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Research Article

An Exploratory Factor Analysis of Lean Construction Elements Reflecting Project Management Performance among Local Construction Enterprises

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Abstract

Background and Objectives: The construction industry remains a pivotal sector in national development, yet it frequently faces systemic inefficiencies, including project delays, cost overruns, and materials waste. These challenges are especially pronounced among local construction enterprises, which often operate with limited resources, simple organizational structures, and minimal access to modern technologies. The adoption of Lean Construction Concepts (LCC) has gained increasing attention as a viable solution to address the issues. Lean construction emphasizes minimizing waste, while maximizing value creation, aiming to optimize construction processes and improve labor productivity throughout project execution. Despite the growing global adoption of lean methodologies, their implementation in Thailand's local construction sector remains underexplored, particularly regarding how various lean components influence overall project management performance. The main objective of this study was to identify and classify the structural elements of lean construction that significantly affect project management efficiency within local construction enterprises in Thailand. This research aims to bridge the existing knowledge gap and provide a systematic framework tailored to the unique challenges faced by such enterprises.

Methodology: The study adopted a quantitative research methodology, using Exploratory Factor Analysis (EFA) to uncover the underlying structure of lean construction elements that influence project management performance. Data were collected through a structured questionnaire survey distributed to local construction professionals across Thailand. A total of 115 valid responses were obtained, satisfying statistical adequacy tests. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was found to be 0.845, while Bartlett's test of sphericity yielded a p-value < 0.001, indicating that the dataset was suitable for factor analysis. Items with a Measure of Sampling Adequacy (MSA) below 0.50 were excluded to enhance model accuracy. Reliability was confirmed through Cronbach's alpha values of 0.927 and 0.938 for the factor groups and the overall instrument, respectively, indicating high internal consistency.

Main Results: The EFA results reveal six key components comprising 31 variables that collectively explained 59.70% of the total variance. The identified factors are: (1) cost and quality, emphasizing process improvement, elimination of redundancy, and resource optimization; (2) strategy and planning, underscoring the importance of effective project scheduling, budget adherence, and personnel management; (3) safety, highlighting the implementation of safety measures and proper use of personal protective equipment to prevent accidents and health risks; (4) people and processing, which focus on reducing task duration, enhancing labor efficiency, and streamlining procurement and logistics; (5) waste, emphasizing reduction of materials waste and promotion of 5S principles for environmental and operational efficiency; and (6) health and accident, which relate to monitoring accident rates, ensuring health standards, and minimizing disruptions caused by workplace incidents. The variable with the highest factor loading (0.818) pertains to materials waste reduction, reflecting its critical importance in resource-constrained local enterprises.

Conclusions: The study successfully establishes a comprehensive framework for understanding how lean construction elements impact project management performance among local construction enterprises in Thailand. The six-factor model provides empirical support for the strategic implementation of lean principles, illustrating their effectiveness in enhancing cost efficiency, process reliability, safety performance, and environmental sustainability. These findings emphasize the importance of tailored lean applications that consider the unique operational characteristics of local firms, such as capital constraints and labor management challenges. The research contributes to the broader field of lean construction by extending its practical relevance to developing economies, where localized adaptation is crucial for successful implementation.

Practical Application: The study offers practical insights to local construction practitioners, project managers, and policymakers seeking to improve project outcomes through lean methodologies. By categorizing the essential elements of lean construction into six actionable components, the findings provide a structured implementation roadmap for local enterprises. Project managers can use these insights to prioritize lean strategies that directly enhance productivity and efficiency, including waste reduction, strategic planning, and safety compliance. Moreover, the research lays the groundwork for developing training programs, organizational policies, and performance monitoring tools aligned with lean construction principles. Future research should expand this model to examine its applicability in large-scale infrastructure projects and conduct comparative analyses with international case studies. Such extensions will foster the creation of globally informed best practices and reinforce the long-term sustainability and competitiveness of Thailand's construction sector.

Keywords: Exploratory Factor Analysis, Lean Construction, Local Construction Enterprises

Introduction

The construction industry is one of the most crucial economic sectors for national development, as it involves extensive utilization of resources including labor, materials, and capital investment. However, numerous construction projects encounter various challenges such as delays, cost overruns, material waste, and low operational efficiency. These issues significantly impact both contractors and project stakeholders [1-5]. Consequently, Lean Management principles have garnered significant attention as a crucial tool for effectively minimizing waste and enhancing value throughout operational processes [6-10]. The fundamental principles of Lean Construction encompass construction operations that strive to minimize waste while maximizing value creation. The primary objective is to optimize construction processes and methodologies to enhance operational efficiency and improve labor productivity throughout the project execution phase [11]. This aligns with research by Romo et al. [12] which found that volatility in the construction industry leads to increased competition and project challenges. Consequently, the industry must seek methods to optimize waste management and cost efficiency. The Lean Construction concept has been proven to be an effective approach for improving construction project management efficiency, as demonstrated through conceptual, empirical, and qualitative studies [13]. The application of Lean Construction Concepts (LCC) has been implemented across various sectors, including commercial buildings, educational facilities, and hospitals. Many contractors working in these sectors show an increasing tendency to adopt more collaborative contract models and demonstrate greater willingness to experiment with LCC [14]. The Lean system can be implemented through the Last Planner System (LPS), designed to support production planning and control in construction projects, resulting in up to 8% reduction in project delays [15]. Lean Management is a technique for reducing unnecessary waste, which affects the overall construction cost reduction and creates value for construction project investments through cost savings. The Lean Management process automatically transitions to Value Management, meaning creating value without compromising project functionality [16].

