Journal of Project Management 9 (2024) 471–484

Contents lists available at GrowingScience

Journal of Project Management

homepage: www.GrowingScience.com

Risk management in Egyptian construction: Comparative analysis of general and banking sectors using advanced quantitative methods

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C H R O N I C L E

Article history:
Received: April 10, 2024
Received in revised format: June 15, 2024
Accepted: July 7, 2024
Available online:
July 7, 2024

Keywords:
Risk management
Risk in Construction Projects
Banking Construction Projects
Construction Projects in Egypt
Design Structure Matrix (DSM)
TOPSIS

A B S T R A C T

To effectively manage the challenges associated with meeting schedules, costs, and quality requirements in construction projects, it is crucial to address potential risk factors. Despite extensive research on risk management in construction, a significant gap persists concerning the uniformity of risk factors and their effects across various construction project types, geographical locations, and cultural contexts. This research presents a structured three-step approach to risk management, covering risk identification, analysis, and response. The methodology is applied to both the General Construction (GC) and Banking Construction (BC) sectors in Egypt, involving industry professionals through surveys. Quantitative analysis using the Relative Importance Index (RII) and Fuzzy-set theory gauges the influence of each risk factor, while Spearman Ranked Correlation tests differentiate risk profiles between sectors. A comparative analysis highlights Egypt-specific risk factors versus regional or global factors. Key risk factors with high centrality scores are identified, and optimal risk reduction strategies are selected using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The study reveals significant sector-specific risk differences and highlights the need for tailored risk management strategies. Key contributions include identifying vital risk factors, comparing them globally and regionally, and proposing effective mitigation strategies to enhance project timelines, costs, and quality.

1. Introduction

Construction projects encompass a multitude of challenges related to meeting schedules, costs, and quality standards. However, uncertainties and risks in the construction industry can hinder success. Managing these risks through effective strategies is crucial. While research has focused on risk management in construction, there's still a gap in understanding how risk factors apply across different projects, locations, and cultures. To address this gap, this study presents a structured three-step risk management approach for Egypt's construction sector. This method covers risk identification, analysis, and response, offering a holistic way to tackle challenges. This approach helps practitioners better understand risks and create tailored solutions. This study deals with General Construction (GC) and Banking Construction (BC), where these sectors have unique challenges, demanding specific risk management. Using a mix of quantitative and qualitative methods, this study surveys professionals in Egypt's construction industry to assess risk factors' importance and impact. Advanced techniques like the Relative Importance Index (RII) and Fuzzy-set theory quantify risk significance. Comparing GC and BC sectors using Spearman Ranked Correlation tests reveals sector-specific risk differences. The study does not only consider Egypt but also compares risk factors globally and regionally, broadening its perspective on risk management. The study's key contribution lies in pinpointing vital risk factors and suggesting strategies to mitigate them. Using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), it selects suitable risk reduction strategies based on their potential impact on timelines, expenses, and quality.

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doi: 10.5267/j.jpm.2024.7.002

The paper is divided into six sections that complement the introduction. In Section 2, an extensive literature review covers risk factors, assessment methods, and research gaps. Section 3 explains the methodology. Section 4 details the proposed three-step approach to risk management. Section 5 summarizes outcomes, discusses Egypt's construction landscape, draws conclusions, and suggests future research.

2. Literature review

Construction projects aim to adhere to planned timelines, minimize costs, ensure high quality, and maintain safety standards for the environment, equipment, labor, and materials. However, numerous studies have shown that achieving alignment with these parameters is often challenging (Zou et al., 2007; Jomaah et al., 2014; Sastoque et al., 2016; Abd El-Karim et al., 2017; Durdyev et al., 2017; Szymański, 2017).

One significant challenge in construction projects is schedule delays, which can result in missed objectives, cost overruns, and client dissatisfaction (Sweis et al., 2008; Hwang et al., 2013). Factors contributing to such delays include a lack of experience among contractors and consultants, leading to errors in design, communication breakdowns, and slow decision-making processes (Al-Khalil & Al-Ghafly, 1999' Koushki et al., 2005;Lo et al., 2006). Additionally, inadequate site management and coordination among various parties further exacerbate schedule delays (Abd El-Razek et al., 2008; Hwang et al., 2013). In various regions, cooperation and coordination among project stakeholders are crucial to prevent delays (Chan & Kumaraswamy, 1997; Abdul Kadir et al., 2005; Abd El-Razek et al., 2008; Hwang et al., 2013). Moreover, decisions regarding material specifications and supply can significantly impact project schedules (Faridi & El-Sayegh, 2006; Le-Hoai et al., 2008). Another common cause of delays is design changes introduced during the construction phase (Abd El-Razek et al., 2008). Unrealistic project durations set by owners can also lead to challenges and wrong decisions (Sweis et al., 2008). Furthermore, the availability of labor and materials on-site plays a critical role in meeting project schedules (Faridi & El-Sayegh, 2006; Sweis et al., 2008; Enshassi et al., 2009; Mahamid et al., 2012). In 2023, Yousri et al. analyzed previously listed risk factors to verify the workability of these factors in building construction projects in Egypt, 15 experts were asked, and thirty-five risk factors were selected during the pilot survey, which was distributed to 95 participants. High-risk factors identified in the study included funding problems from contractors, material price fluctuations, unrealistic project activity duration estimates, and shortages of construction materials in the market. The study aimed to redefine and arrange risks based on current circumstances to help stakeholders achieve project success by identifying and controlling these high-risk components (Yousri et al., 2023).

