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RESEARCH ARTICLE

A risk-based cost estimation model for optimizing construction projects in Palestine

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Abstract - This study investigates the critical risk factors affecting cost estimation in the Palestinian construction industry and develops a risk-based cost estimation model. Given the complexity of construction projects, this research employed a mixed-methods approach that combined qualitative interviews with industry professionals and a quantitative survey. A total of 39 risk factors were identified, with the most influential being project location, material availability, and market fluctuations. The study emphasizes the importance of these risks in the context of Palestine, where challenges such as geopolitical instability, resource limitations, and market volatility are common. A risk-based model incorporating Monte Carlo simulations and the Analytic Hierarchy Process was proposed to improve the accuracy and reliability of cost estimation. The model allows for a more systematic approach to managing risk by quantifying its impact on project costs. The results indicate that the top five risk factors account for 68.56% of the total cost of risk, underscoring the need for targeted risk management strategies. This research provides valuable insights and actionable strategies for construction professionals in enhancing cost estimation accuracy, improving decision-making processes, and contributing to more resilient and sustainable construction projects in Palestine.

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1. Introduction

Construction projects are inherently intricate, both in terms of technical aspects and contractual obligations. This complexity increases the likelihood of risks that adversely affect project execution. Effective management of these risks requires early identification and thorough analysis (Marks, 2020). Estimating costs is a fundamental part of managing construction projects, but inherent uncertainties, such as unforeseen changes in scope, can pose challenges to accurate estimations (Alhammadi et al., 2024; Alkhuadhan & Naimi, 2023; Alshihri et al., 2022). A risk-based approach to cost estimation provides a structured framework to address these uncertainties. This approach emphasizes identifying and analyzing risks and formulating contingency plans to manage potential variations effectively (Popovic & Knezevic, 2022). Monte Carlo simulation is a commonly used quantitative tool for this purpose, as it allows for reliable cost predictions by generating a range of potential outcomes through repeated random sampling (Mahmoud et al., 2021). This is particularly relevant in regions like the Middle East, where construction projects frequently experience delays and cost overruns due to inadequate planning, contractual disputes, and external factors such as market volatility (Mosly, 2025).

Various risk categories influence cost estimation, including contractual, technical, project-specific, financial, and environmental risks. For instance, research indicates that a significant number of construction projects in Dubai suffer from delays and cost overruns, primarily due to insufficient planning time and contractual issues (Gómez-Cabrera et al., 2024). Financial instability, resource shortages, and environmental challenges further complicate accurate cost predictions (Ahmad et al., 2024). Addressing these risks in the early stages of a project can significantly enhance the likelihood of achieving project success (Ullah et al., 2021). The construction sector is particularly significant in Palestine, where it serves as a vital economic pillar that contributed 16.78% to the GDP in 2022 (Palestinian Central Bureau of Statistics, 2022). Its contribution to employment has also grown significantly, as evidenced by the increase from 7.4% in 2009 to 10.4% in 2018, with 9.3% in the West Bank and 1.1% in the Gaza Strip. However, the industry faces persistent challenges, including geopolitical instability, inefficient stakeholder collaboration, resource constraints, and unpredictable environmental conditions (Rasshyvalov et al., 2024). Studies show that all road construction projects in the West Bank face time overruns, with 70% of delays ranging between 10% and 30% of the contracted duration. Furthermore, cost overruns are prevalent, with an average deviation of 16.73% from initial estimates (Krechowicz & Piotrowski, 2021). Addressing these challenges requires robust, context-specific risk management strategies to enhance project delivery and sustainability (Do et al., 2023).

Palestine’s construction sector is uniquely vulnerable to geopolitical challenges, such as restricted access to resources, border closures, and political instability, which significantly impact project feasibility and execution (Arif et al., 2024). These factors introduce uncertainties that directly affect cost estimation accuracy, making effective risk management critical for sustainable project outcomes. Addressing these challenges requires tailored risk management frameworks that incorporate local socio-political and economic conditions to enhance project efficiency and stakeholder collaboration (Dandan et al., 2020; Glette-Iversen et al., 2023). Traditional risk management methods often rely on qualitative approaches, such as brainstorming, which, while effective in identifying risks, lack the precision needed for dynamic construction environments (Lee et al., 2022). However, advancements in quantitative risk assessment methodologies, including Monte Carlo simulations, probabilistic analysis, and artificial intelligence, offer significant potential to improve risk identification and integrate mitigation strategies into cost estimation processes (Pineda & Stamatakis, 2022). Effective

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frameworks incorporating these advanced tools can reduce project delays and enhance cost estimation accuracy and overall project performance.

