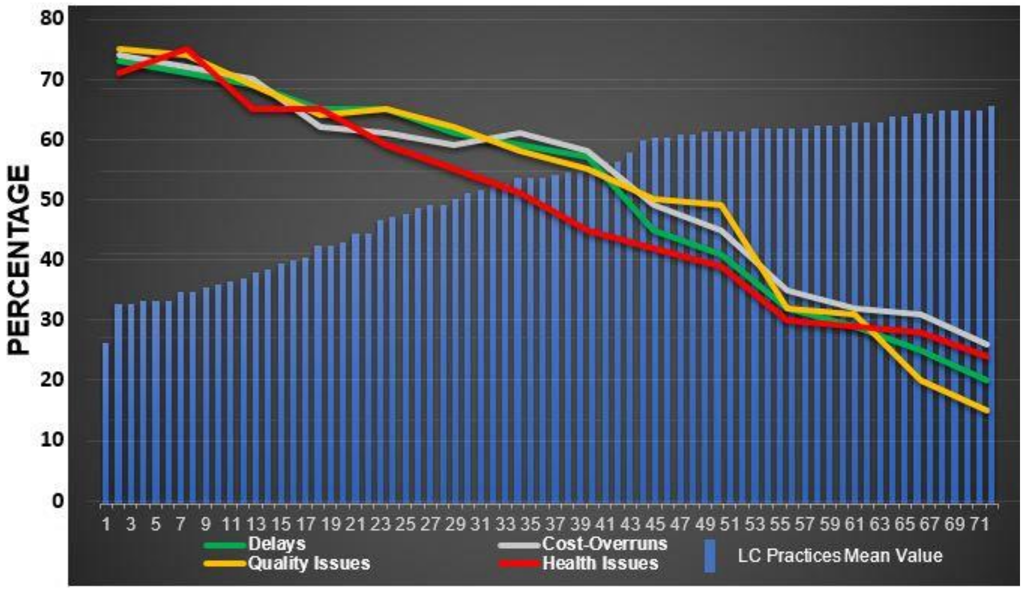

Figure 2. Comparison - LC Practices Followed vs Project Outputs

Furthermore, the mean values for all 27 sub-principles and four project outputs were utilized as inputs in the Chi-square test to individually assess whether LC practices improved performance or not. The input mean scores were rounded to whole numbers to meet the data type requirements of the Chi-square test, following the method suggested by García-Bernal and García-Casarejos [5]. The conversion of mean values to whole numbers was executed using the scale provided by Sozen & Guven [61].

The results of the Chi-square analysis demonstrate that the enhancement in project execution performance offered by LC practices is statistically significant. Based on a p-value of <0.05, all four alternative hypotheses are accepted, proving that LC practices significantly improve project performance by reducing project delays, cost overruns, quality issues and reworks, as well as reducing health-related issues faced on construction sites. An overview of the study's overall results can be found in Table 6.

Table 6. Chi-Square Mean Comparison of LC and Traditional Approaches

No.	Relation Studied	Likelihood Ratio		(Kruskal Wallis Test P value)		Remarks
		Value	P-value	Value	P-value	
01	LP vs Delays	33.80	<0.001	35.085	<0.001	LC practices improve project performance by reducing delays.
02	LP vs Cost Overrun	27.119	<0.001	28.704	<0.001	LC practices improves project performance by reducing cost overruns.
03	LP vs. Quality issues/ Reworks	21.104	<0.001	20.646	<0.001	LC practices ensure a decrease in quality related issues and prevent requirement for reworks.
04	LP vs Health Issues	20.661	<0.001	19.845	<0.001	Results conclude that increase LC practices reduce health related issues otherwise faced on construction sites.

To further explore the association or independence between LC practices and individual project outcomes, a Kruskal-Walli's test was conducted. As the p-value obtained is significantly less than 0.05, it provides strong evidence against the null hypothesis, suggesting there is indeed an association or relationship between LC practices and individual project outcomes. Consequently, the alternative hypothesis is accepted, which asserts that LC practices lead to improved project performance outcomes. Therefore, based on the results of the Kruskal-Walli's test, it can be concluded that the efficacy of LC practices is valid, and further adoption is recommended (see Table 6).

