INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
ISSN: 2180-3242 e-ISSN: 2600-7959

IJSCET

Vol. 15 No. 2 (2024) 39-53
https://publisher.uthm.edu.my/ojs/index.php/ijscet

A Lean Management Framework for Achieving Sustainability Through Reducing Risks During the Design Process

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DOI: https://doi.org/10.30880/ijscet.2024.15.02.004

Article Info

Received: 14 May 2023
Accepted: 18 December 2023
Available online: 03 March 2024

Keywords

Sustainability, risks, design process, lean management, , framework

Abstract

The building sector is a substantial global industry that plays a significant role in the social and economic advancement of nations. The construction industry has been criticized for its unsustainable practices, including waste generation, pollution, and the consumption of non-renewable resources and energy. Due to the dynamic nature of the construction industry and the involvement of multiple parties with diverse goals, knowledge, and skills, the industry is susceptible to various risks that can undermine the sustainability of projects. This research aims to develop a Lean Management (LM) framework to deliver sustainable construction projects through reducing risks during the design process. A research methodology consisting of literature review, case studies and survey questionnaire was designed to achieve the research aim. Firstly, literature review was used to investigate the concepts of sustainability, risks in the design process and LM. Secondly, two case studies were presented and analysed to investigate the role of LM in achieving sustainability in construction projects through reducing the risks of the design process. Thirdly, a survey questionnaire was conducted with a representative sample of Architecture Design Firms (ADFs) in Egypt to investigate their perception and application of LM towards delivering sustainable projects by reducing the risks during the design process. A framework is developed to facilitate integrating LM within the design process to reduce risks during the design process as an approach for achieving sustainability goals. The research identifies 18 design risk factors, their causes and impacts on delivering sustainable project. In addition, it correlated LM tools and techniques that could be used to reduce risks during the design process. Case studies showed that ADFs that adopted LM approach succeeded in achieving sustainability objectives and reducing associated risks. Moreover, data analysis of the survey questionnaire helped ranking the presented risks by the ADFs along with investigating their perception towards using LM within the design process. These findings necessitated acting towards developing a framework to reduce these risks towards achieving sustainability objectives in construction projects.

1. Introduction

According to Ofori (2015), the construction industry is a major industry on a global scale and contributes significantly to the social and economic development of countries. It is widely acknowledged that the industry's contribution to a country's development and economic prosperity is substantial. Hence, it is crucial to study the industry's requirements and characteristics to support its development for the benefit of countries (Ofori, 2015). Socially, the construction industry is concerned developing projects and infrastructure facilities that help meeting the needs of current and future generations (Oyedele, 2016) and coping with the continuous growth of population and the increasing demand for facilities to fulfil their emerging needs (Xiahou, et al., 2018). Economically, the construction industry contributes toward increasing countries' GDP and offering employment opportunities and supporting other industries to prosper (Oyedele, 2016). The construction industry has been criticized for its unsustainable practices, including waste generation, pollution, and the consumption of non-renewable resources and energy. In response, various United Nations summits have been held over the years to articulate society's call for environmental protection, ensuring a prosperous future for upcoming generations. (Rafindadi et.al, 2014). Due to the dynamic nature of the construction industry and the involvement of multiple parties with diverse goals, knowledge, and skills, the industry is susceptible to various risks that can undermine the sustainability of projects. Consequently, identifying and considering the risks related to the design process at an early stage of the project life cycle is crucial because the decisions made during this phase have a significant impact on the overall life cycle of the construction project (Abdellatif & Othman, 2006). LM is an innovative approach utilized for improving the performance of the construction industry. However, its implementation in the design process is not widely adopted (Mazlum, 2015). Thus, this research aims to propose a LM framework to develop sustainable construction projects through reducing risks during the design process.

2. Literature Review

2.1 Sustainability

Sustainability has become a focal point for various fields globally. It is generally defined as a form of development that fulfils the present needs of society without jeopardizing the ability of future generations to satisfy their own needs (World Commission on Environment and Development, 1987). Achieving sustainability in the environment, society, and economy is considered a critical challenge for the 21st century. It demands a change in perspectives and attitudes, necessitating novel approaches, actions, and aspirations, leading towards a new, sustainable reality (Ben-Eli, 2005). There are 5 main core principles of sustainability shown in table (1).