The primary aim of this research is to develop a comprehensive risk-based cost estimation model tailored specifically for the Palestinian construction industry. This model is designed to address the unique challenges and risk factors prevalent in the region, including geopolitical instability, resource limitations, market volatility, and environmental uncertainties. By systematically identifying and quantifying the impact of these risks, the research seeks to enhance the accuracy, reliability, and practicality of construction cost estimation processes. It also emphasizes integrating advanced methodologies, such as Monte Carlo simulations and the Analytic Hierarchy Process (AHP), to provide a structured framework for prioritizing and mitigating risks. Ultimately, the research aims to equip construction professionals in Palestine with actionable insights and robust tools to improve project planning, reduce cost overruns, and contribute to the industry's sustainability and resilience.

2. Literature Review

Construction projects in Palestine face significant obstacles due to various factors. Geopolitical instability, characterized by border restrictions and political conflict, often results in project delays and increased costs because of disrupted supply chains and labor shortages (Alazemi & Mohiuddin, 2019). Additionally, material import restrictions, driven by reliance on imported construction materials subject to border regulations, lead to price volatility and procurement delays. Economic pressures, such as inflation, currency fluctuations, and limited access to financing, further complicate cost estimation and affect project sustainability. Environmental and social factors, including natural disasters and limited access to skilled labor, exacerbate the unpredictability of construction costs (Mahamid, 2024a). Studies indicate that 76% of construction projects in the West Bank experience cost overruns, with an average deviation of 14.6% attributed to these challenges (Mahamid, 2015). Several studies have explored risk management and cost estimation approaches tailored to Palestine's unique context. Alqudah et al. (2023) emphasized the importance of integrating local risk factors into project cost models and advocated for stakeholder input to identify and mitigate region-specific risks. Their study revealed that 44.07% of the total cost risks in construction projects stem from factors such as fraudulent practices, inflation, incomplete scope definitions, and frequent design changes. Other research also highlighted the value of proactive risk identification and planning, suggesting that collaboration among stakeholders, combined with comprehensive data analysis, could significantly improve cost estimation reliability (Mahamid, 2024b).

Dandan et al. (2020) analyzed 169 road construction projects in the West Bank between 2004 and 2008 and found that 76% of these projects experienced cost overruns. The average cost deviation was 14.6%, with variations ranging from -39% to +98%. Their findings underscored the critical role of adopting advanced tools, such as Monte Carlo simulations and scenario analysis, to better predict and manage cost uncertainties. Furthermore, Mahamid (2015) emphasized improving coordination among project stakeholders as a key strategy to mitigate inefficiencies and delays that contribute to cost overruns. Similarly, Shaheen et al. (2020) highlighted the necessity of developing tailored risk-based frameworks that address Palestine's unique socioeconomic and political conditions. Their research indicated that over 70% of construction project delays were linked to ineffective risk management practices, including a lack of proper leadership, insufficient stakeholder collaboration, and inadequate contingency planning. Other study emphasized that combining qualitative tools, such as expert consultations, with quantitative approaches, like probabilistic models, is essential for creating sustainable and adaptable project management strategies (Alhammadi et al., 2021).

3. Materials and Methods

This study employed a combination of qualitative and quantitative methodologies to ensure a comprehensive risk-based cost estimation model. The integration of Severity Index (SI), Frequency Index (FI), and Importance Index (IMPI) allows for the identification and prioritization of critical risk factors influencing construction costs, while AHP is used to systematically assign relative weights to these factors based on expert judgment, ensuring consistency in risk assessment. A focus group discussion was conducted with industry professionals to gather expert insights into risk identification and validation of risk factors, ensuring that the model incorporates real-world challenges and experiences from construction practitioners. Additionally, a survey was distributed to a diverse group of construction professionals to collect quantitative data on risk factors' frequency and severity, hence supporting the statistical validation of the model. To enhance the accuracy of cost estimation, Monte Carlo Simulation (MCS) was employed to model uncertainties by running 10,000 iterations. It generated a probabilistic distribution of total cost risk, which enabled a more realistic understanding of potential cost variations and extreme scenarios. Meanwhile, Sensitivity Analysis evaluated the influence of each risk factor on overall cost fluctuations, ensuring the robustness and reliability of the model. The choice of methodologies is justified by their complementary strengths: Focus groups provide qualitative depth, surveys offer empirical validation, AHP provides structured decision-making in weight assignments, Monte Carlo Simulation quantifies probabilistic uncertainties, and Sensitivity Analysis verifies the stability of results. Together, these approaches create a robust and data-driven framework for construction cost estimation, enhancing decision-making and financial planning in high-risk construction environments.