Construction project management in Thailand typically faces various problems and obstacles that prevent construction from proceeding according to plan, involving numerous factors. Delay factors can be categorized into four groups: 1) contractor-related factors, 2) client-related factors, 3) supervisor-related factors, and 4) external factors [17]. Key factors affecting cost management in construction projects during the pre-construction phase include lack of coordination, design management, and unclear client requirements. Factors during the construction phase include site management, resources, labor capability, and contract-related issues [18]. Furthermore, construction projects in Thailand face multiple challenges, including skilled labor shortages, inefficient contractor management, and fragile political situations [19]. To address various problems in construction project management in Thailand, the lean concept has been applied to multiple aspects of construction project management. The application of lean techniques in analyzing and developing procurement processes to identify wasteful processes and find management approaches has shown that waste can be reduced by 68.86% when comparing the number of steps between traditional and lean-applied procurement systems [20]. The application of lean principles to reduce costs and installation time in truss roof structures, focusing on eliminating seven types of waste: 1) overproduction, 2) inventory, 3) transportation, 4) motion, 5) processing, 6) waiting, and 7) defects, has led to improvements in roof truss installation methods. By switching from individual piece installation to group installation, costs were reduced by 56.47% and construction time by 25.70% [21]. Implementing lean principles to improve work process efficiency has effectively reduced waste in construction project design, streamlined work processes, reduced work obstacles, decreased hidden costs in construction project design, enabled appropriate timeline setting aligned with actual construction conditions, and enhanced post-delivery user satisfaction [22]. Literature review reveals that lean construction applications in Thailand's construction industry span multiple dimensions including procurement, structural installation, and project design. Current knowledge remains limited to specific case studies and isolated problem-solving approaches, lacking systematic analysis of lean construction components that influence overall project management efficiency. Thai local construction enterprises differ significantly from large construction companies in terms of resource limitations, experience-based management rather than academic processes, simpler organizational structures, and restricted access to modern technologies [23-24]. These factors directly affect lean construction implementation effectiveness. Therefore, any study developing lean application approaches must comprehensively consider these contextual factors. This research employs Exploratory Factor Analysis (EFA) to identify lean construction factor structures influencing project management efficiency in local construction enterprises, focusing on classifying key components associated with project performance in these specific contexts. The research aims to develop in-depth understanding of structural relationships between lean construction variables at the local enterprise level and create a conceptual framework that systematically explains each component's role in project management efficiency. The findings will contribute significantly to both academic and practical domains—expanding knowledge about lean construction applications in developing countries, particularly at the under-researched local enterprise level, while providing practical guidelines for executives and practitioners to efficiently implement lean principles, enhancing competitive advantage and long-term organizational sustainability.

Literature Review

This study focuses on analyzing factors related to the application of lean concepts in construction project management to enhance the efficiency of local contractors. The research framework is based on principles, concepts, and relevant research studies, namely: (1) Lean Construction Concept (LCC), (2) Construction Project Management (CPM) efficiency assessment for contractors, and (3) Exploratory Factor Analysis (EFA). The details can be elaborated as follows:

Lean Construction Concept (LCC)

The lean concept originated from the Toyota Production System (TPS), which was developed during the 1990s with the primary objective of reducing waste and defects in the production process. This concept introduced a systematic strategy focusing on enhancing efficiency in both production and consumption of goods and services in the automotive industry.

Subsequently, the construction industry adopted and adapted this concept, developing it into the Lean Construction Concept (LCC) for implementation in construction processes [25]. Furthermore, the implementation of Lean Construction Concept (LCC) was conducted through a dual framework integrating waste reduction and value enhancement strategies. The 5S methodology achieved 96.99% readiness levels, significantly mitigating time inefficiencies, resource misallocation, and workplace incidents. On-time delivery systems attained 88.55% implementation readiness via strategic planning, cross-functional coordination, and systematic monitoring protocols. The Aceh Province case study demonstrates that these integrated approaches substantially enhance operational efficiency and reduce project costs across contractor organizations of varying scales. These findings empirically validate lean principles' applicability in construction contexts and advance construction management theory [11]. This aligns with research by Romo et al. [12], who noted that the volatility of the construction industry results in increased competition and project challenges. Consequently, the industry must seek methods to optimize waste reduction and cost management. The Lean Construction Concept, which principles focus on meeting customer expectations while improving waste reduction in processes, evolved from Lean Production principles.

The Lean Construction Concept has been empirically proven as an effective approach for improving construction project management efficiency across conceptual, empirical, and qualitative studies [13]. Moreover, research by Lekan and Segunfunmi [26] defines lean thinking as the elimination of wasteful activities and non-value-adding processes, with the primary goal of delivering high-quality projects at minimum cost within the shortest timeframe. Factors related to the lean construction concept in construction project management refer to the systematic elements that drive efficiency improvement, waste reduction, and value creation through multidimensional perspectives (encompassing management, technology, human resources, and process factors within the construction project management process). From previous research; the lean construction factors had been suggested as table 1 below. These factors can be grouped and developed to be question of L1 to L35 in questionnaire.

Table 1 Factors related to lean concept application in construction project management

Author's	Indicator's description
Babalola et al. [27]	1.1 reduction of project cost, 1.2 more inventory control, 1.3 reduction in project time/schedule, 1.4 continuous improvement of process, 1.5 improvement of project quality, 1.6 increment in market share, 1.7 risk minimization, 1.8 decrease in variability of workflow, and 1.9 improvement in project delivery method.
Maradzano et al. [28]	2.1 quick turnover and low cost of construction projects, 2.2 minimization of conflicts that can dramatically change budget and schedule, 2.3 delivery of product and services on time and within budget, 2.4 reduction of direct cost in transportation and communication, 2.5 reducing total project duration, 2.6 improved project delivery methods, 2.7 supporting the development of teamwork, and transferring the responsibility in the supply chain, 2.8 reduction of direct time in transportation and communication, 2.9 improving quality of work, 2.10 improving environmental performance, 2.11 improving the safety of workers, 2.12 managing uncertainties in supply, 2.13 continuous improvement in projects, 2.14 delivery of custom products instantly without waste, 2.15 reduced waste, 2.16 improved overall equipment effectiveness (OEE), 2.17 improved quality control and minimization of risks, and 2.18 improved employee satisfaction and supplier relationships.
Hasan et al. [29]	3.1 reducing cycle time, 3.2 reducing non-value adding activities, 3.3 focus on customer needs, 3.4 reducing diversity and uncertainty in process, 3.5 simplifying processes, components, materials, 3.6 increasing production output flexibility, 3.7 increasing the transparency of production processes, 3.8 focus on all processes, 3.9 interfacing continuous improvement into processes, 3.10 analyze and optimize workflows before they change, and 3.11 comparison for weakness and superiority detection.
Fauzan and Sunindijo [30]	4.1 effective management process, 4.2 high client satisfaction, 4.3 reduced reworks, 4.4 reduced material and equipment storage cost, 4.5 future partnership potential with client, 4.6 on-time work package delivery, 4.7 product consistency, 4.8 material waste reduction, 4.9 high productivity
Mohd Arif et al. [31]	5.1 reducing construction wastes, 5.2 compliance with local authority's or government requirement, 5.3 reducing energy consumption of the project, and 5.4 production a neat & clean site environment.
Marhani et al. [32]	6.1 long approval process, 6.2 clarification need, 6.3 excessive safety, 6.4 excessive training time, 6.5 excessive supervision, 6.6 excessive use of equipment, and 6.7 overqualified resource.
Pejerrey et al. [33]	7.1 accident rate, 7.2 frequency rate, 7.3 severity rate, 7.4 percentage of training compliance, 7.5 5S audit, 7.6 percentage of safe behaviors, and 7.7 percentage of correct use of PPE (personal protective equipment).
Archana et al. [34]	8.1 reduce variability, 8.2 transparency, 8.3 flow variability, 8.4 continuous improvement, 8.5 customer focus, and 8.6 waste reduction.
Khakimin et al. [35]	9.1 Price, 9.2 Financial Ability, 9.3 Experience, 9.4 Equipment Support, 9.5 Contractor Performance, and 9.6 Occupational Health and Safety (K3)
Monyane et al. [36]	10.1 time, 10.2 cost, 10.3 quality, 10.4 health and safety, 10.5 client satisfaction, 10.6 environmental impact, 10.7 waste, 10.8 speed, and 10.9 value.

