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THE INFLUENCE OF PRECONSTRUCTION PHASE AND LEAN CONSTRUCTION IMPLEMENTATION ON PROJECT PERFORMANCE

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ABSTRACT

Effective design management during the preconstruction phase has significant effects on project performance within the Architecture, Engineering, and Construction (AEC) sector. This research examines critical factors that impact the design outcomes at the preconstruction phase in the construction of infrastructure projects which affect the overall project performance. Using a sequential hybrid research approach that combines qualitative interviews and quantitative surveys, this study identifies ten crucial factors that influence project performance during the preconstruction phase. The relative importance index (RII) method is used to prioritise these factors, emphasising the most influential areas for enhancement. This study investigates the use of lean construction (LC) principles and tools to minimize the impact of these factors. These tools include integrated project delivery (IPD), building information modelling (BIM), last planner system (LPS), value stream mapping (VSM), target value design (TVD), set-based design (SBD), and choosing by advantage (CBA). Authors propose a comprehensive Lean Construction-based Risk Mitigation (LC-RM) framework to integrate these methodologies and enhance the design process during the preconstruction phase, thereby improving overall project performance. This research makes a valuable contribution to the field of construction management by providing practical recommendations for effective decision-making and lean practices during the preconstruction phase. It serves as a preliminary step towards improving construction management processes and has the potential to be further explored in future studies.

KEYWORDS

Lean construction, Design management, Preconstruction, Risk mitigation, Critical factors, Infrastructure construction project

INTRODUCTION

Poor design management (DM) in construction projects can have significant negative impacts on various aspects of the project, including cost, schedule, quality, and overall project success (Pikas et al., 2019). The most effective and efficient method for managing the design during the preconstruction phase is still unclear (Niranjan et al., 2022). The architecture, engineering, and construction (AEC) industry is well-known for its dynamic and unpredictable nature, which presents challenges in achieving effectiveness. Effectiveness, as conceptualised by scholars,

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pertains to the efficient allocation of resources necessary for the successful execution of a given task (Gholinezhad Dazmiri & Hamzeh, 2023). According to Koskela (2000), the main objective of improving productivity within the context of LC is to reduce waste and enhance value. The AEC sector generates a substantial quantity of waste. In recent years, the organisation has been utilising lean tools such as the LPS in order to reduce waste (Skaar et al., 2023). Within the framework of lean principles, waste is operationally defined as the suboptimal utilisation of machinery, supplies, personnel, or other valuable resources, leading to the inappropriate allocation of time, financial resources, or other valuable assets (Skaar et al., 2023). As per Koskela (2000), it denotes any task or asset that does not add value to the final product. According to Aslam et al. (2020a), waste in design can be defined as any activity that results in the depletion of resources without providing any value. Time measurement is a crucial metric for assessing waste, particularly when determining the proportion of tasks that do not add value. According to Aslam et al. (2020b), waste during the design phase can arise due to various factors such as delays, waiting times, design flaws, excessive processing, and negative iteration or rework. The presence of these waste materials can significantly affect construction projects, as design errors are the primary factor contributing to the decrease in both cost and value (Tzortzopoulos et al., 2020). Tzortzopoulos et al. (2020) posit that the incorporation of rework and non-value-adding activities within the design process has the potential to prolong the duration of the design phase and give rise to delays. The delays mentioned above can be attributed to various factors, such as the delayed acquisition of design information, frequent modifications to the design, alterations in the timing and order of the implementation, fluctuations in demand, and insufficient design efforts (Naji et al., 2022a; Salam et al., 2023). As a result, it is critical to engage in thorough design management (DM) planning during the preconstruction stage of the infrastructure project in order to ensure its long-term success. This is because DM planning has a significant influence on multiple factors, including client satisfaction and operational and maintenance expenses (Chaize et al., 2022). Hasty designs, design processes, and DM practices are the root causes of many persistent production and construction challenges (Naji et al., 2022b&c). Naji et al. (2022b) identified design errors as the primary cause of structural failures, time and cost overruns, and catastrophic accidents in building construction and maintenance. Inadequate designs may give rise to the need for rework, change orders, and preliminary estimates, thereby potentially resulting in excessive expenditure or project delays. The AEC sector widely acknowledges the aforementioned concerns as prominent contributors to waste (Naji et al., 2022a, b, c)