3.1 Research Design

This study adopted a mixed-methods research design by integrating both qualitative and quantitative approaches to provide a comprehensive analysis of risk factors influencing cost estimation. The qualitative component focused on uncovering the underlying causes, opinions, and perspectives related to these risks. Data collection was conducted through in-depth, face-to-face interviews with key stakeholders in the Palestinian construction industry. This method offered valuable insights into the identified risks and their root causes. Semi-structured interviews were chosen as the primary qualitative tool due to their ability to capture detailed information about participants' thoughts (Easwaramoorthy & Zarinpoush, 2006). The flexible nature of this format allowed interviewees to expand on specific topics while ensuring that critical areas of interest were systematically explored. The quantitative aspect of this study focused on evaluating the influence of identified risk factors and collecting data essential for formulating a risk-based cost estimation model. Data were gathered through a self-administered questionnaire, allowing participants to respond at their convenience, thereby reducing the likelihood of bias (Millet, 2009). The questionnaire was divided into two sections: the first aimed to identify and rank the risk factors based on their frequency and severity, while the second employed the AHP scale to assess the relative significance of each factor (Saaty & Kearns, 1985).

3.2 Defined Participant Demographic

The study focused on a target demographic of professionals actively engaged in building construction projects within Palestine. This diverse group, illustrated in Figure 1, includes individuals from various disciplines essential to construction project management. The participants were carefully selected from those registered with recognized professional associations and organizations in Palestine, ensuring that only professionals with substantial expertise and practical experience in construction-related disciplines contributed to the research. This multidisciplinary representation emphasizes the collaborative and innovative approaches integral to successful construction project execution.

3.2.1 Sample Size

This study utilized the formula proposed by Kish to calculate the sample size (Wiegand, 1968). The formula was chosen for its accuracy and resilience against outliers, making it a superior option compared to alternative methods (Akinshin, 2023). The Kish formula is presented in Eq. (1) and Eq. (2).

$$n_o = \frac{pq}{S^2} \tag{1}$$

$$n = \frac{n_o}{1 + \frac{n_o - 1}{N}} \tag{2}$$

where n_o is the initial estimate of the sample size, *p* is the Proportion of the population with the characteristic of interest, *q* = *1*−*p* (proportion without the characteristic), *S* is the maximum allowable standard error, *N* = Target population size, and *n* = Final adjusted sample size.

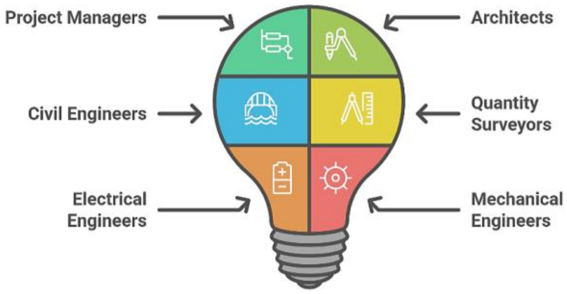

Figure 1. Key professions represented within the target demographic

With a 95% confidence level and a 10% margin of error, the initial sample size (n_o) was determined to be 25. By applying proportional allocation based on the population distribution across various professional categories in the Palestinian construction sector, the total sample size was expanded to 125 respondents. The final sample size estimates (*n*) for each group were determined by substituting the total population size (*N*) for each professional category into Eq. (2). The study encompassed a total population of 1,329 professionals, divided into six key professional groups. The sample size was proportionally allocated to represent each group's population as in Figure 2. Project Managers and Architects, each with a total population of 143, contributed 21 individuals each, representing 17% of the sample. Quantity Surveyors, with a population of 69, contributed 18 individuals, accounting for 14% of the sample. Civil Engineers, the largest group with a population of 717, contributed 24 individuals, making up 19% of the sample. Electrical Engineers, with a population of 148, and Mechanical Engineers, with a population of 109, contributed 21 (17%) and 20 (16%) individuals, respectively. This resulted in a total sample size of 125 individuals, distributed proportionally across the groups to ensure fair representation of the professional categories.