Table 1 *General sustainability principals (Ben-Eli, 2005)*

Material domain	This principle ensures and organizes the proper flow of resources. It amplifies performance and strives for higher productivity.
Economic domain	This principle guides the economical processes through a comprehensive well accounting system.
Life domain	This principle helps maintaining and overcoming the diversity of life through enhancing the adaptability of people.
Social domain	This principle motivates self-realization and freedom through enhancing democracy, tolerance, and human rights.
Spiritual domain	This principle seeks to understand human needs, mystery and fulfill their needs.

In the past few years, the construction industry in the Middle East has undergone rapid development. However, this growth has come at a cost, as the surrounding environment has been neglected. As a result, the risks of polluting the air, contaminating water, and depleting land have increased. The construction industry is a major consumer of energy worldwide, accounting for nearly 40% of global energy consumption. It is also one of the major contributors to carbon dioxide emissions among different industries (Safinia, et al., 2017). Achieving sustainability in the construction industry involves utilizing resources efficiently and taking the surrounding environment into account during the initial stages of the design process (Tyler, 2016). There are numerous obstacles that can hinder the successful implementation of sustainable practices in construction projects. These barriers may pose significant risks to the delivery of sustainable construction projects. See Table (2).

Table 2 *Barriers to Sustainability Implementation in Construction (Ametepey, et al., 2015)*

Financial	Due to the fear of higher cost which leads to longer payback period, and the client worrying about the profitability being affected.
Political	Due to lack of governmental support and sustainable building codes.
Leadership	Due to delay in decision making which hinders achieving innovative ideas, lack of motivation and planning.
Technical	Due to lack of labor, sustainable materials, guidance, and tools.
Knowledge	Due to lack in professional awareness and knowledge of the client.
Social/cultural	Sustainable ideas are not common among clients; thus, the sustainable construction cannot be implemented without the full support of the owner.

2.2 Risks in the Design Process

Achieving sustainable construction projects involves meeting the needs of current generations while also ensuring that the ability of future generations to meet their own needs. This requires the integration of social, economic, and environmental aspects of sustainability throughout the various stages of the project life cycle. Invalid source specified. Table (3) shows the design risk factors and causes as well as their impact on sustainability aspects.

Table 3 *Key risk factors and their impact on sustainability aspects (developed by authors)*

No	**Design risk factors**	**Causes of the risk factor**	**Impact on sustainability aspects**		
			Economic	**Environmental**	**Social**
	Design cost overrun	Poor information provision and lack of definition of the scope of the project. Insufficient project design Design changes and variation Lack of allocating adequate resources to develop adequate design of the project. Unrealistic estimation of project duration Unrealistic estimation of project duration (Bassioni et al., 2013). Budget estimation failure (Keng et al., 2018) Complexity of construction project (Olawale and Sun, 2010).	Reduce the value delivered to project stakeholders. Extend the design duration that impacts the project's feasibility (Baloyi and Bekker, 2011).		Decrease the client and end users' interest in the project (Baloyi and Bekker, 2011).
	Brief changes by client	Client lack of knowledge Lack of understanding client requirements by designers	Time and cost overrun. Reduces value of the project 64% of the projects require additional 10% of the estimated project budget by the end of the project due to change of orders (Mahat & Adnan, 2018).		In adequate design brief results in failure to achieve client satisfaction (Mahat & Adnan, 2018).

	Design variations by architect	Lack of communication between stakeholders	Up to 21% increase of project budget (Aslam et al., 2019).	Errors in design can cause environmental (Aslam et al., 2019).	Impact on project performance Misunderstanding of client's requirements (Balbaa et al., 2019).
	Design delay	Different priorities of project stakeholders	Time overrun		Impact client satisfaction
	Lack of coordination between design parties	Poor integration of design information Design information comes from various sources so it can be scattered and uncertain	Unnecessary design changes and time variations Errors in the design drawings can lead to rework (Ali & Rahmat, 2009).		Increase client and end users dissatisfaction (Ali & Rahmat , 2009).
	Incomplete environmental analysis	Lack of accuracy in environmental analysis	Design changes and rework (Ipsen et al., 2021).	The building will impact the environment during its lifecycle (Ipsen et al., 2021).	Impacting the building operation causing use discomfort (Fuentes-Bargues, Bastante-Ceca, Gisbert, & Cruz, 2020)
	Tight project design schedule	When the project has a tight deadline for the design phase	Hinders managing project risks. Impact producing accurate specifications which may result in rework. Risk directly producing the required quality and cost (Smith, 1999).	Affect accurate environmental analysis (Smith, 1999).	Impact achieving the desired outcome (Smith, 1999).
	Design errors and omission	Insufficient details of work drawings	Major contribution to project failure Causes coordination problems, rework, budget, and time overrun (Lopez, Love, Edwards, & Davis, 2010).	Errors in the environmental analysis (Lopez, Love, Edwards, & Davis, 2010).	Effect on the safety of building users (Lopez, Love, Edwards, & Davis, 2010).
	Noncompliance to building standards	Failure to abide to building guidelines	Errors in building standards may lead to major errors and rework (Ching & Winkel, 2016).		Lowering the level of safety and comfort in the design of buildings (Ching & Winkel, 2016).
10	**Qualifications gap among qualified architects and organizational requirements**	Rapid technology advancement and global fast changes	Risk delivering a design which meets the required quality and time. Hindering the innovation, creativity and problem solving (Khodeir & Nessim, 2020).	Lack of technology affects environmental analysis (Khodeir & Nessim, 2020).	Facing hardships in adaptability to the changing information and technology (Khodeir & Nessim, 2020).
11	**Stakeholders' late changes in the project**	Level of authority of different stakeholders	Risk of budget and time overrun (Nguyen &		Impact customer satisfaction (Nguyen & Aguilera, 2010).