The assessment of construction risks often involves categorizing them based on their impact on critical project criteria such as Schedule, Cost, and Quality (Jomaah et al., 2014; Taylan et al., 2014). This categorization serves as a framework for analyzing prominent risks that influence each specific criterion, facilitating the formulation of effective control strategies. Alternatively, risk factors can be grouped according to the project stakeholders involved, namely Owners, consultants, and contractors, aiming to allocate responsibilities and formulate actionable plans (Zhao et al., 2016; El-Sayegh, 2008). Another reported approach involves the segmentation of risk factors based on different project phases—feasibility study, design, construction, and operation (Zou et al., 2007). Additionally, risk factors can be classified based on environmental aspects, encompassing political, financial, social, governmental, and economic factors (El-Sayegh, 2008; Samantra et al., 2017). Habib et al. addressed the risk management for large projects in the construction phase in Egypt. The study identified the top ten risk factors in construction projects, including delayed payment of contractors, inefficiency of subcontractors, and design errors and omissions. A qualitative risk analysis was conducted to prioritize response to risks, and a Monte Carlo simulation was performed to prioritize project risks related to sustainability. The impact of risks on project time and cost was clarified using the Primavera Risk Analysis program, categorizing risks into red (most dangerous), yellow (medium), and green (least dangerous) based on probability and impact (Habib et al., 2023).

The assessment of construction risks often involves a qualitative exploration of expert opinions and experiences (Lyons & Skitmore, 2004), while quantitative methodologies come into play for modeling, prioritizing, and ranking these risks (Subramanyan et al., 2012). Techniques such as opinion polls and brainstorming sessions help capture expert insights and generate recommendations. The quantitative analysis of construction risks primarily relies on statistical and possibilistic approaches (Samantra et al., 2017). Recently, in 2023, Khodabakhshian et al. used a systematic literature review method with the objective of investigating and comparatively analyzing the main deterministic and probabilistic methods applied to construction risk management. They highlighted the importance of utilizing artificial intelligence (AI) in construction risk management to enhance automation, decision-making, and standardization. They emphasized the proactive nature of risk management, focusing on risk identification, analysis, mitigation planning, and control stages to ensure project success (Khodabakhshian et al., 2023). Fuzzy set theory is particularly effective in managing uncertainty and subjectivity in expert opinions. Over the past two decades, both single and hybrid fuzzy methods have been widely used in assessing construction risk. Notable applications include:

- FAHP, for subway construction projects (Zou et al., 2007) and (Islam et al., 2017)
- Fuzzy logic, in pipeline construction (Abdelgawad & Fayek, 2011)

- Fuzzy TOPSIS, for tunnel construction projects (Fouladgar et al., 2012)
- Fuzzy MCDM, for underground construction (Samantra et al., 2017)
- Fuzzy TOPSIS, for power plant construction (Kuo & Lu, 2013)
- Fuzzy ANP, for general construction projects (Taylan et al., 2014)

Risk control represents the final phase of Risk Management. However, this phase is often understudied or briefly discussed in research (Samantra et al., 2017). While some studies pool actions for grouped risks based on their importance, others assign specific actions to individual risks based on characteristics like responsible party and project phase. Qualitative methods dominate the generation of actions, occasionally supported by quantitative techniques. Yet, these methods struggle to address conflicting project management objectives like Time, Cost, and Quality.

TOPSIS (Technique for Order of Performance by Similarity to Ideal Solution) was first introduced by Hwang (Hwang & Yoon, 1981) and further enhanced by Chen (Hwang & Yoon, 1981) among several others has become a classical Multi Criteria Decision Making (MCDM) method. For example, Zheng (Chen et al., 2018) applied the Analytical Hierarchy Process (AHP) to estimate the weight of Time, Cost, and Quality attributes of a criteria, and then applied TOPSIS to rank the risk factors according to their impact on that criterion. Luo et al. (2018) assigned weights using Entropy-AHP, then applied TOPSIS to rank risks for a natural gas spherical tank. More recently, Husin et al. (2019) applied a Fuzzy TOPSIS (FTOPSIS) method to estimate fuzzy crisp ratings of risks followed by prioritizing them according to their impact on the project criteria using TOPSIS.

Despite considerable research in this field, there remains a gap in the literature regarding the specific risk factors affecting different types of construction projects in various geographic and cultural contexts. This research addresses the lack of understanding of sector-specific and region-specific risk factors in construction projects. By integrating advanced quantitative methods like Fuzzy-set theory and TOPSIS, this study not only identifies critical risks but also ranks and prioritizes mitigation strategies based on their impact on project outcomes. The contributions of this research are twofold: it provides a detailed comparison of risk factors between GC and BC sectors in Egypt, comparing them with international standards, and offers a robust framework for selecting optimal risk reduction strategies tailored to the unique challenges of the Egyptian construction industry.

3. Methodology

The methodology employed in this study follows a structured three-step approach for risk management, detailed as follows:

1. **Risk Identification:**
   - A comprehensive list of 78 risk factors was compiled from existing literature.
   - Questionnaires were distributed to professionals in the Egyptian construction industry, encompassing both GC and BC sectors.
2. **Risk Analysis:**
   - The Relative Importance Index (RII) was utilized to assess the severity of each identified risk factor.
   - Fuzzy-set theory was applied to quantify the impact of each risk factor on GC and BC projects.
   - Spearman Ranked Correlation tests were performed to identify differences in risk profiles between GC and BC sectors.
   - The research also compared Egypt-specific risk factors with those relevant on a regional or global scale.
3. **Risk Response:**
   - Key risk factors with significant centrality scores were identified through Design Structure Matrix (DSM) analysis.
   - TOPSIS was used to select the best strategies for mitigating the identified risks.
   - Experts from the construction industry evaluated the potential impact of each proposed mitigation strategy on project schedules, costs, and quality.