4.2. Case Study

A total of 25 interviews were conducted, with five interviewees selected from each project. These interviews were carried out face-to-face to facilitate the resolution of any communication or understanding gaps before collecting responses. To streamline the analysis and interpretation of interview results, the interviews were mapped to the Lean principles and sub-principles. In the Tunneling Institute (BTI) project, most of the 12 Lean principles were adopted, with the exception of training. The overall adoption rate for these principles was 67%. Regarding the adopted LC principles, the project experienced only a 1.67% delay, with no significant issues related to cost overruns, quality, or health (see Table 7).

Table 7. Mean Percentage Value of Conformance to LC Principles by Case Study Projects

LC Principles	Statement	ITCH Disease Centre (%)	Tunneling Institute (BTI) (%)	Approach road project (ARR) (%)	High-rise Residential (HRB) (%)	Hilly terrain project (HTR) (%)
Error Proofing	Did supervisors always plan their work methodologies through due consultation with team members on regular basis?	52	74	62	15	30
Workplace Organization	Did your firms pay enough attention to housekeeping in administration block as well as jobsite?	64	76	62	10	60
Supply Chain Management	Firms select reliable suppliers who meet requirements in time. Changing suppliers is never planned.	70	72	48	30	50
Waste reduction/ Supply Chain Management	Did companies identify construction waste and was there any effort made to minimize it?	66	68	58	0	0
Optimize Work Content	Did your company use repetitive, pre-assembled or prefabricated standard construction elements?	76	84	56	0	0
People Involvement	Was input of foreman and key workers considered in preparation of plans and schedule?	68	82	64	30	40
Reduce Process Cycle Time/ coordination	Was coordination and cooperation ensured among all departments of the organization given importance to minimize internal conflicts?	52	48	54	18	26
Reduce Process Cycle Time/ risk management	Was risk management performed throughout the project and risk register maintained?	50	60	60	2	10
Training	Did the organization train and utilize employees for multi-skilled activities?	0	0	52	0	0
Optimize Value	Was the company focusing on customer needs throughout the project? And what efforts were made to execute a project based on those needs?	82	84	58	30	70
Response to Defects	Were defects identified and monitored through quality plans and RACI charts so that future occurrences can be minimized?	80	80	56	0	0
Organizational Commitment	Were changes in construction management techniques readily adopted by your top-level management, and were these changes reflected in the training of employees to incorporate new skills in them?	76	76	62	0	0
Lean Construction Conformance		**61.33**	**67.00**	**57.67**	**11.25**	**23.83**

Similarly, the Isolation hospital and infectious treatment center project had a 61% adoption rate of LC principles, which effectively prevented cost overruns, quality issues, and health problems, resulting in only a 2.5% project delay. The Approach Road project (ARR) exhibited an adoption rate of 57.66%, and the project faced a 5.1% delay, 6% quality issues, with minimal cost overruns and safety issues (see Table 7).

On the other hand, the High-rise residential building project had a much lower LC adoption rate of only 11.25%, leading to a 37.5% project delay, a 0.03% cost overrun, 6% quality and rework-related issues, and 5% health issues. Similar results were observed in the Hilly terrain road project (HTR), where the LC principles adoption rate was only 23.5%, resulting in a 33% delay, 10% cost overrun, 12% quality issues, and 3% health-related issues. Mean percentage values of LC principles conformance by case study projects can be found in Table 7.

By combining these conformance values with the mean output values, a trend was observe in which increased LC conformance leads to a reduction in delays, cost overruns, quality issues, and health problems. The BTI project recorded the highest conformance to LC principles at 67%, resulting in comparatively fewer health, quality, delay, and cost overrun issues. Conversely, the High-rise residential project (HRB) had the lowest LC principle adoption rate, at only 11.25%. This project experienced the highest project delays (37%) and relatively more quality issues (6%)

In Figure 3, a clear trend emerges, demonstrating that an increase in LC conformance leads to a reduction in project delays, cost overruns, quality issues, and health concerns. Conversely, projects with low LC conformance rates experienced higher rates of project delays, cost overruns, quality issues, and health problems. Therefore, the idea that LC principles conformance significantly enhances overall project and product performance has been substantiated. This conclusion underscores that embracing LC principles in their true sense can substantially mitigate these four adverse outcomes, as noted by Aziz & Hafez [32] (2013).