Previous studies seek to improve the design process during the preconstruction phase in the AEC industry, with particular emphasis on integrating design with advanced technology like BIM to enhance efficiency (Gholinezhad Dazmiri & Hamzeh, 2023; Gunduz et al., 2023), focusing on developing a framework to facilitate early supplier involvement as an approach for reducing construction waste generated during the design process (Othman & El-Saeidy, 2024), investigating only the activities related to early contractor involvement (Memić et al., 2023), targeting preconstruction phase management practices (PCMPs) that can improve labor productivity in multistory building projects (Tarekegn Gurmu, 2023), focusing on the financial aspect of collaboration but undervalued the social dimension which reflects behavioral actions that can lead to goal misalignment (Salam et al., 2023), supporting a visual model with design parameters that are specific to manufacturing to reduce waste in the design stage of a construction project (Cardenas Castaneda et al., 2022), focusing on collaborative decision-making process in the design phase (Schöttle et al., 2018), and developing an initial framing for design process support systems to facilitate the error and knowledge management (Pikas et al., 2019).

According to Lin and Golparvar-Fard (2021), lean is a management methodology that adopts a proactive approach to planning. This approach entails the early identification of constraints to prevent their occurrence during the execution phase. The transformation of the aforementioned limitations into potential risks and inefficiencies significantly impacts the entire lifespan of the construction project (Bajjou & Chafi, 2020). Therefore, various scholarly sources in the field of construction management (Naji et al., 2022b&c) provide a comprehensive analysis of the quantification of performance factors in project management. Construction companies are prioritizing efficient DM and implementing more stringent strategies to evaluate it in order to create preventive measures and improve performance during the preconstruction phase (Naji et al., 2022a). The prompt identification of outcome measures and risk factors linked to DM can aid in mitigating these effects and diminishing the probability of a construction project encountering cost and schedule repercussions.

KNOWLEDGE GAP AND POINT OF DEPARTURE

The literature review reveals that inadequate design management during the preconstruction phase has a significant impact on the overall performance of a project. The authors contend that the current frameworks pertaining to enhancing DM during the preconstruction phase of infrastructure exhibit various limitations. Furthermore, the main reason for these limitations is the absence of a comprehensive lean construction-based risk mitigation framework (LC-RM) that encompasses the global perspective of design management activities during the preconstruction phase (Naji et al., 2022b) (Salam et al., 2023). This framework should encompass the most effective practices, factors contributing to success, and operational procedures that can be implemented in infrastructure projects. Therefore, the primary objective of this study is to investigate the monitoring of performance factors related to design management in order to mitigate the impact of design management during the preconstruction phase and enhance the overall performance of infrastructure projects. Additionally, it aims to explore the potential applications of the study's findings for construction management practitioners, with the goal of proactively addressing and minimising adverse design modifications during the preconstruction phase of infrastructure projects. Hence, the primary aims of this research endeavour encompass the identification of pivotal factors that contribute to suboptimal design outcomes, the evaluation of their significance in impacting project performance, and the proposition of a LC-RM framework to address the existing research gap.

METHODOLOGY

The chosen research methodology is derived from the sequential hybrid approach proposed by Naji et al. (2022c), which involves the collection, interpretation, and modelling of both qualitative and quantitative data. Figure 1 visually represents this approach. The research methodology consists of four phases, namely: (1) identification of the critical factors resulting in poor design outcomes; (2) questionnaire and data collection; (3) data analysis and discussion; and (4) conclusion. Phase one deals with identifying the key factors that contribute to subpar project performance and are associated with unsatisfactory design outcomes; a set of semi-structured interviews with eight construction experts as a pilot-based study (Naji et al., 2022b) to validate the identified factors; and the development of the initial questionnaire of the study. Literature research was undertaken to discover the critical factors, which consisted of three phases: journal selection, article selection, and paper analysis. Using databases such as Scopus, The International Group for Lean Construction (IGLC), the American Society of Civil Engineers (ASCE), Taylor & Francis Online, the International Journal of Project Management (IJPM), IEEE Xplore library, Elsevier, and Emerald, the first stage involved a thorough selection of highly ranked publications in construction engineering and management research.