Table 1 Factors related to lean concept application in construction project management (continued)

Author's	Indicator's description
Moradi and Sormunen [37]	11.1 time and cost reduction, 11.2 increased productivity (task and project levels), 11.3 increased labor productivity, 11.4 increased process efficiency, 11.5 competence-based selection in bidding phase, 11.6 decreased inventory, 11.7 better operational performance, 11.8 quality improvement, 11.9 waste reduction, 11.10 better diffusion of LC at managerial levels of company, 11.11 establishment of collaborative climate, 11.12 stakeholder satisfaction, 11.13 better health and safety, and 11.14 increased market share.
Rushabh and Krupesh [38]	12.1 transportation, 12.2 inventory, 12.3 motion, 12.4 waiting/delay, 12.5 over-processing, 12.6 over-production, 12.7 defects, 12.8 skill misuse
Deepika Sterlin et al. [39]	13.1 procurements and delivers fast as possible, 13.2 quality and continuous improvement, 13.3 leadership and communications, 13.4 training and empower the team, 13.5 shifts in organizational behavior, 13.6 employers' perceptions

Construction project management performance of Enterprises

Contemporary construction project management faces multiple challenges, including cost control issues where expenses frequently exceed allocated budgets, operational delays, and increasing workload responsibilities. These factors directly impact declining profit margins while competition in the construction industry continues to intensify. However, successful project management necessitates appropriate resources and planning within budget and time constraints while maintaining quality standards across various dimensions, including cost, time, and quality metrics [38]. Construction project management operations typically encompass diverse specialized components, such as design, operational planning, construction, and maintenance. Each component operates under the supervision of domain specialists, including design engineers, construction engineers, or project architects, with the project manager assuming overall responsibility for comprehensive project management. Construction efficiency depends on the capability to manage projects within prescribed timeframes and budgetary constraints [40, 41]. Furthermore, project management performance measurement should incorporate additional factors beyond those mentioned above, including client satisfaction, team satisfaction, project leadership, productivity, and proper training and recruitment [42]. Organizational operational efficiency reflects success and impact outcomes, where the application of lean concepts can support strategic initiatives, defect elimination, and process development and improvement, leading to the effective achievement of organizational goals and objectives [43].

Exploratory Factor Analysis (EFA)

Exploratory Factor Analysis (EFA) was developed based on philosophical and statistical principles, with Spearman [44] pioneering its implementation. It has evolved into an essential tool for theory evaluation and rapid, efficient validation of measurement instruments, while clearly identifying empirical relationships between structures and key variables [45]. EFA plays a crucial role in optimizing questionnaire data structure by reducing variable redundancy and minimizing data dimensionality [46]. Research by Mahat et al. [47] supports that this analysis assists in assessing variable validity and reliability through structural examination of variable groups, reducing variables into fundamental factors or components that reflect their shared relationships or properties. Therefore, Exploratory Factor Analysis is an invaluable technique for examining relationships between observable variables and underlying fundamental factors, enabling researchers to comprehend in-depth data structures [48]. For the EFA analytical process, the researcher utilized R Studio Version 4.2.1 for calculations. The analysis procedure, adapted from Al Baldawi et al. [49], comprises the following steps:

Step 1: Analysis of respondent data using Frequency and Percentage

Step 2: Determination of variable correlations within the dataset, testing appropriateness using Kaiser-Meyer-Olkin of Sampling Adequacy (KMO) statistics, where KMO>0.50 is considered acceptable, while KMO<0.50 results in no variable interpretation [50]. Bartlett's Test of Sphericity (Bartlett's test) should yield p<0.05, indicating sufficient variable similarity for EFA analysis [51], as shown in equations (1) – (2) [52].

Step 3: Variable extraction using Principal Component Analysis (PCA) to eliminate non-significant minimum variables while retaining influential dataset variables. The Measures of Sampling Adequacy (MSA) for each item should be >0.70, although research by Chan and Idris [53] suggests that good MSA values should be >0.50

Step 4: Presentation of Factor Loading for each variable and Cumulative Variance to demonstrate dataset variance examination, displayed in following format.

$$\mathrm{KMO_j} = \frac{\sum_{i \neq j} R_{ij}^2}{\sum_{i \neq j} R_{ij}^2 + \sum_{i \neq j} U_{ij}^2} \tag{1}$$

Where:	KMO	represents	Kaiser-Meyer-Olkin
	R_{ij}	represents	Correlation between i^{th} and j^{th} variable
	U_{ij}	represents	Partial Correlation between i^{th} and j^{th} variable

$$\text{Bartlett's test of Sphericity} = \left(\text{n-1-}\frac{2\text{p}+5}{6}\right) \text{x 1n}|\text{R}| \quad (2)$$

Where:	p	represents	Number of Variables
	n	represents	Sum of Sample Size
	R	represents	Correlation Matrix

Methodology

The research methodology was executed following the sequential protocol illustrated in Figure 1, which outlines the procedural research phases as follows: Stage 1 began with a literature review focusing on "Lean Concepts in Construction Projects." After eliminating redundant or similar items, the performance criteria were refined from 114 to 91 items to best align with the research objectives. Stage 2 involved designing a questionnaire for evaluation by nine experts [54] with diverse professional backgrounds: two construction consultants, three contractors, three project engineers, and one civil works supervisor. Each expert possessed a minimum of 10 years of experience [29]. This stage comprised two steps: Step 1: Assessment of item relevance to lean construction implementation. Items deemed irrelevant by more than four experts (over 50% of evaluators) were eliminated. Step 2: Content validity evaluation using a 5-point Likert scale (5 = most relevant, 4 = very relevant, 3 = moderately relevant, 2 = slightly relevant, 1 = least relevant) [55]. Only items with a total score > 0.60 were retained, resulting in 35 final items.