			Aguilera, 2010).		
12	**Uncoordinated and incorrect construction documents**	Errors in drawings, specifications, geotechnical reports, site topographical documents and environmental information.	Errors in construction documents impact Project budget (Pruett, 2004).		Impact project quality and safety which causes end used dissatisfaction (Pruett, 2004).
13	**Using outdated construction materials and technology**	Rapid technology advancements and the global fast changes.	Risks the project's long-term success and exposes it to delays and budget overruns (Tunstall, 2006).	Affect accurate environmental analysis (Smith, 1999).	Impact project completion with the required quality and time.
14	**Lack of consideration of environmental studies**	Designs are not harmonious to the surrounding environment		Causes disturbing to the natural ecosystem (Beder, 1993).	
15	**Failure to complete work in accordance with the contract.**	Failure to perform work while adhering to contract requirements	Budget overrun, project delays (Othman & Abdelwahab, 2017).		Poor delivered quality and client dissatisfaction (Othman & Abdelwahab, 2017).
16	**Failure to consider the project's life cycle cost**	The initial construction cost of a project is less than the project's operational cost over its lifecycle.	Project cost overrun (Bogenstätter, 2000).		Poor Project quality (Bogenstätter, 2000)
17	**Lack of coordination and communication between the government and design firms**	Failure to abide to governmental rules and regulations	Delayed delivery due to design rework to meet codes and standards (Othman & Abdelwahab, 2017).		Impact project completion with the required quality and time.
18	**Public objections**	Failure to respect public constrains during design			Impact satisfying user's requirements as well as abiding to their culture and identity (Othman & Abdelwahab, 2017).

2.3 Lean Management

2.3.1 Definition and Principles

LM is an innovative approach developed by Toyota Motor Company with the aim of maximizing the value delivered to the customer while reducing production waste and without compromising the quality (Lehman & Reiser, 2000). LM has 5 principles as follows:

(a) Identify the value The principle aims to recognize value based on the perspective of the client by achieving the necessary functions that fulfil the needs, expectations, and desires of clients and users. The value is attained in a manner that supports the environment, enhances society, and promotes the economy (Othman, 2007). What the customer is willing to pay for is defined as value. It is critical to identify stakeholders and learn about their actual or latent needs using quantitative and qualitative techniques like interviews, surveys, demographic data, and web analytics. The lean tools that could be