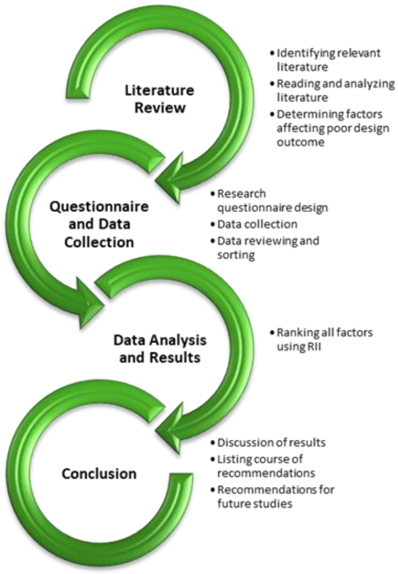

Figure 1: Research Methodology Stages

The second stage involved identifying relevant papers published between 2014 and 2024, based on their titles, abstracts, and keywords. "lean construction", "design phase", "infrastructure project", "lean in design stage", "successful factors in design stage," and "design management" were among the terms used in the study. Papers were chosen based on the following criteria: (1) the paper should be specifically related to DM with the goal of mitigating the impact of poor DM; (2) the paper should discuss techniques and tools for controlling and managing DM with an emphasis on application in the field of construction management; and (3) the paper should use a unique assessment technique. Consequently, the review has identified 10 key factors that significantly contribute to the subpar performance of projects. Table 1 displays a comprehensive list of these factors, accompanied by their corresponding references.
The second phase involved the developing the questionnaire and the collecting data. The questionnaire was developed to gather data on the relative significance of the predetermined factors. After finalising the questionnaire design, the sample size was determined, and the data was gathered and organised. The questionnaire was divided into three parts, namely general information, the importance of lean implementation at the preconstruction phase, mainly the design phase and its influence on the project performance, and the level of importance of design management factors influencing the project performance.
Naji et al. (2022b) recommend aiming for a sample size of at least 100, preferably exceeding 200. As per Naji et al. (2022b) findings, the sample size should be sufficiently large to maintain a ratio of observations to estimated parameters of 1:5. In the context of this study, this implies that a minimum sample size of 50 is required. The sample size of the population is determined to be 96, using a confidence interval of 95% and a margin of error of 10%, according to the equation provided below.

$$Sample\ Size = \frac{\frac{z^2 * p\ (1-p)}{e^2}}{1 + (\frac{z^2 * p(1-p)}{e^2 * N})} \qquad (1)$$

Table 1: 10 critical factors that contribute to both poor project performance and a subpar design outcome

Code	Factor	References
DES1	Improper defining of client value/ need	(Aslam et al., 2020b) (Mahamid, 2021) (Osamudiamen et al., 2022)
DES2	Insufficient and unrealistic constraints on project cost	(Schöttle et al., 2018) (Aslam et al., 2020b) (Osamudiamen et al., 2022)
DES3	Insufficient and unrealistic constraints on project time	(Schöttle et al., 2018) (Aslam et al., 2020b) (Naji et al.,2022c)
DES4	Lack of information for project full scope	(Naji et al.,2022c) (Aslam et al., 2020b) (Mahamid, 2021) (Salam et al., 2023)
DES5	Lack of awareness of local market	(Naji et al.,2022c) (Mahamid, 2021) (Schöttle et al., 2018) (Salam et al., 2023)
DES6	Individual decision making of design conflicts	(Pikas et al., 2019) (Osamudiamen et al., 2022) (Pikas et al., 2020)
DES7	Making design decision based on cost rather than the value of work	(Pikas et al., 2019) (Pikas et al., 2020) (Naji et al., 2022c)
DES8	Inadequate coordination meeting with other stakeholders	(Aslam et al., 2020b) (Naji et al., 2022c) (Mahamid, 2021) (Salam et al., 2023)
DES9	Lack of constructability review of design	(Pikas et al., 2019) (Naji et al., 2022c) (Assaf et al., 2023) (Gunduz et al., 2023)
DES10	Inadequate involvement of construction experts during design	(Naji et al., 2022c) (Salam et al., 2023) (Gholinezhad Dazmiri & Hamzeh et al., 2023)

Where z is the number of standard deviation a given proportion is away from the mean which is related to the level of confidence, p the population proportion, e the margin of error and N the population size.

