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A lean management framework for achieving sustainability through reducing risks during the design process

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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. Duo 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 by reducing risks during the design process. A research methodology consisting of a literature review, case studies and a survey questionnaire was designed to achieve the research aim. Firstly, the 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 by 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 to achieving sustainability goals. The research identifies 18 design risk factors, their causes and their impacts on delivering sustainable projects. 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 the LM approach succeeded in achieving sustainability objectives and reducing associated risks. Moreover, data analysis of the survey questionnaire helped rank 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.

Keywords: Sustainability, risks, design process, lean management, framework.

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INTRODUCTION

The construction industry is one of the largest industries worldwide. It plays a significant role in the social and economic development of countries. The contribution of the construction industry to a country's development and economic prosperity is widely recognized; therefore, researching the requirements and characteristics of the construction industry is critical to assisting its development for the benefit of countries (Ofori, 2015). Socially, the construction industry is concerned with developing projects and infrastructure facilities that help meet the needs of current and future generations (Oyedele, 2016) and coping with the continuous growth of the population and the increasing demand for facilities to fulfill 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). Contrary, the construction industry is blamed for its unsustainable practices such as generating waste and pollution as well as consuming non-renewable resources and energy. Over the decades, UN summits were held to express society's demands for protecting the environment to prosper future generations (Rafindadi et al., 2014). The complexity of the construction industry due to the involvement of many parties with different goals, knowledge and skills in addition to its dynamic nature, subjected the industry to various risks that can affect the project's sustainability. The decisions made during the design process have a significant impact on the life cycle of the construction project. As a result, it is critical to identify and consider the risks associated with the design process early in the project's life cycle (Abdellatif and 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 an LM framework to develop sustainable construction projects by reducing risks during the design process.

LITERATURE REVIEW

Sustainability

Sustainability has received great attention from different disciplines worldwide. It is commonly described as the development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). It is one of the crucial challenges of the 21st century to achieve a sustainable environment, society and economy. The sustainability concept requires a shift in visions and consciousness, it needs new dreams, approaches, and actions and calls for a fresh new reality (Ben-Eli, 2005). There are 5 main core principles of sustainability shown in Table 1.

Table 1. General sustainability principals.

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 economic processes through a comprehensive well accounting system.
Life Domain	This principle helps maintain and overcome the diversity of life by enhancing the adaptability of people.
Social Domain	This principle motivates self-realization and freedom by enhancing democracy, tolerance, and human rights.
Spiritual domain	This principle seeks to understand human needs, and mystery and fulfil their needs.

Source: Ben-Eli (2005).

In the past few years, there was a rapid development in the construction industry especially in the Middle East. During this time, the surrounding environment was neglected which caused the risks of polluting the air, contaminating water and depleting the land. The world's construction industry consumes nearly 40% of the world's energy and acts as one of the major carbon dioxide producers among the different types of industries (Safinia et al., 2017). Sustainability in the construction industry can be achieved by efficiently using resources and considering the surrounding environment during early design decisions (ESUB, 2019). However, practicing sustainable construction faces several barriers which risk the sustainable delivery of construction projects (Table 2).

Table 2. Barriers to sustainability implementation in construction.

Financial	Due to the fear of higher costs which leads to longer payback periods, and the client worrying about the profitability being affected.
Political	Due to a 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 a lack of labour, sustainable materials, guidance, and tools.
Knowledge	Due to a lack of professional awareness and knowledge of the client.
Social/cultural	Sustainable ideas are not common among clients; thus, sustainable construction cannot be implemented without the full support of the owner.

Source: Ametepey et al. (2015).

Risks in the design process

The sustainable delivery of construction projects requires achieving the needs of the present generations without compromising the attainment of future generations' needs. In addition, it necessitates integrating the social, economic, and environmental aspects of sustainability in the different phases of the project life cycle (Apine and Valdés, 2016). 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
1	Design cost overrun	• Poor information provision and lack of defining the scope of the project • Insufficient project design • Design changes and variation • Lack of allocating adequate resources to develop the 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) • The complexity of construction projects (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).
2	Brief changes by the client	• Client lack of knowledge • Lack of understanding of client requirements by designers	• Time and cost overrun • Reduces the value of the project • 64% of the projects require an additional 10% of the estimated project budget by the end of the project due to a change of orders (Mahat and Adnan, 2018).		• An adequate design brief results in failure to achieve client satisfaction (Mahat and Adnan, 2018).
3	Design variations by architect	• Lack of communication between stakeholders	• Up to 21% increase in the 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).
4	Design delay	• Different priorities of project stakeholders	• Time overrun		• Impact client satisfaction

Table 3. Continues.