		used to achieve this principle include Voice of Customer (VOC) and 5 Why (Seddigh & Alimohamadi, 2009).
(b)	**Map the value stream**	The principle seeks to comprehend the value stream. It concentrated on understanding the activities that add value to the development of the design (Hines et al., 2004). The principle encourages businesses to identify and optimise all value-added activities involved in project development, including automating supporting activities and eliminating non-value-added activities. The lean tools that could be used to achieve this principle include Value Stream Mapping (Womack et al., 1990).
(c)	**Create the flow**	The principle aims to improve the flow of work and information in the value-added processes (Lian and Landeghem, 2002). Its goal is to ensure that information reaches the client as quickly as possible. This can be accomplished by distributing workload among architects (Liker and Morgan, 2006), creating a communication framework to simplify communication and the smooth the transfer of information between the project participants (Varaksina et al., 2020), and the process of encoding information involves including important details such as architectural terminology. It is important that the information is clear, descriptive, visible, and easily understandable. (Gifu & Teodorescu, 2014). The lean tools that could be used to achieve this principle include Last Planner System, Standardization, Takt Time Planning and 5S (Gamal, 2013).
(d)	**Establish pull**	This principle aims to guarantee that the client receives the design they require at the appropriate time. The architect should have the ability to identify and manage the timing and format of the information delivered to the client. Additionally, the architect should provide the necessary information to the client in a timely and suitable manner (Thangarajoo, and Smith, 2015).
(e)	**Seek Perfection**	This principle seeks perfection through constant identification of ways to improve the production process and reduce waste. A continuous improvement process which enables business to continuously define and eliminate waste is an important way to achieve perfection. Emiliani (1998) stated that perfection could be attained through implementing the previous principles with the support of education and training. The lean tools that could be used to achieve this principle include Kaizen and standardization (Hargrave, 2021).

The principles of lean, which prioritize maximizing value and minimizing waste, can be applied to minimize risks during the design phase. By doing more with less, lean principles can help create more value using fewer resources. Additionally, lean thinking allows for adaptability in addressing current challenges and risks (Saieg et al. 2018).

2.3.2 Benefits of Adopting LM Principles

The construction industry plays a significant role in many countries' economies, often contributing to their national GDP. Poor project management practices can result in wasted time, resources, and money. It is confronted with several managerial obstacles. Project management tools are used to achieve the project objectives. However, when opposed to standard construction management techniques, lean construction is a significant new practice that will result in an improvement in the construction sector. Benefits of applying LM are divided into economic, environmental, and social, thus using LM can have a good influence in sustainable project delivery. Economically, LM can help reduce project costs and time reduction, improving productivity and quality, and minimizing errors and rework. Environmentally, LM can reduce waste materials, energy consumption and help conserving water. Socially, LM can achieve customer and employee satisfaction, minimize conflicts, enhance teamwork and improve decision making (Shaqour, 2021).

2.3.3 Barriers to Adopting LM Principles

The implementation of lean thinking in the construction industry has been the subject of considerable effort, with some researchers describing the results as "revolutionary". In a study conducted in Jordan, 326 questionnaires were completed by participants from the three main construction groups: contractors, consultants, and owners. The study identified three types of barriers to implementing lean: those related to the internal environment, input variables (labour and materials), and external factors. Internal environment barriers included management resistance to change, potential additional costs associated with lean implementation, lack of information about lean application, and lack of motivation. Labour and materials barriers included unskilled labour, resistance to change and insufficient training, delays in materials delivery, and lack of long-term relationships with suppliers. Finally, external factors barriers included a lack of support from the government. (Balkhy et al., 2021).

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 2 (2024) p. 39-53

2.3.4 Lean Tools and Techniques for Reducing Design Risks

Many years of worldwide experience with implementing lean thinking in industries have revealed that there a certain sequence of actions, projects, and combinations of lean technologies that produce the greatest results for the system (Womack, Jones, & Roos, 1990). Design decisions directly affect the success of sustainable projects, while construction risks related to cost, time, and quality arise throughout the process. The design phase is particularly critical and poses various risks that can impact the project's life cycle. (Goral, 2007) Lean tools and techniques can help reduce risks that occur during the design phase as shown in table (4).

Table 4 *Lean tools and techniques for reducing design risks (Developed by the authors)*