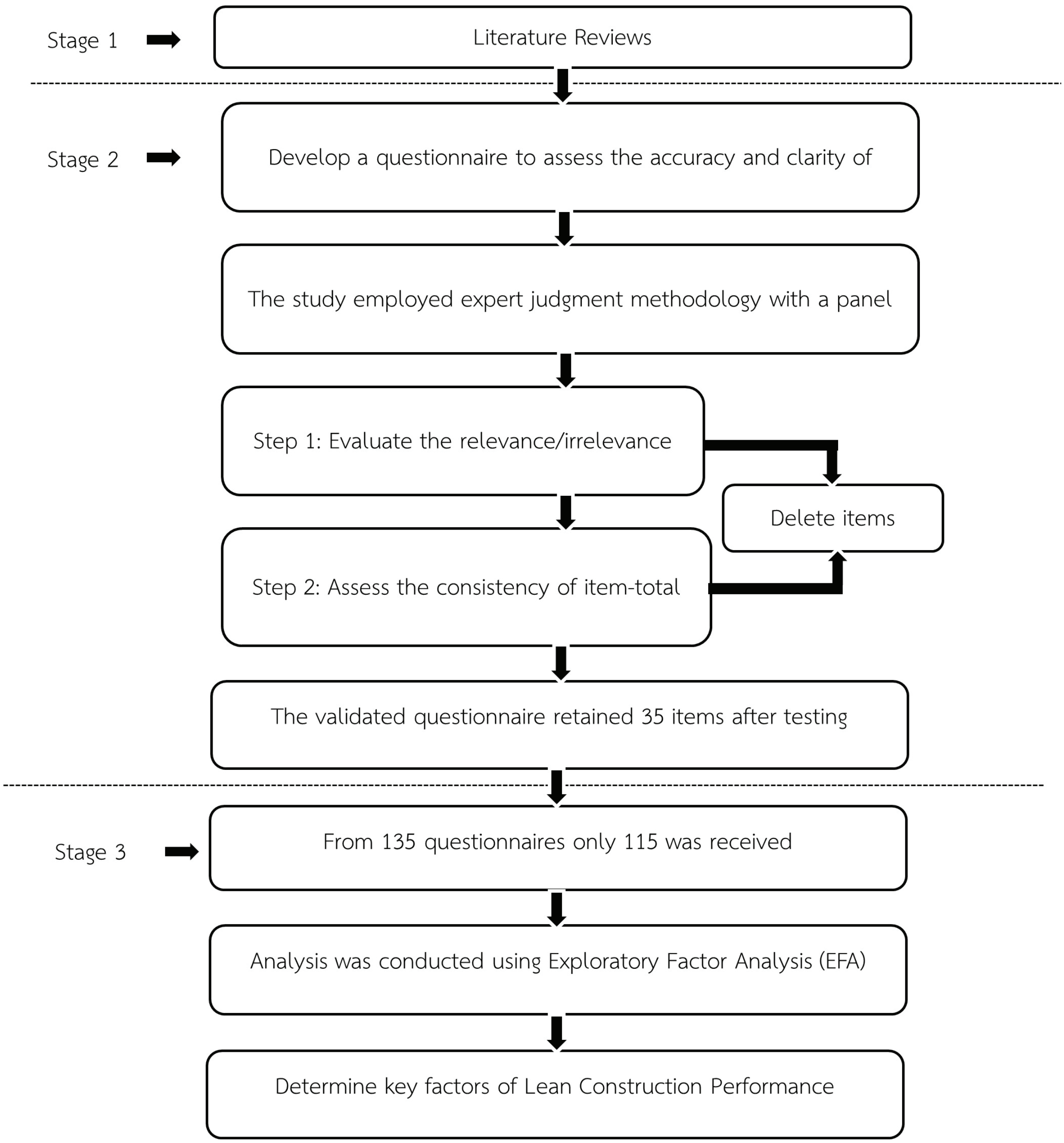

Figure 1 Research flow of procedures and analysis contents

Stage 3 involved conducting a pilot survey to assess questionnaire reliability regarding the importance of lean concepts in construction project management, which refers to a systematic evaluation of the extent to which lean principles influence efficiency, quality, risk management, collaboration, sustainability, and the overall success of construction projects. Using Cronbach's Alpha coefficient, items were rated on a 5-point Likert scale (5 = most important, 4 = very important, 3 = moderately important, 2 = slightly important, 1 = least important) [56]. Data collection were performed using snowball sampling, a non-probability sampling method particularly effective for investigating novel concepts [57]. However, snowball sampling limits the representativeness of the sample due to its reliance on network recruitment, which can introduce selection bias. Therefore, the findings should be viewed as indicative rather than generalizable. Results of the 40 pilot questionnaires distributed, 35 complete responses were received (87.50% response rate). The primary survey targeted construction project management professionals across 53 local construction organizations with well-defined administrative structures. The population included Business Owners (Contractors), Project Managers, Project Engineers, and Civil Engineers, ensuring comprehensive representation and enhanced data reliability through multi-stakeholder perspectives. Online questionnaires were distributed via email to 135 participants, yielding 115 valid responses (85.19% response rate). Exploratory Factor Analysis (EFA) was performed on 35 observed variables with a case-to-item ratio of 3.29:1. Sampling adequacy was verified through Kaiser-Meyer-Olkin (KMO $\geq$ 0.60) and Bartlett's sphericity test ($p < 0.001$). Data underwent reliability analysis prior to EFA implementation.

Results and Discussion

The survey methodology yielded 115 valid responses, exceeding the minimum threshold of 100 and satisfying methodological requirements established by Enshassi et al. [58], who validated samples larger than 50, and Orosco et al. [59], who confirmed the acceptability of sample sizes between 100-200 responses. Respondent demographics (Table 2) revealed construction contractors as the majority (n=64, 55.65%), with 47.83% (n=55) having 10-20 years' experience and 60.87% (n=70) holding bachelor's degrees. Statistical analysis yielded mean scores of 3.79-4.77, indicating respondents assessed factors as highly to very highly significant. Standard deviations approximating 1.0 demonstrated substantial concordance in factor evaluations (Table 3).