5	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 and Rahmat, 2009).		• Increase client and end user dissatisfaction (Ali and Rahmat, 2009).
6	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 et al., 2020)
7	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 produces the required quality and cost (Smith, 1999).	• Affect accurate environmental analysis (Smith, 1999).	• Impact achieving the desired outcome (Smith, 1999).
8	Design errors and omission	• Insufficient details of work drawings	• The major contribution to project failure • Causes coordination problems, rework, budget, and time overrun (Lopez, Love, Edwards and Davis, 2010).	• Errors in environmental analysis (Lopez, Love, Edwards and Davis, 2010).	• Effect on the safety of building users (Lopez, Love, Edwards and Davis, 2010).
9	Noncompliance with building standards	• Failure to abide by building guidelines	• Errors in building standards may lead to major errors and rework (Ching and Winkel, 2016).		• Lowering the level of safety and comfort in the design of buildings (Ching and Winkel, 2016).
10	Qualifications gap among qualified architects and organizational requirements	• Rapid technological advancement and global fast changes	• Risk delivering a design that meets the required quality and time • Hindering innovation, creativity and problem-solving (Khodeir and Nessim, 2020).	• Lack of technology affects environmental analysis (Khodeir and Nessim, 2020).	• Facing hardships in adaptability to the changing information and technology (Khodeir and Nessim, 2020).
11	Stakeholders' late changes in the project	• Level of the authority of different stakeholders	• Risk of budget and time overrun (Nguyen and Aguilera, 2010).		Impact customer satisfaction (Nguyen and Aguilera, 2010).

Table 3. Continues

12	Uncoordinated and incorrect construction documents	• Errors in drawings, specifications, geotechnical reports, site topographical documents and environmental information.	• Errors in construction documents impact the 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 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 with the surrounding environment		• Causes disturbing the natural ecosystem (Beder, 1993).	
15	Failure to complete work following the contract.	• Failure to perform work while adhering to contract requirements	• Budget overrun, and project delays (Othman and Abdelwahab, 2017).		• Poor delivery quality and client dissatisfaction (Othman and 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 by governmental rules and regulations	• Delayed delivery due to design rework to meet codes and standards (Othman and Abdelwahab, 2017).		• Impact project completion with the required quality and time.
18	Public objections	• Failure to respect public constraints during design			• Impact satisfying users' requirements as well as abiding by their culture and identity (Othman and Abdelwahab, 2017).

Lean management

Definition and principles

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

Identify the value: The principle seeks to identify value from the client's point of view. Value is the optimal achievement of required functions that meet the needs, desires, and expectations of clients and users in a way that protects the environment, improves society, and prospers 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 and Alimohamadi, 2009).

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).

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 the workload among architects (Liker and Morgan, 2006), creating a communication framework to simplify communication and smooth the transfer of information between the project participants (Varaksina et al., 2020), and encoding information such as architectural terms and other important information. The information conveyed must be transparent, descriptive, visible, and simple to comprehend (Gifu and Teodorescu, 2014). The lean tools that could be used to achieve this principle include the Last Planner System, Standardization, Takt Time Planning and 5S (Gamal, 2013).

Establish pull: This principle seeks to ensure that the client receives the required design at the time they need it. The architect has to be able to identify and control when and what type of information is delivered to him and in which format. Furthermore, the architect should provide the required information to the client at the most appropriate time (Thangarajoo, and Smith, 2015).

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 businesses 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).

As lean aims to maximize the value and eliminate waste; its principles can be used to minimize the risk factors during the design phase. Lean principles show that LM relies on doing more with less thus more value with fewer resources. Moreover, lean thinking enables adapting to face current challenges and risks (Saieg et al., 2018).

Benefits of adopting LM principles

The construction industry is one of the most important economic sectors in many nations throughout the world, affecting national GDP. Inefficient management of projects wastes time, money, and resources. 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. The benefits of applying LM are divided into economic, environmental, and social, thus using LM can have a good influence on sustainable project delivery. Economically, LM can help reduce project cost and time reduction, improving productivity and quality, and minimizing errors and rework. Environmentally, LM can reduce waste materials, and energy consumption and help conserve water. Socially, LM can achieve customer and employee satisfaction, minimize conflicts, enhance teamwork and improve decision-making (Shaqour, 2021).