Data was analyzed using the Survey Monkey package, providing insights into participant responses and the relative importance of risk factors. Industry experts were consulted to ensure the relevance and applicability of the proposed strategies.

4. The three-step proposed approach to risk management

4.1 Identification of Risk Factors

A thorough literature survey has been performed to identify risk factors in construction projects. A list of 78 different risk factors was compiled. All these factors are reported to be relevant to construction practitioners worldwide. Additionally, around 39 more risk factors specific to certain sectors or countries have been identified. However, risk factors related to

Banking Construction specifically have not been studied in the literature. This extensive list of factors was reviewed by experts in the Egyptian construction industry to identify those most relevant to local practices. Out of 117 factors, they pinpointed 16 key risks, adding new factors specific to Egypt, such as bribery, nepotism, delays in approvals, and corruption. Additional factors specific to Banking Construction (BC) included issues like fixed contractor lists, slow decision-making by owners, and work permit delays. Ultimately, 49 risk factors were categorized into four groups: 18 in the "Main group" (most common and top-ranked), 12 affecting project schedules, 10 impacting costs, and 9 influencing quality. These factors are detailed in Table 1.

Table 1
Risk Factors under the four groups (Main, Schedule, Cost, and Quality)

	Code	Risk Factors	Code	Risk Factors
Main Risk-Factors	R1-1	Error of Design	R1-10	Change of design during construction phase
	R1-2	Financial and administrative corruption	R1-11	Delay of project by owner
	R1-3	Accuracy of feasibility study of project.	R1-12	Contacts with owner.
	R1-4	Political Interference	R1-13	Fixed contractors list
	R1-5	Bribery and nepotism	R1-14	Slowness of making decisions by Owner
	R1-6	The suitability of contractor's experience with project's requirements	R1-15	Delay of work permits
	R1-7	Contractors follow safety and health regulations	R1-16	Lack of Coordination between department
	R1-8	Tighe project schedule	R1-17	Delay of invoices procedures
	R1-9	Owner stops payments to the project	R1-18	Lack of scheduling planning
Schedule risk-factors	R2-1	Delay of payment	R2-7	Delay of materials
	R2-2	Sudden stop of payment	R2-8	Shortage of materials and equipment
	R2-3	Delay of Design	R2-9	Shortage of materials in market
	R2-4	Change of design	R2-10	Lack of Coordination between department
	R2-5	Errors of design	R2-11	Lack of human resources in management
	R2-6	Delay of invoices procedures.	R2-12	Slowness of making decisions
Cost risk-factors	R3-1	Error of Design	R3-6	High prices change and currency change
	R3-2	Change of design	R3-7	Material Monopoly
	R3-3	Inaccurate initial cost estimation	R3-8	Change of regulations, legislation and laws
	R3-4	Allocated funding covers estimated cost	R3-9	Accidents and Lack of safety
	R3-5	Overestimating the costs of project	R3-10	Supply of non-conforming raw materials
Quality risk-factors	R4-1	Design suitability	R4-6	Supply of non-conforming raw materials
	R4-2	lack of specifications and conditions of the required works	R4-7	Bribery and nepotism
	R4-3	The accuracy of tests of operations and final delivery	R4-8	Financial and administrative corruption.
	R4-4	Lack of Follow up and monitoring procedures	R4-9	Lack of Coordination between project parties
	R4-5	Lack of experience of project management		

4.2 Risk analysis

4.2.1 respondents' selection

Two groups of experts were consulted to score the 49 risk factors: one with experience in General Construction (GC) projects in Egypt and the other with experience in Banking Construction (BC) projects.

Based on literature review, it is reported that the target sample of respondents should be thoroughly selected to reflect opinions of different years of work experiences, different project parties, and different functions within a project. Sample sizes (target number of respondents) ranges between 30 and 65 for similar general studies (B. G. Hwang et al., 2013), (Kartam & Kartam, 2001), (El-Sayegh, 2008). The sample structure usually includes 4 to 6 different project parties and covers a range of 5 to more than 20 years of experience. A questionnaire is designed based on this structure as shown in Table 2. It uses five-point Likert scale, where it is less confusing and improves response rate (Babakus & Mangold, 1992). The *Monkey survey Software* (Mazen, 2013), a professional survey tool that accumulates responses and issues status and progress reports upon request and offers few statistical and graphical analysis tools, is used to collect data from targeted experts.

Table 2
Actual respondents' number and mix vs Literature averages

	Respondent's Profile	literature Average Profile	Attempted Sample Profile	Actual Sample Profile
Project Party	Contractor	27 (57%)	37 (50%)	13 (29%)
	Consultant	10 (22%)	16 (22%)	27 (60%)
	Owner	10 (21%)	20 (28%)	5 (11%)
Years of experiences	Less than 5	2 (5.7%)	10 (14%)	8 (19%)
	5 to 10	5 (9.4%)	30 (40%)	18 (39%)
	11 to 20	27 (58.5%)	20 (27%)	10 (23%)
	More than 20	12 (26.4%)	13 (14%)	9 (20%)
	Total sample	46	73	45

A total of 45 responses were received: 30 for GC, and 15 for BC. The profile of those who responded is as shown in Fig. 1

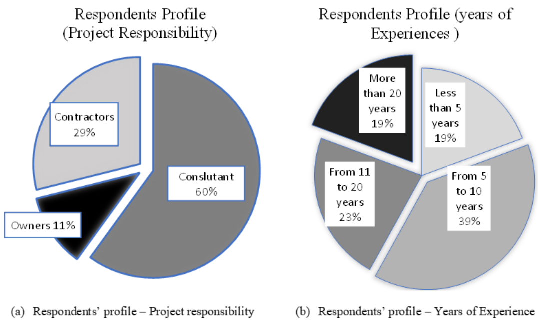


Fig. 1. Respondents'' Profiles

In addition, personal interviews were also conducted with few distinct respondents to explore some aspects, discuss opinions, and/or answer some queries.