The study includes a total of 111 participants, surpassing the minimum requirement in all instances. The questionnaire was disseminated as an online survey in response to limitations on conducting in-person interviews imposed by various organisations. The third stage involved conducting data analysis using the Relative Importance Index method (RII) to identify the primary factors causing poor project performance.

The final phase involved formulating recommendations that could enhance productivity and project delivery, as well as address the triple constraints (i.e., time, cost, and scope) in infrastructure projects. These recommendations pertain to all individuals and groups who are accountable for subpar performance and design results.

DATA COLLECTION AND ANALYSIS

The data was collected through an online questionnaire survey that was distributed using the SurveyMonkey platform. The researchers employed the nonprobability sampling technique to select potential participants, which involves using non-random methods to gather the sample (Naji et al., 2022a). The study employs purposive sampling, a method that involves selecting participants based on specific criteria or their knowledge of particular phenomena. The questionnaire survey was disseminated to over 200 participants in the State of Qatar who possess expertise and familiarity in lean construction, design, engineering, and construction projects through the assistance of industry experts, personal connections, and social media platforms. 116 individuals have participated in the survey, with 5 responses being excluded due to incompleteness. This leaves us with a total of 111 complete responses. The questionnaire was disseminated among various categories of organizations, including clients, designers, consultants, and contractors, to mitigate any potential bias in data collection. In part 1, the respondents were asked to provide information about their backgrounds. In part 2, rate the influence of the lean approach at the design phase on the project performance using a five-point Likert scale with the following numbers and corresponding answers: 1 = not at all important; 2 = slightly important; 3 = moderately important; 4=very important; and 5=extremely important. In the last part of the questionnaire, the respondents were asked to rate the level of importance of design management factors that influence the project performance using the same Likert scale. The ratings were analyzed utilizing a systematic approach employing quantitative statistical results to guide the next step in data collection.

RESULTS

RESPONDENT DEMOGRAPHICS

The responses include executive managers, department managers, project managers, infrastructure facility managers, senior design engineers, construction engineers, and quantity surveyors in the private and public sectors using a variety of parameters, including years of experience, working division, organization type, and position. Most of the respondents were international experts and practitioners from the public and private sectors, representing a wide range of experience and backgrounds in infrastructure projects. For example, the distribution of respondents based on years of experience was nearly equal, except for those with 11 or more years of experience who constituted the majority, accounting for approximately 65%. Figure 2 depicts a summary of the respondents' years of experience. Figure 3 demonstrates that approximately 56% of the respondents were highly or exceedingly knowledgeable about LC, while roughly 33% had a moderate level of familiarity. This demonstrates that the survey respondents were knowledgeable about the subject and were able to understand and respond accurately to the survey questions. As a result, the gathered data are deemed to be sufficient for experienced respondents in this sort of perception study to reach a sound judgment.

DATA ANALYSIS

Using the Relative Importance Index (RII) method, which ranks the influence of various factors on poor project performance, the data were analysed. Afterwards, the five most important factors are selected as the main areas for improvement using the lean approach during the design phase. In their study, Naji et al. (2022a) demonstrated that the RII is a highly efficient approach for analysing questionnaire data and precisely prioritising factors or variables. The RII value, which ranges from 0 to 1, represents the extent of influence on the dependent variable, with higher values indicating a stronger impact. Equation 2 calculates the RII.

$$RII = \frac{\sum W}{A * N} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5 * N} \qquad (2)$$

Where W is the weight value (ranging from 1 to 5) given by respondents to each factor, in where 1 represents “Not at all Important” and 5 represents “Extremely Important”. A is the highest weight value which is 5 in this case, and N is the total number of responses. However, n is the number of responses to each weight value.