Table 2 Characteristics of respondents (n = 115)

Respondent Information	Details	Frequency	Percentage
1. Job Position	Business Owner (Contractor)	64	55.65
	Project Manager	9	7.83
	Project Engineer	29	25.22
	Civil Engineer	13	11.30
2. Work Experience	< 5 years	12	10.43
	5-10 years	16	13.91
	10-20 years	55	47.83
	> 20 years	32	27.83
3. Academic Qualifications	Below Bachelor's Degree	2	1.74
	Bachelor's Degree	70	60.87
	Master's Degree	37	32.17
	Doctoral Degree	6	5.22

Table 3 Means and standard deviations (SD) of all items in questionnaires

Item	Mean	S.D.
L1	4.32	1
L2	4.21	0.97
L3	3.94	1.09
L4	3.79	1.3
L5	4.2	0.98
L6	4.69	0.62
L7	4.67	0.64
L8	4.72	0.54
L9	4.3	0.85
L10	4.61	0.59
L11	4.6	0.68
L12	4.68	0.6

Item	Mean	S.D.
L13	4.44	0.8
L14	4.46	0.86
L15	4.58	0.6
L16	4.63	0.62
L17	4.68	0.55
L18	4.63	0.6
L19	4.5	0.68
L20	4.52	0.66
L21	4.58	0.66
L22	4.65	0.58
L23	4.63	0.56
L24	4.44	0.74

Item	Mean	S.D.
L25	4.43	0.76
L26	4.33	0.79
L27	4.45	0.75
L28	4.48	0.75
L29	4.77	0.49
L30	4.7	0.54
L31	4.64	0.67
L32	4.4	0.99
L33	4.43	0.89
L34	4.48	0.81
L35	4.6	0.78

Analysis of Pearson correlation coefficients revealed weak correlations among the factors, as evidenced by a predominance of values ranging from 0.01 to 0.50, compared to values between 0.51 and 0.77, as shown in Table 4.

Table 4 Correlation matrix of all variables

Items	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18
L1	1.00	0.38	0.38	0.31	0.37	0.23	0.26	0.10	0.20	0.24	0.19	0.19	0.11	0.33	0.22	0.19	0.20	0.17
L2	-	1.00	0.57	0.14	0.15	0.11	0.17	0.09	0.21	0.36	0.06	0.09	0.27	0.21	0.13	0.30	0.14	0.25
L3	-	-	1.00	0.21	0.23	0.07	0.21	0.13	0.35	0.41	0.13	0.25	0.32	0.20	0.30	0.43	0.17	0.34
L4	-	-	-	1.00	0.28	0.08	0.12	0.07	0.36	0.31	0.31	0.10	0.28	0.18	0.06	0.12	0.25	0.09
L5	-	-	-	-	1.00	0.26	0.19	0.22	0.36	0.27	0.15	0.18	0.30	0.37	0.17	0.19	0.36	0.31
L6	-	-	-	-	-	1.00	0.46	0.47	0.19	0.38	0.44	0.41	0.26	0.16	0.37	0.29	0.39	0.46
L7	-	-	-	-	-	-	1.00	0.47	0.30	0.49	0.37	0.45	0.28	0.15	0.43	0.33	0.39	0.59
L8	-	-	-	-	-	-	-	1.00	0.25	0.40	0.41	0.48	0.37	0.28	0.47	0.42	0.40	0.52
L9	-	-	-	-	-	-	-	-	1.00	0.51	0.25	0.24	0.51	0.29	0.27	0.30	0.44	0.34
L10	-	-	-	-	-	-	-	-	-	1.00	0.46	0.44	0.48	0.24	0.52	0.49	0.47	0.53
L11	-	-	-	-	-	-	-	-	-	-	1.00	0.45	0.37	0.15	0.33	0.33	0.40	0.42
L12	-	-	-	-	-	-	-	-	-	-	-	1.00	0.28	0.22	0.35	0.29	0.40	0.49
L13	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.25	0.42	0.48	0.44	0.38
L14	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.32	0.43	0.31	0.29
L15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.77	0.41	0.63
L16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.39	0.64
L17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.58
L18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00
L19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4 Correlation matrix of all variables (continued)

Items	L19	L20	L21	L22	L23	L24	L25	L26	L27	L28	L29	L30	L31	L32	L33	L34	L35
L1	0.01	0.04	0.22	0.15	0.13	0.14	0.14	0.13	0.15	0.12	0.11	0.14	0.07	0.02	0.15	0.05	0.04
L2	0.30	0.18	0.26	0.22	0.15	0.10	0.12	0.28	0.19	0.20	0.13	0.25	0.21	0.04	0.16	0.21	0.03
L3	0.23	0.03	0.32	0.27	0.27	0.21	0.26	0.27	0.16	0.14	0.10	0.29	0.22	0.05	0.03	0.18	0.10
L4	0.15	0.01	0.09	0.12	0.15	0.21	0.23	0.22	0.15	0.08	0.12	0.13	0.03	0.36	0.40	0.31	0.16
L5	0.36	0.16	0.22	0.19	0.26	0.27	0.27	0.31	0.23	0.30	0.13	0.16	0.19	0.18	0.24	0.29	0.20
L6	0.31	0.35	0.32	0.23	0.34	0.26	0.30	0.26	0.19	0.28	0.42	0.27	0.23	0.22	0.20	0.30	0.26
L7	0.38	0.40	0.41	0.35	0.24	0.31	0.18	0.16	0.27	0.36	0.37	0.27	0.09	0.18	0.05	0.15	0.15
L8	0.40	0.51	0.43	0.39	0.35	0.42	0.38	0.28	0.36	0.44	0.42	0.31	0.30	0.26	0.27	0.33	0.17
L9	0.41	0.33	0.27	0.30	0.24	0.50	0.30	0.38	0.28	0.31	0.18	0.23	0.20	0.28	0.29	0.33	0.19
L10	0.42	0.39	0.55	0.55	0.51	0.40	0.32	0.41	0.42	0.39	0.36	0.40	0.26	0.22	0.33	0.32	0.31
L11	0.35	0.31	0.21	0.22	0.41	0.21	0.35	0.33	0.32	0.36	0.32	0.29	0.20	0.18	0.14	0.24	0.19
L12	0.33	0.44	0.41	0.38	0.53	0.36	0.24	0.34	0.34	0.36	0.46	0.35	0.23	0.25	0.23	0.28	0.21
L13	0.52	0.56	0.38	0.41	0.38	0.56	0.42	0.50	0.33	0.38	0.41	0.42	0.34	0.29	0.35	0.37	0.38
L14	0.21	0.11	0.40	0.29	0.28	0.38	0.37	0.47	0.43	0.33	0.25	0.39	0.43	0.13	0.25	0.32	0.25
L15	0.40	0.48	0.63	0.56	0.52	0.47	0.37	0.47	0.38	0.46	0.32	0.52	0.34	0.26	0.34	0.30	0.27
L16	0.45	0.38	0.60	0.62	0.56	0.33	0.35	0.46	0.35	0.34	0.35	0.55	0.46	0.24	0.24	0.33	0.33
L17	0.54	0.36	0.44	0.36	0.46	0.52	0.45	0.50	0.54	0.52	0.37	0.41	0.42	0.28	0.36	0.58	0.43
L18	0.61	0.54	0.55	0.58	0.47	0.40	0.37	0.43	0.36	0.36	0.36	0.41	0.38	0.22	0.16	0.43	0.33
L19	1.00	0.43	0.48	0.44	0.45	0.43	0.33	0.44	0.33	0.37	0.28	0.33	0.35	0.34	0.34	0.49	0.36
L20	-	1.00	0.48	0.54	0.44	0.50	0.27	0.37	0.31	0.44	0.52	0.36	0.26	0.32	0.40	0.30	0.24
L21	-	-	1.00	0.76	0.60	0.47	0.34	0.52	0.49	0.46	0.54	0.58	0.47	0.27	0.43	0.44	0.30
L22	-	-	-	1.00	0.60	0.51	0.32	0.45	0.45	0.41	0.55	0.51	0.42	0.32	0.43	0.49	0.37
L23	-	-	-	-	1.00	0.43	0.32	0.60	0.39	0.45	0.42	0.58	0.48	0.34	0.42	0.40	0.34
L24	-	-	-	-	-	1.00	0.52	0.51	0.52	0.59	0.42	0.41	0.37	0.33	0.56	0.62	0.52
L25	-	-	-	-	-	-	1.00	0.61	0.58	0.53	0.40	0.43	0.47	0.26	0.40	0.53	0.55
L26	-	-	-	-	-	-	-	1.00	0.68	0.63	0.48	0.59	0.58	0.34	0.50	0.59	0.43
L27	-	-	-	-	-	-	-	-	1.00	0.79	0.49	0.39	0.37	0.28	0.53	0.52	0.37
L28	-	-	-	-	-	-	-	-	-	1.00	0.57	0.48	0.42	0.30	0.52	0.56	0.33
L29	-	-	-	-	-	-	-	-	-	-	1.00	0.66	0.59	0.48	0.48	0.58	0.56
L30	-	-	-	-	-	-	-	-	-	-	-	1.00	0.78	0.41	0.45	0.58	0.58
L31	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.33	0.42	0.59	0.61
L32	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.63	0.53	0.31
L33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.71	0.45
L34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.67
L35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00