4.2.2 Filtration of identified risk factors

First, the Relative Importance Index (RII) method is used as a filtration process that helps in excluding similar factors, and factors of very low influence (weight). *RII* requires that each respondent expresses the importance of each risk factor using a single point-rating (on Likert scale) according to his own conception of importance. RII is calculated using Eq. (1)

$$RII = \frac{\sum_{i=1}^{5} W_i x_i}{\sum_{i=1}^{5} x_i} \tag{1}$$

where: W_i: is the ith point rating in the Likert scale, and x_i is the frequency of respondents who selected this rating. Table 3 presents the calculation of the RII values for the first two factors in the general group, as examples.

Table 3
Calculation of RII, examples for first two factors

Code	Factors of risk	Likert Scale					$\sum_{i=1}^{5} x_i$	General Construction	
		1	2	3	4	5		RII	Rank
R1-1	Error of Design	3	2	7	9	9	30	3.63	7
R1-2	Financial and administrative corruption.	1	0	4	8	16	29	4.31	2

A total of 36 risk factors are selected from the 49 ones identified earlier, after eliminating few repeated ones and least ranked risks based on their RII values.

4.2.3 Weighting of identified risk factors

Although the RII method gives a relative weight of each identified factor on a scale out of 5, the fuzzy set theory is used here to take care of the subjectivity associated with human judgment on uncertain and vague characteristics of risks.

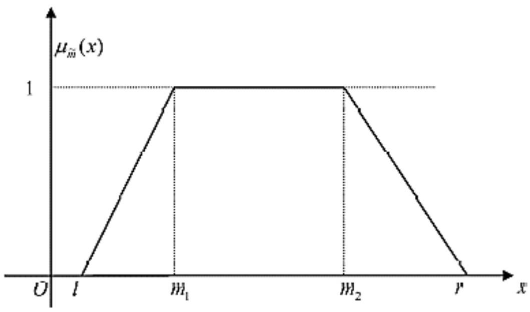


Fig. 2. Trapezoidal fuzzy number representation

The procedures followed are according to (Samantra et al., 2017), which applies both concepts of ‘Circumference of centroids’ and ranking of crisp ratings. Each Likert scale rating (level) is transformed into a fuzzy membership of Trapezoidal shape. Where, a trapezoidal fuzzy number can be represented in the form (l, m_1, m_2, r) as shown in Fig. 2. The values of the four points (l, m_1, m_2, r) for each of the five-membership functions of the proposed model is shown in Table 4 (Xia et al., 2006).

Table 4
Five membership functions of proposed fuzzy model

Likert scale		Trapezoidal fuzzy Number
Points	Levels	
1	Very low	(0,0.1,0.2,0.3)
2	Low	(0.1,0.2,0.3,0.4)
3	Medium	(0.3,0.4,0.5,0.6)
4	High	(0.5,0.6,0.7,0.8)
5	Very high	(0.7,0.8,0.9,1)

For each risk factor, each of the four values (l, m_1, m_2, r) in each of Likert scales is weighed by its corresponding respondents’ frequency, then by summing these values and dividing by the number of responses, four values are obtained (a, b, c, d) (S. J. Chen & Chen, 2007), as shown in Table 5.

Table 5
Calculation of fuzzy membership values for a risk-factor (an example)

		Likert scale					Weighted fuzzy number					a, b, c, d
	Responses	1	2	3	4	5	Trapezoidal fuzzy Number × Scale frequency					Weighted sum
“Error of Design” risk factor scale frequency (responses)	30	3	2	7	9	9						
Trapezoidal fuzzy Number	l	0	0.1	0.3	0.5	0.7	0	0.2	2.1	4.5	6.3	0.44
	m1	0.1	0.2	0.4	0.6	0.8	0.3	0.4	2.8	5.4	7.2	0.54
	m2	0.2	0.3	0.5	0.7	0.9	0.6	0.6	3.5	6.3	8.1	0.64
	r	0.3	0.4	0.6	0.8	1	0.9	0.8	4.2	7.2	9	0.74

Finally, the crisp rating of the four crips values (a, b, c, d) represents the severity of the corresponding risk factor. Traditionally, crisp rating of a fuzzy number is represented by the centroid of its trapezoid, however, the method of ‘circumference of centroids’ defines a crisp rating of a fuzzy number to be the Center of that circumference (Samantra et al., 2017). The centroid of a trapezoid is known to be the balancing point of the trapezoid. The method of ‘Circumference of centroids’ splits the trapezoid into three planes: a triangle (APB), A rectangle (BPQC), and a triangle (CQD) respectively, as shown in Fig. 3. The Centroid Points of these planes are G1, G2, and G3 respectively. The circumcenter $S_{\bar{A}}$ ($\bar{X}_0$, $\bar{Y}_0$) of the circumference of the centroids that is formed by the triangle G1, G2 is calculated using Eq. (2). Hence, the crisp rating R($\bar{A}$) of a single factor ($\bar{A}$) is estimated using Eq.(3) and assuming *w =1*.