Table 2 presents a summary of the RII value and ranking outcome for the level of significance of the ten identified factors. It has been observed that factors DES9 and DES10 have identical RII values. Further examination revealed that the descriptions of these two factors essentially convey the same point: the insufficient involvement of construction experts during the design phase.

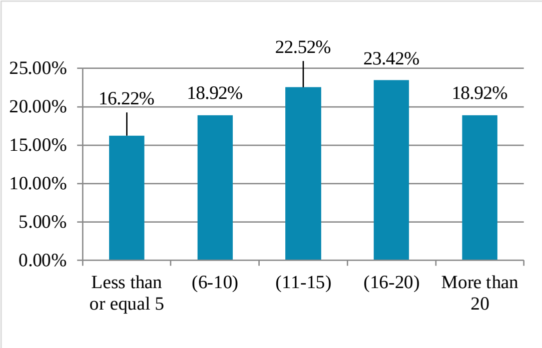

Figure 2: Respondents' years of experience

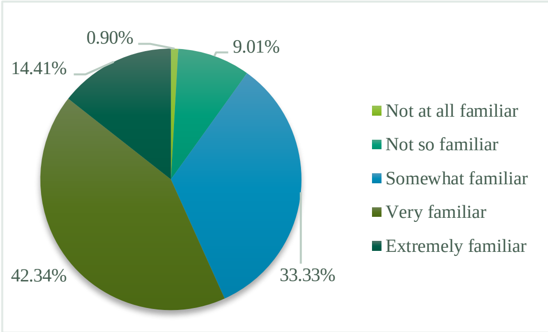

Figure 3: Participant's self-reported level of awareness regarding lean construction

Table 2: RII Value and Ranking Results for DM factors

Code	Factor	RII	Ranking
DES4	Lack of information for project full scope	0.838	1
DES1	Improper defining of client value/ need	0.818	2
DES3	Insufficient and unrealistic constraints on project time	0.811	3
DES9	Lack of constructability review of design	0.810	4
DES10	Inadequate involvement of construction experts during design	0.809	5
DES2	Insufficient and unrealistic constraints on project cost	0.806	6
DES8	Inadequate coordination meeting with other stakeholders	0.798	7
DES6	Individual decision making of design conflicts	0.785	8
DES7	Making design decision based on cost rather than the value of work	0.766	9
DES5	Lack of awareness of local market	0.742	10

DISCUSSION

The result of questionnaire shows the implementing lean practices has a greater impact on project performance during the preconstruction phase, in design phase. Table 3 illustrates the influence degree categorized by various types of organizations. The feedback from the client, consultant, and contractor revealed that the influence of lean principles in design varied from moderate to high. In contrast, the responses from the designers indicated a range of impact from slight to moderate. However, a substantial 76% of all participants hold the belief that integrating lean practices during the design phase has considerable significance, ranging from moderate to extremely crucial. Lack of information for the full scope of the project is the highest RII, which is considered a critical factor to be considered during the development the design in the preconstruction phase to avoid change orders during construction. The outcome is in-line with the outcome of Naji et al. (2022c) study to manage the change-orders. Improper defining of client value is the second RII has been highlighted in Cardenas Castaneda et al. (2022) paper, as one of the wastes during the design phase has to be mitigated. The third RII factor concerns about the inadequate and unrealistic constraints on project time that have been assigned for some activities, which may affect the project duration. The same has been considered a significant and top ranked delay factor in Mahamid (2021) study.

Table 3: The influence of implementing lean principles during the design phase on project performance, with respect to the type of organization

	Level of Impact (%)				
Organization Type	Extreme Impact	Highly Impact	Moderate Impact	Slightly Impact	No Impact at all
Client	8.33	41.7	41.67	0.00	8.33
Consultant	11.36	40.9	31.82	13.64	2.27
Contractor	5.13	51.3	28.21	12.82	2.56
Designer	0.00	25.0	37.50	37.50	0.00

Moreover, inadequate involvement of construction experts during design phase plays a vital role in minimizing the design error and installation priority. This waste can be avoided and considered during the design phase as highlighted in Gholinezhad Dazmiri & Hamzeh et al. (2023), and Aslam et al. (2020a) as the main lean successful factors to avoid time and cost wastes during the project design. Besides, insufficient and unrealistic constraints on project cost as a sixth RII has a bad impact during the construction that has to be controlled during the design phase as mentioned in Osamudiamen et al. (2022) study.