No.	Design risk factors	Lean Principle	Lean Tools and Techniques	References
1	Design cost overrun	Create flow. Map the value stream	Value stream mapping Just in time 5 S' Takt time planning	Seddigh & Alimohamadi (2009) Gamal (2013) Salem (2006). Frandson et al. (2013)
2	Brief changes by client	Identify value. Customer focus Establish Pull	Voice of customer Just in time	Swefie (2013) Gamal (2013)
3	Design variations by architect	Seek perfection	Kaizen 5 why technique	Hargrave (2021) Seddigh & Alimohamadi (2009)
4	Design delay	Establish pull	Last planner system	Gamal (2013) Swefie (2013)
5	Lack of coordination between design parties	Create flow. Culture and people	5 S' Takt time planning	Salem (2006) Seddigh & Alimohamadi (2009) Frandson et al. (2013)
6	Incomplete environmental analysis	Identify value. Customer focus	Value stream mapping	Womack et al., (1990)
7	Tight project design schedule	Establish pull.	Last planner system	Gamal (2013) Swefie (2013)
8	Design errors and omission	Strive for perfection	Kaizen Standardization	Hargrave (2021) Seddigh & Alimohamadi (2009)
9	Noncompliance to building standards	Culture and people Continuous improvement and built-in quality	Standardization	Seddigh & Alimohamadi (2009). Diekmann, et al. (2016)
10	Qualifications gap among qualified architects and organizational requirements	Culture and people	Kaizen	Diekmann, et al. (2016)
11	Stakeholders' late changes in the project	Map the value stream	Just in time	Gamal (2013)
12	Uncoordinated and incorrect construction documents	Culture and people Create flow	Value stream mapping	Diekmann, et al. (2016)
13	Using outdated construction materials and technology	Continuous improvement and built-in quality	Kaizen	Hargrave (2021)
14	Lack of consideration of environmental studies	Identify value. Strive for perfection	Kaizen 5 S' Takt time planning	Hargrave (2021) Frandson et al., (2013)
15	Failure to complete work in accordance with	Identify value. Customer focus	Voice of customer Just in time	Diekmann, et al. (2016)

	the contract.	Establish Pull		Gamal (2013) Swefie (2013)
16	Failure to consider the project's life cycle cost	Create flow. Map the value stream. Waste elimination	Voice of customer Value stream mapping Just in time 5 S' Takt time planning	Diekmann, et al. (2016) Gamal (2013) Frandson et al. (2013)
17	Lack of coordination and communication between the government and design firms	Culture and people	Kaizen Operation improvement	Diekmann, et al. (2016) Hargrave (2021)
18	Public objections	Identify value. Culture and people Continuous improvement and built-in quality	Kaizen 5 S' Takt time planning	Hargrave (2021) Frandson et al. (2013)

3. Case Studies

3.1 Definition and Selection Criteria

Two case studies, one from Poland and the other from Sweden, were analysed to explore the potential role of lean principles, tools, and techniques in minimizing design risks to achieve sustainability objectives. The cases were chosen based on factors such as the nature of the projects, location, and availability of data. Both cases presented successful examples of implementing lean tools and techniques to minimize design risks in construction projects. Due to the scarcity of published case studies addressing design risks, data availability was a crucial factor in case selection. Even though the survey was conducted in Egypt, cases from other countries were chosen since there were no relevant cases in Egypt. This research method, known as case study, is used to examine a single subject matter, event, or project, describe and analyse it, define its variables, structures, and forms, or evaluate its work performance and development progress (Sturman, 1997).

3.2 Case Study 1

In Sweden's construction industry, the market share of industrialized housing is increasing rapidly, and it now accounts for approximately 15% of the total market. A case study is presented in this context, which showcases the work of a Swedish timber housing company that focuses on building student housing, hotels, and senior housing. These buildings usually have a maximum height of four stories, and the company primarily serves real estate clients and student organizations. Customized and standardized design is a common feature in these projects. The company employs 135 people at a single production site. By using lean principles, the project was able to achieve a number of sustainability goals through overcoming design risks (Othman et al., 2014). Despite facing risks such as a tight project schedule, lack of coordination between design parties, and design errors and omissions, the Swedish timber housing company in the previous case study successfully applied lean principles. The company identified value by creating organizational strategies focused on satisfying customers, managed multiple projects simultaneously while remaining flexible in the design process, increased the value of the design team by holding weekly meetings and communicating with project participants, and reduced project waste by introducing constructability early in the project life cycle. Their primary focus was on student housing, hotels, and senior housing, with buildings typically reaching a height of four stories. Then mapping value stream through focusing on the project processes while effort spent on standardizing sub-tasks and identifying activities that add economic value to the company. Then the company aimed to create a smooth flow of work by minimizing errors and saving time through using fewer software programs and standardizing processes. They also optimized the construction process and data flow by implementing pull techniques to make better use of the limited construction time and reduce errors on site through prefabrication methods. The company sought perfection by utilizing visual planning, checklists, templates, and performance practices to track project progress. These lean principles allowed the company to manage multiple projects simultaneously, adapt to changes during the design process, and communicate effectively, leading to the successful achievement of various sustainability goals.