The analysis results of Lean project management efficiency measurement criteria in construction projects using EFA technique involve analyzing various efficiency measurement criteria obtained from questionnaires through statistical analysis, with details as follows:

1. Assessment of Data Efficiency Measurement Criteria

Data reliability analysis revealed a Kaiser-Meyer-Olkin (KMO) value of 0.824, indicating good suitability for Exploratory Factor Analysis (EFA), consistent with Al Baldawi et al. [49] findings. The model's significance testing (Bartlett's test) yielded $p < 0.001$, satisfying Shrestha [52] recommendation of $p < 0.05$. Upon examining individual Measure of Sampling Adequacy (MSA) indices, variables 1.1, 1.2, and 1.3 exhibited values of 0.61, 0.57, and 0.68 respectively—below the 0.70 threshold recommended by Anggraini et al. [60] but above the marginally acceptable 0.50 level. These variables were nonetheless removed to enhance model precision. Subsequent reanalysis produced an improved KMO value of 0.845 with $p < 0.001$, confirming continued data suitability. Reliability assessment yielded Cronbach's alpha values of 0.927 for the sample group and 0.938 overall, exceeding Yuan et al. [61] 0.90 threshold and demonstrating high reliability. Tables 5 and 6 provide comprehensive details. The range there for, construction process in Thai study case be acceptable compared with another researcher.

Table 5 Analysis of KMO, Bartlett's test, and Cronbach's alpha

Test		Result	
		First run	Last run (Third run)
KMO		0.824	0.845
Bartlett's test	K-squared	432.14	348.94
	df	34	13
	p-value	0.001	0.001
Reliability test		Sampling 35 items	Overall, 115 items
	Cronbach's alpha	0.927	0.938
	Cronbach's alpha based on standardized items	0.942	0.948

Table 6 Analysis results of measure of sampling adequacy (MSA) for individual variables

Item	MSA First run	Last run (Third run)
L1	0.61	Remove in the 1st run
L2	0.57	Remove in the 1st run
L3	0.68	Remove in the 1st run
L4	0.70	Remove in the 2nd run
L5	0.78	0.81
L6	0.86	0.89
L7	0.86	0.85
L8	0.92	0.92
L9	0.81	0.84
L10	0.86	0.91
L11	0.82	0.90
L12	0.90	0.90
L13	0.86	0.85
L14	0.83	0.85
L15	0.76	0.79
L16	0.83	0.83
L17	0.86	0.90
L18	0.87	0.85

Item	MSA First run	Last run (Third run)
L19	0.85	0.90
L20	0.81	0.84
L21	0.90	0.89
L22	0.86	0.88
L23	0.78	0.80
L24	0.87	0.86
L25	0.90	0.92
L26	0.84	0.86
L27	0.78	0.79
L28	0.81	0.80
L29	0.83	0.83
L30	0.89	0.89
L31	0.84	0.86
L32	0.83	0.81
L33	0.76	0.81
L34	0.79	0.79
L35	0.78	0.79

2. Factor Extraction

In the consideration of Eigenvalues and Total Variance Explained values, which serve to identify the appropriate number of factors for the dataset, the analysis indicated that six factors would be optimal for this dataset, as demonstrated in Figure 2.

Figure 2 demonstrates the Eigenvalues for factors 1 through 6, which are 12.76, 2.47, 1.64, 1.45, 1.29, and 1.17, respectively. The Proportion of Variance percentages for factors 1 through 6 are 41.00%, 8.00%, 5.00%, 5.00%, 4.00%, and 0.04% respectively. Meanwhile, the Cumulative Proportion of Variance percentages are 41.00%, 49.00%, 54.00%, 59.00%, 63.00%, and 67.00% respectively. The eigenvalues exceed 1, and the cumulative variance falls within an acceptable range. This aligns with the research of Upadhyaya and Malek [62], which indicated a cumulative variance of 56.288%, considered acceptable by standard criteria. In contrast, research by Renault et al. [63] reported a cumulative percentage of variance of only 34.021%, which falls below the 50.00% threshold, although their KMO value of 0.796 remained within acceptable limits. Meanwhile, research by Mahat et al. [47] found a cumulative variance of 72.113%, which is categorized as good and appropriate for exploratory factor analysis. Therefore, the range of cumulative percentage in Thai study can be acceptable compared with other researchers.