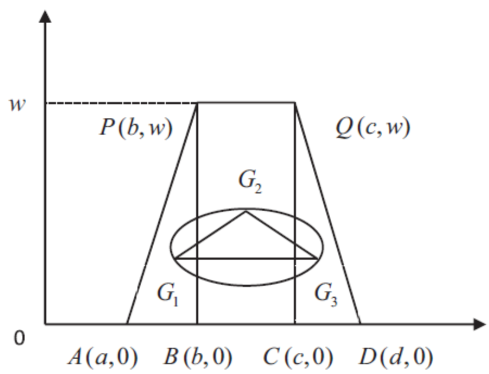


Fig. 3. Circumference of centroids

$$S\bar{A}\ (\bar{X}0, \bar{Y}0) = \left(\frac{a + 2b + 2c + d}{6}, \frac{(2a + b - 3c)(2d + c - 3b) + 5w^2}{12w}\right) \qquad (2)$$

$$R(\bar{A}) = \sqrt{(\bar{X}_0^2 + \bar{Y}_0^2)} \qquad (3)$$

The crisp ratings, utilizing the Fuzzy sets theory, for the 36 factors for both General and Banking Construction projects are listed in Table 6. The table lists also the ranking of each factor among all factors, and within each type of project.

Table 6
Crisp Ratings for factors of General and Banking Constructions

Code	Risk Factor	General			Banking		
		Crisp Rating	Overall Rank	Group Rank	Crisp Rating	Overall Rank	Group Rank
R1.1	Error of Design	0.708	25	10	0.74	21	11
R1.2	Financial and administrative corruption.	0.818	5	1	0.71	25	12
R1.3	Accuracy of feasibility study of project.	0.733	21	7	0.71	25	12
R1.4	Political Interference	0.708	26	11	0.83	7	4
R1.5	Bribery and nepotism	0.767	14	4	0.75	20	10
R1.6	The suitability of contractor's experience with project's requirements and conditions.	0.750	15	5	0.83	7	3
R1.7	Contractors follow safety and health regulations	0.620	35	17	0.70	28	15
R1.8	Tight project schedule	0.658	33	15	0.71	25	12
R1.9	Owner stops payments to the project	0.801	7	2	0.92	1	1
R1.10	Change of design during construction phase	0.705	27	12	0.78	13	6
R1.11	Delay of project by owner	0.719	23	8	0.65	32	17
R112	Contact with owner if needed availability	0.627	34	16	0.61	34	18
R1.13	Fixed contractors list	0.617	36	18	0.69	30	16
R1.14	Slowness of making decisions by Owner	0.699	29	13	0.90	2	2
R1.15	Delay of work permits	0.710	24	9	0.78	13	5
R1.16	Lack of Coordination between department	0.781	11	3	0.76	17	8
R1.17	Delay of invoices procedures	0.689	30	14	0.78	13	7
R1.18	Lack of schedule design	0.744	18	6	0.76	17	8
R2.1	Delay of payment	0.783	10	5	0.86	4	2
R2.2	Sudden stop of payment	0.810	6	4	0.90	2	1
R2.3	Delay of Design	0.731	22	6	0.70	28	6
R2.4	Delay of materials	0.832	1	1	0.78	13	4
R2.5	Shortage of materials and equipment	0.832	1	1	0.76	17	5
R2.6	Shortage of materials in market	0.822	4	3	0.84	6	3
R2.7	Lack of human resources management	0.705	27	7	0.61	34	7
R3.1	Allocated funding covers estimated cost	0.774	12	2	0.80	10	2
R3.2	Overestimating the costs of project	0.660	32	6	0.57	36	6
R3.3	High prices change and currency change	0.823	3	1	0.86	4	1
R3.4	Material Monopoly	0.746	17	3	0.74	21	3
R3.5	Change of regulations, legislation and laws	0.686	31	5	0.68	31	5
R3.6	Supply of non-conforming raw materials	0.737	20	4	0.74	21	3
R4.1	Design suitability	0.748	16	4	0.63	33	5
R4.2	Accuracy tests of operation and final delivery	0.738	19	5	0.80	10	2
R4.3	Lack of Follow up and monitoring procedures	0.786	9	2	0.74	21	4
R4.4	Lack of experience of project management	0.771	13	3	0.82	9	1
R4.5	Supply of non-conforming raw materials	0.794	8	1	0.80	10	2

4.2.4 Analysis

A. Correlation Analysis of General and Banking Construction Risks

Although all factors exist for both types of projects, the results in Table 6 indicate that the relative importance (rank) of various risk factors differs between GC projects and BC projects. For instance, "Financial and administrative corruption" is the highest-ranked risk factor for GC projects but ranks 12th in BC projects. Conversely, the risk factor "Owner stops payments to the project" is ranked highest in BC projects. hence, the Spearman's correlation coefficient is used here to quantify these differences. Due to the long list in the GC group, only the top 10 risk factors are included in the test, where for other groups, all risk factors are considered. The results of the analysis are shown in Table 7. The results in Table 7 support the rationale for developing a specialized risk management system uniquely suited for GC projects and for BC projects in Egypt. This distinction is essential due to the varying natures of these project types.

Table 7
Correlation between Risk Factors of General and Banking Construction

	Test Group	Number of Risk Factors	Spearman's Coefficient r_s	Spearman's Coefficient σ_{r_s}	Level of Correlation*
1	Main	10	0.48	0.162	Moderate
2	Schedule	7	0.23	0.095	Weak
3	Cost	6	0.97	0.434	Strong
4	Quality	5	0.05	0.025	Weak

* Weak (or none) if $\gamma s \leq |0.3|$, strong if $\gamma s \geq 0.7$, and moderate otherwise.