3.3 Case Study 2

The British Colombia Children's and Women's Health Centre is a well-known academic and research Centre that provides specialized care to the local and provincial populations. Since 2008, the organization has been on a Lean journey. When a new Care Centre was approved to replace an existing structure, the organization decided to use lean thinking within the building design. This project depended on simulating the flow of the building's occupants to model a new design layout and test its efficiency. When designing circulation in a healthcare centre, the main challenge is the flow of the building's occupants through the centre. To overcome this challenge, guidelines were presented through value stream mapping and flow. Lean principles and tools were applied by identifying value, which involved determining the frequency of usage of each department by patients, medical teams, and administrative employees, and choosing the most urgently required equipment. Then, value stream mapping was performed by identifying activities and transport routes that cause delays and waste of time and materials for the patient. Flow was created by minimizing congestion in vital areas, lowering the distance between the patient and service provider, and improving the efficiency of the flow of information, equipment, supplies, processes, and food. Pull was established by attracting customer flow to specific areas through creating landmarks within these areas. Finally, seeking perfection was achieved by ensuring design effectiveness through creating scaled models and a 1:1 scaled layout of the final design to test important features such as line of sight, speed of flow, and efficiency in delivering services. Customer feedback was collected to improve the final layout design through kaizen (Othman et al., 2014). Table (5) shows the lean principles and tools used to achieve sustainability in both case studies.

Table 5 *Sustainability Aspects Achieved in Case Study (2)*

	Lean Principles	Lean tools used	Sustainability Aspects Achieved		
			Economic	Social	Environment
Case Study (1)	Identify Value	Voice of customer		√	
	Map value stream	Operation improvement	√	√	
	Create flow	Last Planner system	√	√	
	Establish pull	Pull Planning	√		√
	Seek perfection	Kaizen	√	√	√
Case Study (2)	Identify Value	Voice of customer		√	
	Map value stream	Map value stream	√	√	
	Create flow	Standardization	√	√	
	Establish pull	Just in time	√		√
	Seek perfection	Kaizen	√	√	√

4. Research Objectives and Methodology

To achieve the research aim, two approaches - theoretical (literature review) and practical (field studies) - were used to accomplish four objectives:

- First, the literature review was conducted to comprehensively explore the background of the research topic by examining sustainability, risks in the design process, and LM concepts.
- Second, two construction project case studies were collected and analyzed to investigate the role of LM in achieving sustainability objectives by reducing design process risks.
- Third, a survey questionnaire was distributed to a representative sample of ADFs in Egypt, and the collected data was analyzed to investigate their perception and use of LM in achieving sustainability by minimizing design process risks.
- Finally, based on the results obtained from the previous objectives, a framework was proposed to integrate LM into the design process to reduce risks and achieve sustainability goals.

5. Data Analysis

This section will discuss and evaluate the outcomes of a survey questionnaire that was carried out with a representative sample of ADFs in Egypt. The purpose of the survey was to investigate how ADFs perceive and utilize LM as an approach for mitigating risks during the design process.

5.1 Response Rate and Respondents' Profile

Out of the 44 ADFs that were invited to participate in the study, 27 firms responded to the survey questionnaire, representing a response rate of 61.3%. This response rate is considered adequate to support the research conclusions and suggestions. The participating firms have a range of experience in the construction industry, spanning from 5 to 50 years. They are involved in various types of construction projects, including residential, commercial, medical, industrial, cultural, business, recreational, and educational. The firms vary in size, employing between 10 to 50 individuals with backgrounds in architecture, engineering, and construction.

5.2 Risks in the Design Process

- On a scale of 1 to 5, 48% of the respondents showed excellent understanding of risks that occur during the design process, while 37% showed very good understanding. Statistics of responses showed an average mean of (4.33/5), Median (4/5) and Mode (5/5). This enabled the respondents to quantify the probability and severity of risks in the design process.
- Respondents stated that "brief changes by client" was ranked the highest risk during the design process with probability of (4.2/5) and severity of (3.4/5) followed by "Lack of coordination between design parties" with probability of (3.2/5) and severity of (4.2/5). Client changes to the project brief could be a result of many reasons such as lack of knowledge of the client or inability to explain his/her requirements to the designer, lack of understanding the different client's culture and traditions as well as the need to respond to market demand (Othman et al., 2004), see table (6). These changes lead to a delay in the design process and rework of the project design. Table (7) allocates the different risks in a matrix format based on the result of multiplying probability X severity and placing them in their right zone. Most risks are placed in the medium high-risk zone which requires action to be taken to reduce risks.