Barriers to adopting LM principles

Considerable efforts have been made in the construction industry to use lean thinking. Several researchers described the results of lean implementation as "revolutionary". They conducted a study that included 326 questionnaires filled out by survey participants from Jordan's three main construction groups: contractors, consultants, and owners. The barriers were classified into three types namely, internal environment, input variables (labour and materials), and external factors. Barriers related to the internal environment included management resistance to change; additional costs that may be added when using lean; lack of information about lean application and lack of motivation. Barriers related to labour and materials included unskilled labour; resistance to change and insufficient training; delays in materials delivery and lack of long-term relationships with suppliers. Finally, barriers related to external factors included a lack of support from the government (Balkhy et al., 2021).

Lean tools and techniques for reducing design risks

Many years of worldwide experience with implementing lean thinking in industries have revealed that there is a certain sequence of actions, projects, and combinations of lean technologies that produce the greatest results for the system (Womack, Jones and Roos, 1990). Decisions taken during the design process have a direct impact on the delivery of sustainable projects. Although risks arise throughout construction related to cost, time, and quality uncertainty. The design phase is regarded as a critical phase that contains several risks that affect 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 and Alimohamadi (2009) Gamal (2013) Salem (2006). Frandson et al. (2013)
2	Brief changes by the 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 and 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 and 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 and Alimohamadi (2009)
9	Noncompliance with building standards	• Culture and people • Continuous improvement and built-in quality	• Standardization	Seddigh and 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)

Table 4. Continues.

15	Failure to complete work following the contract.	• Identify value • Customer focus • Establish pull	• Voice of customer • Just in time	Diekmann et al. (2016) 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)

CASE STUDIES

Definition and selection criteria

A case study is a research method that is used to describe and analyse a single matter, phenomenon, event, or project to define variables, structures, forms, and orders of interaction between the participants in the situation, or to evaluate work performance or development progress (Sturman, 1997). Two case studies from Poland and Sweden were chosen for this study and analysed to investigate the role of lean principles, tools and techniques in achieving sustainability goals by reducing design risks. The case studies were selected based on the nature of both projects, availability of data, degree of success, project location and regions. All of the case studies featured construction projects that were successful in implementing lean tools and techniques towards reducing risks during the design process. Because there were few published case studies that addressed the issue of risks in the design process, the availability of data was a major factor in selecting the case studies. Even though the survey questionnaire was conducted in Egypt, the case studies were chosen from other countries due to a lack of cases in Egypt.

Case study 1

Industrialized housing is a rapidly growing market in Sweden's construction market, accounting for approximately 15% of the total market share. This case study presents the work of a Swedish timber housing company that specializes in student housing, hotels, and senior housing. Buildings can typically reach a height of four stories. Real estate clients and student organizations are their primary clients. 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 several sustainability goals by overcoming design risks (Othman et al., 2014). This case faced risks such as a tight project schedule, lack of coordination between design parties and design errors and omissions. The company applied lean principles beginning with identifying value through creating organizational strategies focused on satisfying the customers and increasing the value of the project by managing 6 projects at the same time while remaining flexible design process, increasing the value of the design team by keeping weekly meetings and communicating with project participants and reducing project waste by introducing constructability early in the project life cycle. Then mapping value stream through focusing on the project processes while effort is spent on standardizing sub-tasks and identifying activities that add economic value to the company. Then creating flow by converting from one format to another, using fewer software programs to save time and minimize the number of errors and standardizing processes to avoid extra workloads and reduce the amount of rework. Then establishing pull through optimizing the construction process and data flow to allow faster production and make better use of the restricted construction time and using prefabrication ways of reducing the degree of error on site, which could result in economic or environmental waste. Finally seeking perfection by using visual planning, checklists, templates, and performance practices to track the progress of projects. By initiating with lean principles, managing parallel projects with adaptability during the design process and communicating, the project was able to achieve several sustainability goals.