The risk factors related to schedule and quality groups exhibit nearly reversed priorities between General Construction (GC) and Banking Construction (BC). However, the factors influencing project cost in both types of construction projects share the same rank, as they directly impact the project's cost.

B. Comparison of Risks between Egypt and Other Countries

Top Egyptian GC risk factors are compared against their corresponding ranks in some reported international studies. BC risks are excluded from the comparison since no similar results were reported in the literature. The comparison covers four studies related to Middle East countries (Taylan et al., 2014), (Jomaah et al., 2014), (Kartam & Kartam, 2001), and (El-Sayegh, 2008), and three to East Asia countries (Zou et al., 2007), (Samantra et al., 2017), and (B.-G. Hwang et al., 2013). For the purpose of comparison, the top risk factors in Egypt are re-categorized into five categories: Martials & Resources, Financial, Corruption & Governmental, Project & Site Management, and some other Miscellaneous risk factors as listed in Table 8.

Table 8

Comparison of Main Construction Risks in Egypt and Other Countries

			Egypt		Middle East				East Asia		
	Risk Factor code	Risk Factor Description	General	Banking	Saudi Arabia (Taylan et al., 2014)	Saudi Arabia (Jomaah et al., 2014)	Kuwait (Kartam & Kartam, 2001)	Emirates (El-Sayegh, 2008)	China (Zou et al., 2007)	India (Samantra et al., 2017)	Singapore (B.-G. Hwang et al., 2013)
Materials	R2-4	Delay and/or shortage of materials	1				3	4	3		
	R4-5	Supply of non-conforming raw materials	1								
	R3-4	Material Monopoly	3								
Financial	R3-3	Prices, inflation, and currency change	1	1				1			
	R3-1	Allocation and availability of Funding	2	2			1		2		
	R1-9	Owner stops or delay funding to the project	2	1	4		2			4	6
Corrup.	R1-2	Financial and administrative corruption.	1	7							
	R1-5	Bribery and nepotism	4								
	R3-5	Regulations, legislations, Bureaucracy	5		1				2		
Proj Mgmt.	R1-16	Coordination between department	3		5	2	5			2	1
	R4-3	Project Planning and monitoring	2						2	5	4
	R4-4	Experience of project/site management	3		3	2					2
Other Factors	R1-6	Contractor's technical experience	5	2				5	3	2	8
	R4-1	Design errors, suitability, and changes	4			4	4		1	3	4
	R1-3	Feasibility and initial studies	7		2	1			4	1	
	R1-14	Owner decisions and requirements	13					2	1		3

The results indicate that several factors are particularly significant in Egypt but are not as impactful in other countries. This is especially true for the categories of 'Materials & Resources' and 'Corruption'. Examples of such risks include delays and shortages of materials, the supply of non-conforming raw materials, material monopolies, financial and administrative corruption, bribery, and nepotism. Risks related to financing GC projects, such as 'Prices, inflation, and currency change' and 'Allocation and availability of funding', are not universally considered but are top priorities in Egypt and other countries where they exist. The most common high-ranking risk category across all considered countries is Project & Site Management, which includes risks such as 'Coordination between departments', 'Project planning and monitoring', and 'Experience of project/site management'. Other single risks with similarly high ranks across all countries are 'Contractor's technical experience' and 'Design errors, suitability, and changes'. Conversely, the risks 'Feasibility and initial studies' and 'Owner decisions and requirements' have high ranks in other countries but only lower ranks for GC projects in Egypt. When comparing the top risks in Middle Eastern and East Asian countries, it can be observed that they face similar risks with almost identical rankings.

4.3 Risk control

A comprehensive examination is undertaken to identify risk factors with considerable impact not only in isolation but also by influencing other variables. This process occurs in two stages: initially, sifting through the 36 risk factors to select the highest-ranked ones, along with any additional factors that can be reasonably justified. Following this, an assessment of the ***interconnections among these factors*** is conducted to compute the centrality measure for each factor. This measure illustrates the extent to which a given factor affects and is affected by other factors.

4.3.1 Selection of most significant factors

The highest 10-ranking risk factors for ***GC*** projects are chosen, a selection of 11th risk is made to accommodate a tie at the 10th rank. Similarly, the top 10 risk factors in terms of overall rank for ***BC*** are identified, in addition to four risks due to their elevated group rank and their specific relevance to Egypt.

4.3.2 Interconnections Analysis

To map out how different factors interact with each other, a Design Structure Matrix (DSM) is created to allow understanding the connections, dependencies, and influences between various factors.

The DSM, in the context of research and analysis, is a structured representation that helps organize and visualize the relationships between different variables or factors (Clark-Ginsberg, 2017).