Table 6 - *Design Risk Factors Analysis*

No.	Design risk factors	Severity Mean	Probability Mean	Risk (Severity× Probability)
DRF(1)	Brief changes by client	3.4	4.2	14.3
DRF(2)	Lack of coordination between design parties	4.2	3.2	13.4
DRF(3)	Stakeholders' late changes in the project	3.7	3.6	13.3
DRF(4)	Uncoordinated and incorrect construction documents	4.4	3	13.2
DRF(5)	Design cost overrun.	3.6	3.4	12.2
DRF(6)	Lack of considering project life cycle cost.	3.9	3.1	12.1
DRF(7)	Tight project design schedule	3.3	3.5	11.6
DRF(8)	Design delay	3.4	3.4	11.6
DRF(9)	Design errors and omission	3.7	3.1	11.5
DRF(10)	Skills gap of qualified architects and organizational requirements	3.6	3.1	11.2
DRF(11)	Incomplete environmental analysis	3.5	3.1	10.9
DRF(12)	Lack of communication and coordination between the government and design firms	3.6	3	10.8
DRF(13)	Noncompliance to building codes and standards.	3.7	2.7	10.0
DRF(14)	Using outdated construction materials and technology	3.7	2.7	10.0
DRF(15)	Lack of consideration of environmental studies	3.3	3	9.9
DRF(16)	Design variations by architect	2.8	3.5	9.8
DRF(17)	Failure to carry out work in compliance to the contract	3.7	2.6	9.6
DRF(18)	Public objections	3.1	2.5	7.8

Table 7 - *Risk Matrix for Design Risk Factors (developed by authors)*

Severity	**catastrophic**	5			DRF 4	DRF 2	
	Major	4			DRF 13, 14, 15, 17& 18	DRF 3, 5, 6, 7, 8, 9, 10, 11 & 12	DRF 1
	Serious	3				DRF 16	
	Marginal	2					
	Negligible	1					
			1	2	3	4	5
			Improbable	Remote	Occasional	Probable	Frequent
					Probability		

5.3 LM for Risk Reduction During the Design Process

- On a scale of 1 to 5, 30% of the respondents showed excellent understanding of LM concepts and practices, while 33% showed very good understanding. Statistics of responses showed an average mean of (3.7/5), Median (4/5) and Mode (4/5). This enabled the respondents to provide their perception about the role of LM towards reducing risks during the design process.
- 52% of respondents stated that they do not use LM to reduce risks, while 48% of respondents applied LM to reduce risk despite not employing LM experts.
- 74% of designers agreed that “Lack of information about lean and its potential benefits” is the most challenging factor for using lean with Mean responses of (4.1/5), Median and Mode of (5/5).
- 67% of respondents agreed that Lack of training and skills to implement LM and unsuitable organizational structure are challenges that face lean implementation.
- 96% of respondents agreed that ADFs are in need of a framework to help implementing LM to reduce risks during the design process.

6. LM Framework for Risk Reduction During the Design Process (LMFRR)

6.1 Definition and Importance

A framework can be defined as a structure composed of a set of concepts, tools, and technologies necessary to complete a product process and design (Joseph and Mohapatra, 2009). The LM Framework for Risk Reduction (hereafter referred to as "the Framework" or the "LMFRR") is a proposed framework developed by this research to integrate LM into the design process as an approach for reducing risks during the design phase. The successful completion of a construction project is subject to various risks that may result in an unsatisfied client, cost overruns, and low quality. The design phase is a crucial stage that plays a critical role in decision-making, thereby delivering sustainable projects (Raftery, 1994). Hence, the LMFRR aims to reduce risks during the design process to achieve sustainability objectives.

6.2 The Proposed Framework Flow

The objective of the proposed framework is to aid in the integration of LM principles into the design process, serving as an approach for mitigating risks during design stages. It offers a systematic guide for ADFs to follow during the initial stages of a project, with the goal of maximizing value by minimizing risks. The framework is composed of five primary functions.

i. Defining barriers of integration.
ii. Establishing objectives of integration.
iii. Developing plans of integration.
iv. Implementing plans of integration.
v. Monitoring and controlling plans of integration.

6.3 Description of the Proposed Framework

The first function of the proposed framework aims to identify and categorize the barriers to integrating LM principles into the design process. This is achieved by investigating current design practices and identifying sustainability aspects that may be impacted by the lack of LM integration. Strategic issues such as study team structure, budget, and resources must be defined, and senior management support secured to ensure successful implementation of the integration process. Various tools and techniques such as literature review, survey questionnaires, interviews, case studies, brainstorming, and team consensus are required to define the integration barriers. Personnel such as client representatives, project managers, design and construction teams, project stakeholders, risk managers, and sustainability specialists should be involved to achieve the objective of this function.