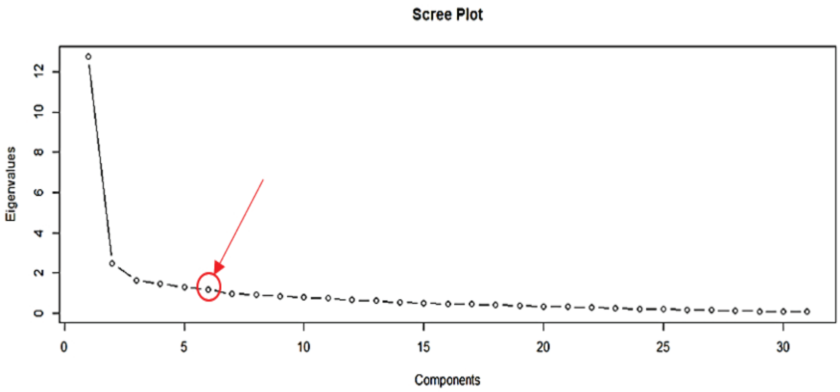

Figure 2 Scree plot of data

3. Factor Rotation and Interpretation

The examination of Factor Loading and criterion interpretation was conducted using Parallel Analysis (PA) and Varimax rotation methods, following Gandhi et al. [64]. This analysis yielded six distinct factors, as presented in Table 7.

Table 7 Results of Exploratory Factor Analysis (EFA)

Indicator's name		Factor loading
Factor 1: Cost and Quality		
L11	High level of customer (owner) satisfaction with construction project outcomes, demonstrating success in meeting customer needs and expectations	0.665
L12	Reduction in work redundancy and rework due to errors or issues in work processes	0.747
L17	Improvement or enhancement of construction project operational efficiency in resource utilization, time, and costs	0.696
L18	Continuous improvement of work processes to increase efficiency, reduce waste, and enhance construction quality	0.686
L19	Implementation of strategies aimed at improving construction project quality to meet standards, customer requirements, and relevant specifications	0.500
% Proportion variance		12.20

Table 7 Results of Exploratory Factor Analysis (EFA) (continued)

Indicator's name		Factor loading
Factor 2: Strategy and Planning		
L2	Project completion within specified time and budget constraints	0.622
L3	Implementation of efficient strategies and methods in planning, execution, and control of construction projects to ensure timely completion	0.663
L4	Delivery of construction project components according to established schedules	0.563
L7	Streamlined project management with minimal redundancy	0.572
L8	Appropriate allocation of personnel skills and capabilities aligned with genuine expertise	0.591
L14	Contractor performance efficiency in construction projects according to contractual terms and conditions	0.569
L6	Improvement and efficiency enhancement in all construction phases for rapid completion	0.424
L16	Contractor selection focusing on capability and expertise rather than price alone	0.454
% Proportion variance		12.20
Factor 3: Safety		
L26	Development or improvement of employee health and safety measures to prevent accidents, injuries, and work-related illnesses	0.672
L27	Implementation of measures and guidelines to protect employee health and safety at construction sites	0.773
L30	Ratio of safe actions and safety compliance compared to total behaviors at construction sites	0.552
L31	Percentage of correct PPE (Personal Protective Equipment) usage according to standards and specifications	0.655
% Proportion variance		10.10
Factor 4: People and Processing		
L5	Reduction in activity duration to achieve project completion ahead of schedule	0.623
L15	Enhancement of labor efficiency or productivity in construction processes	0.521
L1	Project completion in minimal time within lowest budget	0.446
L9	Expedited procurement and delivery of materials, tools, and equipment	0.494
L13	Maintenance of construction quality and standards throughout all project phases to meet client specifications and expectations	0.482
L20	Training and capacity building processes for team members to develop necessary skills and knowledge	0.461
% Proportion variance		8.80
Factor 5: Waste		
L22	Implementation of strategies focused on reducing environmental impact from construction activities and improving natural resource efficiency	0.523
L23	Reduction in waste volume and material losses during construction processes	0.818
L24	Monitoring and evaluation of 5S principles compliance, focusing on workplace management system that emphasizes efficiency improvement, waste reduction, and creation of safe and organized work environment	0.693

Table 7 Results of Exploratory Factor Analysis (EFA) (continued)

Indicator's name		Factor loading
L10	Minimization of construction project-related costs without compromising work quality and safety	0.371
L21	Reduction in non-beneficial material usage in construction processes to improve material efficiency and reduce waste generation	0.447
% Proportion variance		8.30
Factor 6: Health and Accident		
L25	Management and supervision of worker health and safety to prevent hazards and reduce risks in construction projects	0.504
L28	Frequency of accidents or safety-related incidents at construction sites	0.539
L29	Rate used to measure accident severity, generally calculated to assess impact of accidents on employees and work processes	0.710
% Proportion variance		8.00
% Cumulative variance		59.70

The analysis results from Table 7 demonstrate that the 31 efficiency measurement criteria for lean concept application in construction project management yielded a cumulative variance of 59.70% after factor rotation, which is considered acceptable as it exceeds 0.50. This aligns with Wattanakomol and Silpcharu [65] research, which reported a variance of 50.971%. In contrast, while Renault et al. [63] study showed a lower variance of 34.021%, it maintained acceptable levels with KMO = 0.796 and Cronbach's alpha = 0.864. After variable extraction and exploratory factor analysis, six factors were identified: Factor 1: Cost and Quality (5 variables), Factor 2: Strategy and Planning (8 variables), Factor 3: Safety (4 variables), Factor 4: People and Processing (6 variables), Factor 5: Waste (5 variables), and Factor 6: Health and Accident (3 variables).

Examining Factor 1 in detail, the highest factor loadings were found in L12 (0.747), followed by L17 (0.696) and L18 (0.686), indicating that reducing redundant work processes in lean construction significantly impacts construction project management efficiency, along with process improvement and operational enhancement through optimal resource utilization. This corresponds with Kineber et al. [66] research emphasizing process reduction for lean principle reliability, with a factor loading of 0.589. However, the researchers identified additional considerations regarding scope definition, value creation, and customer satisfaction as crucial strategies for measuring lean concept efficiency.

For Factor 2, the highest factor loadings were observed in L3 (0.663), L2 (0.622), and L8 (0.591), reflecting that efficient strategic planning and operational methods facilitate timely project completion within budget constraints, possibly influenced by effective utilization of specialized personnel expertise. Mahat et al. [47] discussed workforce skill levels and turnover rates as crucial project management factors, reporting higher factor loadings of 0.794 and 0.699 compared to this study.