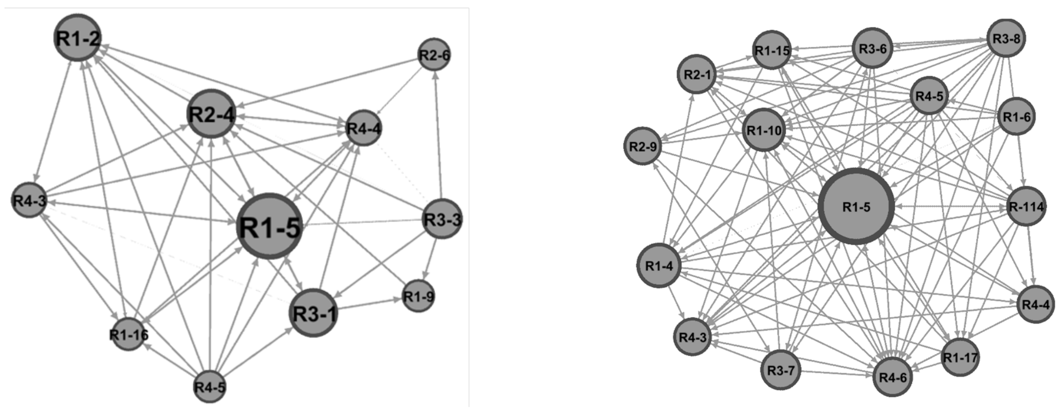
The creation of the Design Matrix involves an interactive process where a few experts (2-3) from both the GC and BC fields are engaged in interviews and discussions.

The researcher collaborates with these experts to determine the values within the Design Matrix. This method simplifies participatory approaches, which are particularly beneficial in situations where data is limited, and certain groups are marginalized (Clark-Ginsberg, 2017).

Table 9, exhibits the DSM of risk factors in GC projects. A risk factor with high degrees-in and degrees-out means it is a crucial risk that causes many others to occur, and it is almost always realized whenever another risk occurs. This type of risk factor deserves to generate actions to prevent it and also to lessen its impact whenever it occurs.

Table 9
The Design Structure Matrix for GC Risk Factors

	R2-4	R3-3	R2-6	R1-2	R1-9	R4-5	R4-3	R1-16	R3-1	R4-4	R1-5
R2-4				3		3					3
R3-3	3		3	1	3	1			3		2
R2-6	3	1				2					
R1-2						3	3	2			3
R1-9	3										
R4-5	3			3							3
R4-3	3			2		3		3	1		3
R1-16	3			3		3					3
R3-1	3			3	3	3					3
R4-4	3			3		3	3	3			3
R1-5	3			3		3	3	3	3		



a. Gephi Network Mapping for GC b. Gephi Network Mapping for BC

Fig. 4. Gephi Network Mapping

For mapping of the DSM into a graph to visualize the centrality of each factor. The 'Gephi' software (Clark-Ginsberg, 2017) is utilized. It is a free open-source network software with good visualization and computational capabilities for network (Knuth, 2009). Fig. 4a shows the network representation for data in Table 9 using Gephi software. The size of each node is proportional to the centrality of the risk factor. Table 10 lists degrees-in, degrees-out, and centrality metrics for each factor in GC. It can be noted that 'Bribery *and nepotism'* and **'**Financial and administrative corruption' have the highest centrality values, hence, both are considered particular to the construction environment in Egypt.

Table 10
Centrality metric for GC risk factors

Factor Code	Risk Factor Description	Degrees			Centrality
		In	Out	Total	
R1-5	Bribery and nepotism	8.00	6.00	14.00	14.75
R2-4	Delay of materials	9.00	3.00	12.00	7.33
R3-1	Allocated funding covers estimated cost	4.00	5.00	9.00	7.00
R1-2	Financial and administrative corruption.	8.00	4.00	12.00	6.50
R3-3	High prices and currency change	1.00	7.00	8.00	3.33
R4-5	Supply of non-conforming raw materials	9.00	3.00	12.00	1.58
R4-3	Lack of Follow up and monitoring procedures	3.00	6.00	9.00	1.25
R1-16	Lack of Coordination between department	4.00	4.00	8.00	0.25
R2-6	Shortage of materials in market	1.00	3.00	4.00	0.00
R1-9	Owner stops payments to the project	2.00	1.00	3.00	0.00
R4-4	Lack of experience of project management	0.00	7.00	7.00	0.00

Based on the data in Table 10, a few risk factors that are considered as '***Key Risks***' are listed in Table 11 and accordingly have the priority to be controlled by effective actions.

Table 11
Key Risks for General and Banking Construction projects

General Construction		Banking Construction	
Factor Code	Key Risk Factor Description	Factor Code	Key Risk Factor Description
R1-5	Bribery and nepotism	R1-5	Bribery and nepotism
R2-4	Delay of materials	R1-4	Political Interference
R3-1	Allocated funding covers estimated cost	R1-10	Change of design during construction phase
R1-2	Financial and administrative corruption.	R1-14	Slowness of making decisions by Owner
R3-3	High prices and currency change	R2-1	Delay of payment

4.3.3 Selection of Appropriate Control Actions

The literature was reviewed for possible control actions, and a new set of actions was introduced by a pool of experts to suit Egyptian work practices and risks. A total of 10 actions for GC and 13 actions for BC were identified. However, these constitute long lists of possible actions, so they were ranked in terms of their impact on project schedule, cost, and quality using the TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution). A group of eight experts (5 for GC, 3 for BC) with known good experiences in construction projects in Egypt, performed an assessment of the impact of each alternative action on each of the three objective attributes; Schedule, Cost, and Quality. Then, the TOPSIS procedures as described by Hwang & Yoon, 1981) is implemented, Table 12 displays the results of this process. The results indicate the risk factors addressed by each control actions, the Closeness and Separation Measures of this action to ideal actions, and the rankings of actions.