6.4 Establishing Objectives of Integration

To enhance the sustainable delivery of construction projects in the design phase, it is crucial to establish and communicate the objectives of integrating LM into the design process to all project stakeholders. This aim can be achieved by implementing brainstorming and team consensus techniques to generate and select objectives that overcome the barriers of LM integration. It is essential to involve various employees in ADFs, such as senior management, design managers, design and construction teams, and other employees related to the study, to establish the integration objectives. This approach gives team members ownership of the objectives and motivates them to achieve them. During this function, an evaluation matrix could be used to rate these objectives according to their importance to the organization. Moreover, this function will result in defining the criteria to be used to assess the effectiveness of integrating LM into the design process towards delivering sustainable projects.

6.5 Developing Plans of Integration

This function aims to ensure that the integration objectives are achieved by establishing the necessary procedures and actions. It involves developing a work breakdown structure that breaks down the work into manageable work packages and a responsibility matrix that links activities to the responsible person. During each phase of the design process, LM tools and techniques will be integrated to achieve the social, economic, and environmental dimensions of sustainability. Training programmers will also be provided to the design team to equip them with the knowledge and skills needed to integrate LM into the design process. Additionally, the integration plan should include performance management procedures and corrective actions in case the plans did not go as required. Finally, a communication plan amongst project participants should be developed to clarify the reporting structure of the integration process.

6.6 Implementing Plans of Integration

Within this function, the plans developed in the previous stage will be implemented. The implementation plans require the application of LM tools and techniques into the different design process activities. In addition, employees involved in the integration process have to be trained and equipped with all tools and technologies required to guarantee the successful implementation of plans. Moreover, senior management support and offering required facilities will help achieving the integration objectives. The implementation function should use the work authorization system to verify the predecessor activities and permit the successor activities to begin. These procedures ensure the quality of work performed.

6.7 Implementing Plans of Integration

The aim of this function is to monitor, evaluate and control the results revealed from the integration of LM into the design process. Activates to be conducted during this stage include measuring results against the performance measures developed earlier, identifying and evaluating causes of failure and issues that resulted in deviation from the original plans. The tools that will be used in this stage are change control procedures, financial controls procedures, and defect management procedures. Documented learned lessons, comments and feedback from the implementation team will enable taking corrective actions if plans were not implemented as planned. Furthermore, this will help reducing risks during the design process towards delivering sustainable projects. Documenting learned lessons and sharing them with government authorities, decision makers, design and construction teams and related project stakeholders.

6.8 Benefits and Limitations of the Framework

The main benefit of the proposed framework lies in its ability to incorporate LM principles into the design process, leading to reduced risks and the delivery of sustainable construction projects. The framework promotes active participation from all project participants, facilitates open communication, and encourages effective collaboration to overcome significant risks that may hinder the achievement of sustainability objectives. However, the framework does have limitations, such as:

- The successful implementation of the framework relies heavily on the willingness of senior management, the design team, the client organization, and project participants to collaborate in integrating LM principles into the design process to achieve sustainable construction projects. In the event of a lack of interest or motivation to adopt the framework, its effectiveness may be limited.

- One of the limitations of the proposed framework is that it requires a considerable amount of time to be implemented effectively. Given the time constraints inherent in construction projects, where there is often inadequate attention paid to identifying the key risks that impact design performance, some sectors of the industry may not be receptive to this framework.

7. Conclusions and Recommendations

The construction industry is a significant contributor to the global economy and society, playing an essential role in supporting infrastructure and meeting the evolving needs of society. However, the industry has been criticized for its unsustainable practices, including waste generation, pollution, and high resource and energy consumption. The construction industry is complex, involving multiple parties with different goals, and is subject to various risks that can impact project value. Effective decision-making during the design phase is critical, and it is essential to identify and address risks early in the project life cycle. This study introduces a Lean management framework to reduce risks during the design phase and achieve sustainability objectives. A survey questionnaire was used to collect data on risks faced during the design process, likelihood and severity of risk occurrence, and knowledge of LM application. While respondents understand the risks and impacts on sustainable project delivery, few companies hire LM experts to reduce design process risks. There is a lack of information about LM and its benefits, which could lead to reluctance to adopt LM principles and tools. Early application of LM principles and tools can aid in reducing project risks during the design phase.

Acknowledgement

The authors acknowledged to the The British University in Egypt, Cairo for the support on publication.

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