DEVELOPING A MITIGATION MODEL USING LEAN TOOLS

The processes of the initial two stages, namely initiation and design, have been dissected to fulfil the objective of this research. Figure 4 illustrates the use of process mapping to depict the sequential stages involved in any new construction project. The visual lean tool facilitates the identification of problematic processes that require improvement. Hence, the Kaizen burst icon is utilized to indicate the processes where the six most influential factors affecting project performance are present (highest RII). These processes include identifying the client's needs, developing a comprehensive project cost, creating a detailed project schedule, defining the scope of work for the project, and selecting the project delivery method. This paper aims to identify various lean construction tools and analyze their application to improve the processes. Table 4 provides a summary of various lean construction tools and methods that can effectively mitigate the influence of the six factors.

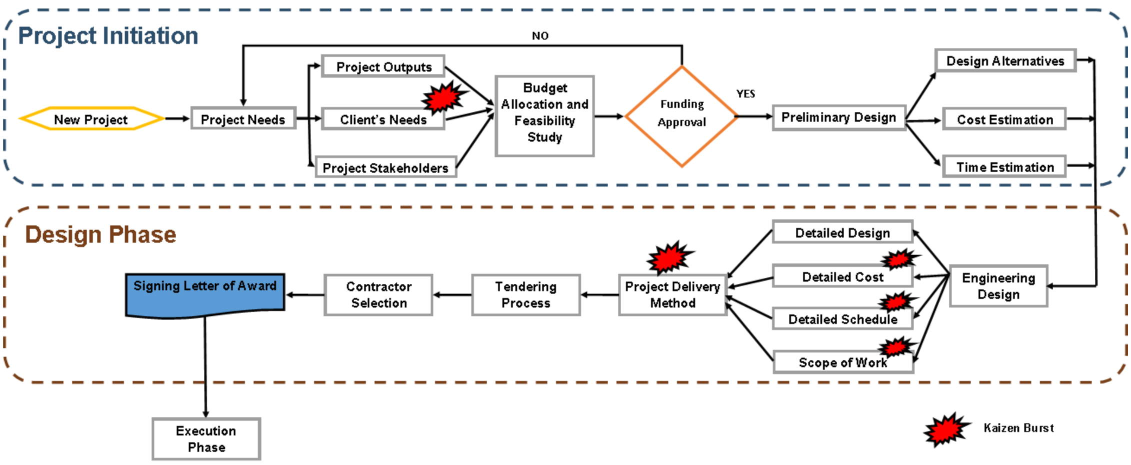

Figure 4: Process map of construction project phases and processes

Each lean tool is utilized and assigned to eliminate the impact factors in Table 4 has the potential to significantly improve the performance of construction projects, during the design phase. That can contribute to mitigating the critical impact factors during the design phase in the following approach:

Table 4: Summary of LC tools for mitigating critical factors affecting the design phase

Lean Tool	Definition	Factors
Integrated Project Delivery (IPD)	A tool that creates a better system of collaboration and communication between the various parties involved in a construction project, from the owner to the designer to the builder and any suppliers involved.	DES 2, DES 3, DES 9 and DES10
Building Information Models (BIM)	A modelling technology and associated set of processes for producing, communicating, and analysing project models.	DES 2, DES 3 and DES 4
Last Planner® System (LPS)	System for project production planning and control, aimed at creating a workflow that achieves reliable execution.	DES 6, DES 8, DES 9 and DES 10
Value Stream Mapping (VSM)	A tool to analyse and identify any weaknesses or waste sources within a complete process.	DES1
Target Value Design (TVD)	A complex system that includes the project definition, design, and construction stages. (Architecture, Engineering, and Construction)	DES1
Choosing by Advantages (CBA)	A tested and effective sound decision-making system to determine the best decision by looking at all the advantages of each option.	DES 6 and DES 7
Set-Based Design (SBD)	A method that keeps requirements and options flexible for as long as possible in design.	DES 5
Lessons Learnt for Continuous Improvement Cycle	Valuable knowledge and experiences gained leveraged for the benefit of future projects.	DES 9 and DES 10