Case study 2

The British Colombia Children's and Women's Health Center 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 Center 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. The flow of the building's occupants through the centre is the main challenge faced while designing the circulation in a health care centre. As a result, value stream mapping and flow presented guidelines for overcoming these circulation challenges. Lean principles and tools were applied beginning with identifying value by Identifying the frequency of usage of each department by patients, medical teams, and administrative employees (Voice of the customer) and choosing the equipment that is most urgently required. Then, mapping value stream by identifying the activities and transport routes within the centre that cause the most delays and waste of time and materials for the patient. Followed by creating flow by minimizing congestion in case vital spots (such as the emergency department) by identifying the most beneficial patterns for the facility's various users to follow in addition to lowering the distance between the patient and service provider and increasing the efficiency of the flow of information, equipment, supplies, processes, and food (Last planner system). Moreover, establishing pull by attracting customer flow to specific areas by creating landmarks within these areas to reduce congestion and enable more efficient process execution (Pull planning). Finally, seeking perfection through ensuring design effectiveness not only by creating scaled models of the various rooms used in each department, but also developing 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 to the designated patient then collecting customer feedback to improve the final layout design even more (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 the 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	√	√	√

RESEARCH OBJECTIVES AND METHODOLOGY

Achieving the research aim called for a research strategy that could gather data sufficiently rich to develop the abovementioned framework. Two approaches, namely, theoretical (literature review) and practical (field studies), were used to achieve four objectives:

• First, the literature review was used to build a comprehensive background about the research topic by reviewing the concepts of sustainability, risks in the design process and LM.

• Second, two case studies of construction projects were collected and analysed to investigate the role of LM in achieving sustainability goals by reducing the risks of the design process.

• Third, a survey questionnaire conducted with a representative sample of ADFs in Egypt was analyzed to investigate their perception and application of LM as an approach to achieving sustainability by reducing the risks during the design process.

• Finally, based on the results derived from the previous objectives, the research proposed a framework to facilitate the integration of LM within the design process to reduce risks in the design process towards achieving sustainability objectives.

DATA ANALYSIS

This section presents and analyses the results of a survey questionnaire conducted with a representative sample of ADFs in Egypt to examine their perception and application of LM as an approach for reducing risks during the design process.

Response rate and respondents' profile

Out of 44 ADFs invited to participate in the study, only 27 firms responded to the survey questionnaire representing (61.3%) which supports the research conclusions and suggestions. The number of years of experience of these firms in the construction industry ranges from 5 to 50 years. They are involved in all types of projects including residential, commercial, medical, industrial, cultural, business, recreational and educational. The size of these firms ranges from 10 to 50 employees with architecture, engineering and construction backgrounds.

Risks in the design process

• On a scale of 1 to 5, 48% of the respondents showed an excellent understanding of risks that occur during the design process, while 37% showed a very good understanding. Statistics of responses showed an average mean of (4.33/5), Median (of 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 the client" were ranked the highest risk during the design process with a probability of (4.2/5) and severity of (3.4/5) followed by "Lack of coordination between design parties" with a 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 of the different client's culture and traditions as well as the need to respond to market demand (Othman et al., 2004) (Table 6). These changes lead to delays 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 the 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)	The skills gap between 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 with 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 with 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						

LM for risk reduction during the design process

• On a scale of 1 to 5, 30% of the respondents showed an excellent understanding of LM concepts and practices, while 33% showed a 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 of 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 they do not employ 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 require a framework to help implement LM to reduce risks during the design process.

LM FRAMEWORK FOR RISK REDUCTION DURING THE DESIGN PROCESS

Definition and importance

A framework could be described as a structure consisting of a set of concepts, tools and technologies needed to complete a product process and design (Joseph and Mohapatra, 2009). The LT framework for risk reduction (hereinafter referred to as “the Framework” or the “LTFRR”) is a suggested framework developed by this research to integrate LT into the design process as an approach for reducing risks during the design process. The successful completion of a construction project is subject to many risks that may result in unsatisfied clients, cost overrun and low quality. The design process is a crucial phase that plays a critical role in decision-making, thus delivering sustainable projects (Raftery, 1994). Therefore, LTFRR will help reduce risks during the design process to achieve sustainability objectives.

Aim and objectives of the framework

The proposed framework aims to facilitate the integration of LT principles into the design process as an approach to reducing risks during the design process. It provides a clear outline of where ADFs can follow during the early stages of the project to achieve maximum value by reducing risks. The framework consists of five main functions:

- Defining barriers of integration.
- Establishing objectives of integration.
- Developing plans of integration.
- Implementing plans of integration.
- Monitoring and controlling plans of integration.