For Factor 3, the highest factor loadings were observed in L27 (0.773), L26 (0.672), and L31 (0.655), respectively. This indicates that appropriate implementation of various guidelines ensures personnel health and safety at construction sites, preventing accidents, injuries, or work-related illnesses. The correct usage of personal protective equipment according to established standards contributes to successful project management goal achievement. This aligns with Upadhyaya and Malek [62] research perspectives on safety management, planning, training, and assessment, considering team and operational manual aspects, with factor loadings ranging from 0.611-0.792.

For Factor 4, the highest loadings were observed in L5 (0.623), L15 (0.521), and L9 (0.494), indicating the importance of reducing activity durations to achieve early project completion, improving labor efficiency, and expediting procurement and delivery of resources. A practical example is the implementation of a Just-In-Time (JIT) delivery system in a housing project, coordinated with a local concrete block manufacturer to supply materials on a weekly schedule. Masonry teams were mobilized upon delivery, which minimized on-site inventory, reduced weather-related risks, improved workspace efficiency, and accelerated masonry completion. These findings align with Mahat et al. [47] research where P1 (type of procurement/contract adopted) showed a factor loading of 0.775, contrasting with MP2 (worker's skill level) at 0.794, which exceeded L15.

Factor 5's highest factor loadings were observed in L23 (0.818), L24 (0.693), and L22 (0.523), respectively. This factor emphasizes the importance of reducing waste and material consumption in construction processes, including monitoring, and evaluating 5S principles to minimize environmental impact and construction activities, thereby enhancing project management efficiency. This aligns with Soewin and Chinda [55] research discussing waste management and reduction, reuse & recycling, with factor loadings of 0.74 and 0.66. Notably, The factor loading L10=0.371 remains acceptable as it exceeds the standard statistical threshold of 0.30 for Exploratory Factor Analysis, consistent with Mitchell et al. [67] who demonstrated that factors with lower loadings (e.g., 0.355) retain theoretical and practical significance, particularly for complex constructs with multidimensional relationships such as cost reduction without compromising quality and safety in construction projects. Despite the relatively modest statistical value, this factor reflects the critical importance of this concept within the industry and should be retained in the model to ensure measurement comprehensiveness.

For Factor 6, the highest loadings were observed in L29 (0.710), L28 (0.539), and L25 (0.504), highlighting the significance of accident occurrence rates, severity, and health and safety management in construction project performance. A practical example is the implementation of daily safety meetings and a Safety Score Board, involving 15-minute safety briefings each morning, weekly safety audits, and visible displays of accident-free days and monthly safety statistics, complemented by monthly rewards for top-performing teams. This approach reduced monthly accident rates, enhanced workers' safety awareness, minimized work stoppages due to accidents, and ensured continuous project progress without schedule delays. These findings are consistent with Enshassi et al. [58], who reported factor loadings of 0.816 and 0.805 for lean construction techniques applied to safety performance improvement.

Overall analysis reveals that L23 achieved the highest factor loading at 0.818, pertaining to reducing waste and material losses in construction processes. This results from local construction operators facing various project management limitations including limited capital, lack of modern equipment, difficult access to necessary technology, and constraints in implementing modern management techniques effectively [23, 24]. This aligns with research by Patil and Bhaumik [68] and Ma'rifah [69] explaining how Lean construction techniques in material management can lead to significant cost savings through reduced material waste and improved project cost efficiency. Furthermore, construction waste, if not properly managed, may lead to excessive project costs, as 6-10% of purchased materials typically become waste in construction projects [70].

Conclusion

Overview of 115 survey respondents can be summarized as follows: The majority of respondents were business owners (construction contractors) at 55.65%, had work experience between 10-20 years at 47.83%, and held bachelor's degrees at 60.87%. Data analysis employed Exploratory Factor Analysis (EFA) technique, with a Kaiser-Meyer-Olkin (KMO) value of 0.845

and p-value less than 0.001, indicating acceptable data suitability, and a Cronbach's alpha of 0.938 demonstrating high reliability. The analysis revealed that lean construction-related factors could be categorized into 6 main components: Cost and Quality, Strategy and Planning, Safety, People and Processing, Waste, and Health and Accident, comprising 31 criteria in total, with a cumulative variance of 59.70%, which falls within acceptable parameters.

Following variable extraction and Exploratory Factor Analysis, the data was categorized into 6 component groups, each representing significant characteristics and variables as follows: (1) Cost and Quality emphasizes the importance of reducing work redundancy, which is crucial for construction project management efficiency, including process improvement and operational enhancement through optimal resource utilization; (2) Strategy and Planning highlights the significance of efficient project planning and management to ensure project completion within scheduled timeframes and budget constraints; (3) Safety reflects the importance of health and safety management at construction sites, including appropriate use of personal protective equipment, preventing accidents, injuries, or work-related illnesses that affect project management success; (4) People and Processing indicates that reducing activity intervals to accelerate project completion, improving labor efficiency, and optimizing material procurement and delivery processes play crucial roles in project acceleration; (5) Waste represents a significant variable in reducing construction waste and material consumption, including 5S principle evaluation and monitoring to minimize environmental impact and enhance construction activities, resulting in more efficient project management; and (6) Health and Accident serves as a crucial variable indicating accident occurrence rates, accident severity, accident frequency, and employee health and safety management, which impact worker performance and project success.

The six core components of Lean Construction can be operationalized through the systematic integration of project management methodologies. These elements provide a foundation for organizational development by facilitating the establishment of a Lean Construction Maturity Model, defining Key Performance Indicators (KPIs) aligned with strategic objectives, developing training programs across organizational levels, and implementing knowledge management systems to promote best practice exchange. Empirical evidence shows that integrating Value Stream Mapping with 5S methodologies in concrete production significantly reduces tool search time and minimizes waste throughout construction workflows. Looking forward, construction project management is expected to increasingly adopt digital transformation strategies, including Building Information Modeling (BIM), Artificial Intelligence for predictive analytics, and Integrated Project Delivery (IPD) systems that enhance collaborative business partnerships. Collectively, these approaches foster a high-performance, sustainable construction ecosystem capable of addressing diverse stakeholder expectations. Future research should extend this approach to analyze lean construction factors in large-scale infrastructure projects and compare implementation practices between Thai local enterprises and their international counterparts. Such comparative studies would help establish broadly applicable principles and internationally recognized best practices in lean construction, advancing both theoretical understanding and practical applications across different geographical and organizational settings.

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