- **Integrated Project Delivery (IPD):** fosters collaboration among key stakeholders (owner, architect, contractor, etc.) from the early stages of a project. It encourages shared risk and rewards, aligning everyone's goals towards project success. By integrating various perspectives and expertise, IPD can lead to more efficient decision-making and problem-solving during the design phase (Assaf et al., 2023).
- **Last Planner System (LPS):** focuses on detailed planning and coordination of tasks, particularly in the construction phase. However, it can also be applied during the design phase to identify dependencies, constraints, and milestones. By breaking down design tasks into manageable chunks and establishing reliable workflows, LPS can improve the efficiency and reliability of the design process (Tzortzopoulos et al., 2020).
- **Building Information Modeling (BIM):** enables the creation of digital representations of a building's physical and functional characteristics. During the design phase, BIM facilitates collaborative design, visualization, and simulation, helping stakeholders better understand the project's scope and requirements. By providing a centralized platform for information exchange, BIM reduces errors, conflicts, and rework, thus improving project performance (Gunduz et al., 2023).
- **Value Stream Mapping (VSM):** is a lean management tool used to analyze and improve processes by identifying value-added and non-value-added activities. Applied

to the design phase, VSM can help identify inefficiencies, bottlenecks, and opportunities for optimization. By streamlining design workflows and eliminating waste, VSM can enhance the overall efficiency and effectiveness of the design process (Gunduz & Fahmi Naser 2017).

- **Target Value Design (TVD):** is a collaborative approach that aims to achieve project goals within a predefined budget. During the design phase, TVD involves setting clear cost targets and continuously evaluating design decisions against these targets. By aligning design decisions with budgetary constraints, TVD helps prevent cost overruns and ensures that the project delivers value to the owner (Kim et al., 2023).
- **Set-Based Design (SBD):** involves exploring multiple design alternatives simultaneously before converging on a final solution. During the design phase, SBD encourages creativity, innovation, and risk management by considering a range of possibilities. By promoting flexibility and adaptability, SBD increases the likelihood of finding optimal design solutions that meet project objectives (Lee et al., 2012).
- **Choosing by Advantage (CBA):** is a decision-making framework that helps prioritize design alternatives based on their advantages and disadvantages. During the design phase, CBA enables stakeholders to evaluate design options systematically, considering factors such as cost, performance, and sustainability. By facilitating informed decision-making, CBA ensures that design choices align with project goals and contribute to overall performance improvement (Dahmani et al., 2023).

Integrating these methodologies throughout the design phase, a lean construction-based risk mitigation model is developed and will enhance the performance of construction projects by fostering collaboration, efficiency, cost-effectiveness, and innovation.

CONCLUSIONS

DM plays a vital role in the AEC industry, particularly during the preconstruction phase, because it has a significant impact on project performance. Preconstruction design management enhances the chances of success in construction projects. A thorough review of the existing literature and an empirical investigation have identified ten critical factors that contribute to poor project performance. The research methodology used a sequential hybrid approach to collect and analyse qualitative and quantitative data. Semi-structured interviews with construction industry experts and practitioners were conducted, as well as an online survey, yielding a comprehensive dataset for analysis. The use of the RII method enabled the identification and prioritization of critical project performance factors, resulting in practical and operational recommendations for improving performance. The study uses LC principles to demonstrate how lean tools and methods can mitigate the identified factors while improving project performance. The proposed framework is a comprehensive approach based on LC principles for risk mitigation during the pre-construction phase, combines lean principles such as VSM, TVD, and SBD with collaborative approaches such as IPD, BIM, and CBA to simplify design processes, maximize resource utilization, and foster innovation. The study enhances construction management by presenting a practical framework for improving project performance through effective decision-making and lean practices during the preconstruction phase, which can be expanded on in future research.

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