Description of the proposed framework

Defining barriers to integration

This function aims to define the barriers to integrating LT into the design process. This aim could be attained by investigating the current practice of the design process, defining, validating and categorising the barriers to LT integration. In addition, it requires identifying sustainability aspects that will be affected if LT principles are not integrated into the design process. Accomplishing this aim requires setting strategic issues including study team structure, study budget and resources. The support of senior management is paramount to ensure that the needed resources are secured, accepting and implementing the recommendations of the integration process. During this function, several tools and techniques are required to define the integration barriers, namely literature review, survey questionnaires, interviews, case studies, brainstorming and team consensus. Involving certain personnel such as the client’s representative, project manager, design and construction teams, project stakeholders, risk manager and sustainability specialist will enable achieving the objective of this function.

Establishing objectives of integration

To improve the sustainable delivery of construction projects during the design phase, the objective of integrating LT into the design process needs to be established and communicated to all project participants. Establishing the integration objectives could be achieved through implementing brainstorming and team consensus techniques to generate and select objectives that overcome the barriers of LT integration. Engaging 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 gives team members ownership of these objectives and encourages them to accomplish them. During this function, the evaluation matrix could be used to rate these objectives according to their importance to the organisation. Moreover, this function will result in defining the criteria to be utilised to assess the effectiveness of integrating LT into the design process toward delivering sustainable projects.

Developing plans for integration

This function aims to establish the procedures and actions required to accomplish the integration objectives. It will include developing a work breakdown structure to downsize the work into manageable work packages and a responsibility matrix to link the activities to be done and the responsible person. Within each phase of the design process, LT tools and techniques will be integrated to achieve the social, economic and environmental dimensions of sustainability. Moreover, providing training programmes for the design team will provide architects with the knowledge and skills needed to integrate LT into the design process. Furthermore, 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 has to be developed to portray the reporting structure of the Integration process.

Implementing plans for integration

Within this function, the plans developed in the previous stage will be implemented. The implementation plans require the application of LT tools and techniques in 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 of required facilities will help achieve 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.

Implementing plans for integration

This function aims to monitor, evaluate and control the results revealed from the integration of LT into the design process. Activities to be conducted during this stage include measuring results against the performance measures developed earlier and 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 reduce risks during the design process toward delivering sustainable projects. Documenting learned lessons and sharing them with government authorities, decision-makers, design and construction teams and related project stakeholders.

Benefits and limitations of the framework

The main benefit of the proposed framework is integrating LT principles into the design process to reduce the risks of the design process and deliver sustainable construction projects. It encourages all project participants to contribute positively, communicate openly, and cooperate effectively towards overcoming the key risks that affect achieving the sustainability objectives. However, there are several limitations, some of which are:

- The effective adoption and application of the framework depend to a large extent on the willingness of the senior management, design team, client organisation, and project participants to participate in the integration of LT into the design process to develop sustainable construction projects. If they do not have the desire to use the framework, then its adoption will be limited.
- The application of the framework is time-consuming, and due to the time constraints in construction projects, where insufficient time is spent on improving the design process through identifying key risks that affect its performance, this framework might not be accepted by some sectors of the industry.

CONCLUSIONS AND RECOMMENDATIONS

The construction industry is one of the largest in the world, with a significant impact on society and the economy. The construction industry's contribution to the country's development and economic growth is widely acknowledged. Furthermore, construction projects socially cope with the continuous growth of the population and the way people live, work, play, and interact with one another as members of society. Economically, the construction industry has a significant impact on the gross domestic product (GDP) because it serves as a growth factor for other industries. On the other hand, the construction industry has been chastised for its unsustainable practices in terms of waste generation, pollution, resources, and energy consumption. The construction industry is one of the most complex because it involves many parties with different goals, in addition to its dynamic nature, which exposes it to several risks that can affect the project's value. The decisions made during the design phase have a significant impact on the life cycle of a construction project. As a result, it is critical to identify and consider the risks associated with the construction process early in the project's life cycle. This research aims to introduce an LM framework as a risk reduction tool during the design phase to achieve sustainability objectives. A survey questionnaire was conducted to collect data about the risks that ADFs face during the design process. In addition to measuring the likelihood and severity of risk occurrence and investigating their knowledge of LM application. According to survey responses, despite respondents' full understanding of the risks in the design process and how they impact the sustainable delivery of projects, as well as an understanding of LM, a large percentage of companies use lean to reduce risk, however, most of the design firms do not hire LM experts to reduce risk during the design process. There is a lack of information about LM and its benefits. Therefore, applying LM principles and tools early in the design process aids in the reduction of project risks.

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