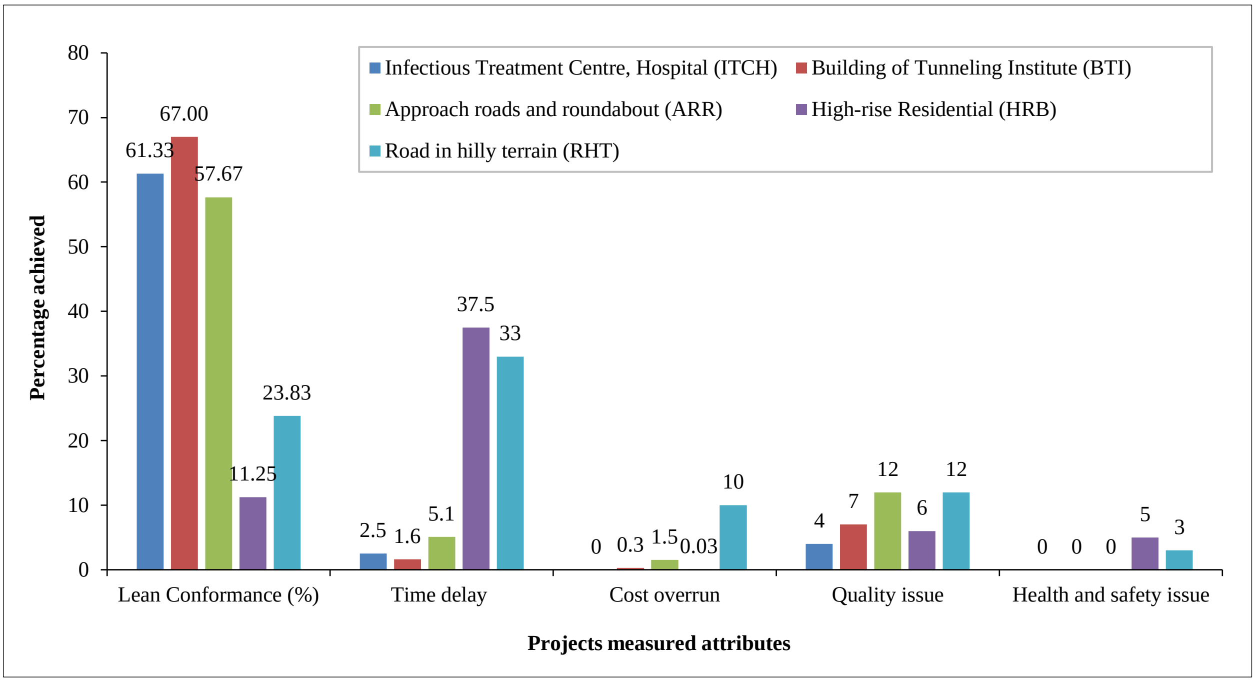

Figure 3. LC Conformance vs. Project Performance

These results also affirm the conclusion that the adoption of lean practices leads to reductions in waste and project delays, as highlighted by Likita et al. [62].

The findings indicate that projects still relying on conventional management tools and methods suffered from cost overruns, delays, quality issues, and safety concerns. In contrast, projects that incorporated some level of LC principles witnessed a decrease in cost overruns, delays, improved quality, and reduced health issues.

5. Discussion

The primary objectives of this study were to evaluate adherence to LC practices and their impact on performance in the construction industry. To achieve this, a questionnaire survey was conducted to assess LC conformance concerning project performance. Results from the questionnaire survey indicate that some LC principles, such as "Error proofing," "Flexibility in resources," "Defined work processes," "Response to defects," "Value management," and "People involvement," are relatively well-adopted in the construction industry. Conversely, certain principles have limited adoption, including "Organizational learning," "Organizational commitment," "Optimized value," and "Optimize production systems." Addressing these less-adopted principles is essential to establishing a standardized environment for complete LC adherence. Mean scores for all LC principles reveal the highest level of conformity for "Optimizing value," followed by "Supply chain management," "Error proofing," "Response to defect," "Organizational commitment," and "Workplace organization." Conversely, there is lower conformity for other LC principles, highlighting the need for focused efforts to establish a standardized implementation process for comprehensive LC adherence [11].