It is easily argued that the highly ranked actions shall decrease the chances of occurrence of the majority of key risks, and have direct impact on meeting the Time, Cost, and the highest possible Quality. For GC projects, holding effective meetings to update project schedules, and costs and discussing cost problems (A10) is a perfect solution to decrease the chances of risks resulting from lack of follow up and monitoring. It also resolves the problems of coordination between mechanical, electric, architecture and structure departments. Setting the owner of scheduled payments during implementation phase (A9) will reduce sudden stop, delay of payments, and their other consequences. Also, a designer should develop and update the project designs to be within the owner's funding capabilities (A8) while satisfying best attainable quality so as to avoid funding and frequent design changes problems. In the case of BC, the quality is already defined according to the standardized security, safety, and comfort banking codes. Banks usually select contractors and vendors out of a fixed list based on their past experiences and quotations in GC and buildings rehabilitation and maintenance works. Many schedule and quality problems arise since they may not be technically competitive to satisfy advanced security, utilities, and systems requirements of new banking facilities. Therefore, action A5 calls for selecting a contractor based on his relevant experience and reputation rather than a fixed list of general contractors. Action A3, *add a contingency premium*, should make up for delayed payments and change in prices and currency and their consequent, shortages, non-conformances, and delays that affect grand opening planned schedules. Like in GC, action A8 is also highly recommended here to hold regular follow up and monitoring meetings for its great impact on preventing serious problems ahead of time.

Table 12
Ranking, Closeness and Separation Measures of Actions

Action Code	Control Actions:	Risk Factor	d+	d-	Ri	Rank
General Construction						
A1	The government agencies should reduce time of approval procedures by using smart systems	R1-5, R1-2	0.108	0.198	0.646	4
A2	Awareness against Committing corruption and bribery crimes.	R1-5, R1-2	0.240	0.050	0.171	7
A3	Add a contingency premium	R3-6	0.180	0.128	0.416	6
A4	Owner chooses lump-sum contractor	R3-3	0.274	0	0	8
A5	The selection of suppliers should be based on reputation	R2-7	0.096	0.237	0.711	3
A6	Materials selection should be from market conditions and avoid long lead time and long transportation.	R2-7, R3-7	0.198	0.188	0.487	5
A7	Owner should set project funding plan in feasibility and design phase.	R2-4	0.050	0.240	0.829	2
A8	Designers develop and update project design according to owner financial capability	R3-4	0.0	0.274	1	1
A9	Owner should set project funding plan for implementation phase.	R3-3	0.0	0.274	1	1
A10	All parties participate in regular meetings, to status and to clarify any outstanding works, and emphasize effective management and coordination among various parties.	R4-4, R2-9 R1-16	0.0	0.274	1	1
Control Actions: Banking Construction						
A7	Client should set project funding plan in feasibility and design phase.	R1-5, R1-15	0.234	0.110	0.320	7
A8	Designers develop and update project design according to client financial capability	R1-5, R1-4	0.0	0.258	1	1
A9	Client should set project funding plan for implementation phase.	R3-6, R2-1	0.206	0.090	0.304	8
A3	Add a contingency premium	R1-10, R1-14	0.0	0.258	1	1
A4	Clients Choose lump-sum contractor	R4-6	0.099	0.216	0.685	3
A15	Subcontractors should be involved at the early stage on the project	R2-1	0.180	0.185	0.508	5
A1	The government agencies should reduce time of approval procedures by using smart systems	R1-10	0.099	0.216	0.685	3
A2	Awareness against Committing corruption and bribery crimes.	R2-1	0.134	0.150	0.529	4
A13	client should know responsibility in case of changing design during construction phase	R1-14	0.204	0.086	0.296	9
A14	Project team should define the project scope and functions precisely	R1-17, R2-1	0.067	0.200	0.749	2
A11	contractors should have a good relationship with clients to minimize uncooperative activities.	R1-10	0.153	0.109	0.416	6
A12	contractors should take legal weapon to vindicate their rights	R1-14, R1-10	0.229	0.045	0.164	10
A5	The selection of suppliers should be based on reputation	R1-6, R4-6	0.0	0.258	1	1

5. Conclusions and Future work

This study presents a comprehensive risk management framework tailored to the Egyptian construction industry, addressing the distinct challenges faced by General Construction (GC) and Banking Construction (BC) sectors. Through a detailed analysis using advanced techniques like RII and Fuzzy-set theory, the research identifies and ranks critical risk factors, highlighting significant differences between the two sectors. The application of TOPSIS enables the selection of effective mitigation strategies, ensuring improvements in project timelines, costs, and quality.

The findings underscore the importance of sector-specific risk management approaches. For GC projects, addressing financial and administrative corruption is paramount, whereas for BC projects, the focus should be on mitigating risks related to payment delays and contractor selection. The study also provides a comparative perspective by analyzing how Egyptian construction risks align with those in other regions, particularly the Middle East and East Asia.

In conclusion, this research fills a crucial gap in the literature by offering a specialized risk management system for GC and BC projects in Egypt. The proposed strategies, validated by industry experts, provide actionable guidance for practitioners aiming to enhance risk management practices and project outcomes in the Egyptian construction sector.

Future research should extend this approach to other types of construction projects and explore the applicability of these strategies in different geographical and cultural contexts. Additionally, the development of sector-specific risk management frameworks can further refine and improve risk mitigation in construction projects globally.

Acknowledgement

In heartfelt remembrance of Prof. Mohamed Adel Shalaby, a remarkable scholar and devoted researcher. Tragically, Prof. Mohamed Adel Shalaby left us prior to the conclusion of this research and its submission for publication. Despite this profound loss, their remarkable dedication and contributions during the research process will forever resonate within this work. We wish to honor Prof. Mohamed Adel Shalaby 's enduring influence and lasting legacy. Also, the authors would like to thank the construction firms and the respondents to the survey used for this paper.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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