To further assess significance, Pearson Chi-square and Likelihood ratio tests were conducted to compare mean scores of lean practices with the four major outcomes. The consistent results from these tests demonstrate that lean practices enhance project performance by reducing delays, cost overruns, preventing quality issues, and mitigating health concerns. The Kruskal-Walli's test results reject the null hypothesis and confirm the validity of lean practices within the construction industry, reinforcing the recommendation for further adoption.

To validate the results, five case study projects were selected to examine their adherence to LC principles and how this relates to issues such as delays, cost overruns, quality problems, and health concerns. The analysis of the mean scores indicates the degree of conformity to LC principles for each of the selected projects. The Tunneling Institute (BTI) achieved a 67% conformance rate, while the ITCH disease center scored 61.33%, the Approach Road project (ARR) scored 57.66%, the Hilly terrain road scored 23.83%, and the High-Rise Residential project (HRB) scored 11.25%. The delays experienced on these projects ranged from 1.67% (projects where LC principles are implemented) to 37.5% (projects where LC principles are not implemented), while quality issues varied from 0% to 10%. Similar patterns were observed for cost overruns and health issues. This pattern demonstrates that as adherence to LC principles increases, project performance improves in terms of reduced delays, cost overruns, quality issues, and health concerns. Berawi et al., [2] (2023) also reported that using LC tools and techniques, the industry can experience a 19.14% reduction in project completion time. This finding aligns with expectations from the literature, which suggests that conforming to lean practices leads to time savings, cost savings, improved quality, and sustainable product development [26, 27, 63].

The results challenge the misconception that LC practices result in additional costs. Instead, it is observed that lean practices prevent cost overruns by saving expenses related to defect correction, reworks, and non-value-adding activities [2, 19, 64].

One limitation of this study was the availability of data for the selected projects in case studies. Data related to quality and health/safety issues were not documented, and researchers had to rely on input from the interviewees for these two project performances. Additionally, all these projects are funded by the Federal Government, so minimal cost overrun is observed. However, the contractors working on these projects reported cost overruns, as documented in this research.

6. Conclusion

This study has offered valuable insights into adherence to LC practices and their profound impact on project performance within the construction industry. Through a comprehensive questionnaire survey and thorough analysis of case study projects, both strengths and areas for improvement in the adoption of LC principles are identified within the Pakistani construction industry. While some principles, such as "error proofing" and "flexibility in resources," are relatively well-adopted, others, like "organizational learning" and "optimized value," show limited adoption, underscoring the need for focused efforts to establish a standardized environment for complete LC adherence.

Our findings unequivocally affirm the positive correlation between adherence to LC principles and improved project outcomes. This is evidenced by reduced delays, cost overruns, quality issues, and health concerns. Statistical tests further validate the significance of lean practices in enhancing project performance within the construction industry, reinforcing the recommendation for their further adoption. The analysis of case study projects emphasizes the practical implications of adhering to LC principles. Projects with higher conformity to LC principles demonstrated superior performance metrics, underscoring the importance of systematic implementation. Moreover, our findings align with previous studies, highlighting the benefits of lean practices in terms of time and cost savings, improved quality, and sustainable development. Contrary to common misconceptions, LC practices were found to prevent cost overruns by addressing issues such as defect correction, reworks, and non-value-adding activities.

Despite encountered limitations, such as data availability for case studies, our study contributes significantly to the growing body of literature on LC. It provides empirical evidence of its effectiveness in enhancing project performance, urging stakeholders in the construction industry to prioritize the adoption and implementation of lean practices.

This study serves as a guiding beacon for the construction industry, dispelling lingering doubts about the tangible benefits of LC. Academia stands to gain valuable insights from this study, providing a robust framework to assess the effectiveness of their own research efforts in LC. Industry stakeholders can leverage the results of this study to identify weaknesses in implementing LC practices and gain confidence in adopting them by recognizing the efficacy of LC to enhance project outcomes.

7. Declarations

7.1. Author Contributions

M.As., E.B.T., M.Ah., and A.U. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Conflicts of Interest

The authors declare no conflict of interest.

8. References

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