$$n_o = \frac{0.5 \times 0.5}{0.1^2} = 25$$

A purposive sampling method was employed to select participants with the necessary technical expertise and experience to meet the study's objectives. This approach ensured that respondents possessed the qualifications needed to provide valuable insights (Akinshin, 2023). By focusing on individuals with relevant expertise, the research aimed to capture data that accurately reflected the challenges and practices within the Palestinian construction sector. The primary data collection tool was a self-administered questionnaire, designed for participants to complete independently. This method allowed participants to provide their input at their convenience while minimizing the researchers' direct involvement. The questionnaire incorporated both open-ended and closed-ended questions, enabling the collection of qualitative and quantitative data. It was structured in two parts: the first section identified and ranked risk factors in cost estimation based on their frequency and severity, while the second section utilized Saaty's AHP scale (Saaty & Kearns, 1985). AHP is widely employed in large-scale surveys due to its ability to handle complex decision-making processes by structuring problems into a hierarchical framework. This method allows researchers to incorporate both qualitative and quantitative data, ensuring a systematic evaluation of multiple criteria. AHP enhances decision accuracy by enabling pairwise comparisons, which help in deriving priority weights based on expert judgments, thereby reducing subjectivity and inconsistencies in responses (Saaty & Kearns, 1985). Furthermore, AHP is particularly beneficial in large-scale surveys as it facilitates consensus-building among diverse stakeholders, supports sensitivity analysis, and ensures robust decision-making in multi-criteria environments (Guillén-Mena et al., 2023). Its structured approach improves the reliability of data interpretation, making it a suitable choice for applications in various fields, including construction management, environmental planning, and policymaking (Çavuşoğlu et al., 2022). Pairwise comparisons were applied to assign weights to critical risk factors. Self-administered questionnaires were chosen for their cost-effectiveness, efficiency, and participant convenience. Special attention was given to the design and wording of the questionnaire to ensure its effectiveness in gathering accurate and relevant data (Weyant, 2022).

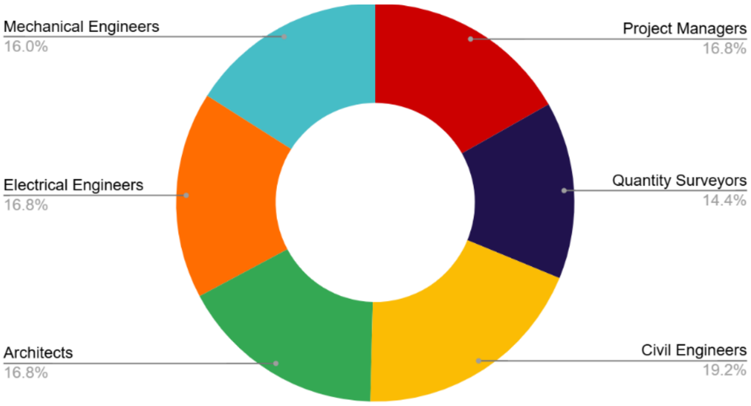

Figure 2. Proportional distribution of sample size (n) and percentage (%) across study groups

A secondary data collection tool (i.e., interview guide) was also utilized to gain deeper insight into the practices, tools, and techniques used for risk management in cost estimation. Semi-structured interviews were conducted, as they are recognized for effectively capturing detailed information about participants' perspectives, experiences, and perceptions (De Paoli, 2024). The flexible format allowed interviewees to elaborate on specific topics while ensuring all key research questions were addressed. Topics explored during the interviews included the risk management strategies employed in Palestinian construction projects, the effectiveness of these strategies in mitigating risks, the tools and software used for cost estimation and risk management, approaches to handling risks during cost estimation, and suggestions for enhancing risk management practices.

3.4 Data Analysis

Normality tests were not conducted as the study primarily relied on Monte Carlo simulation and sensitivity analysis to assess cost estimation risks. To ensure the accuracy and reliability of the risk-based cost estimation model, various software tools were utilized for different analytical methods. Monte Carlo simulation was conducted using Microsoft Excel and R software, both of which provide powerful capabilities for probabilistic modelling and risk analysis. Microsoft Excel was used to generate random sampling and probability distributions, while the R software facilitated advanced statistical computations and graphical representations of cost uncertainty. For sensitivity analysis, Microsoft Excel and R software were employed to evaluate the impact of input variations on cost estimation outcomes. Excel's built-in data analysis features allowed for straightforward calculations, while the R software provided enhanced visualization techniques, such as tornado diagrams, to illustrate the influence of key risk factors. Finally, AHP was implemented using Excel by leveraging its matrix operations and consistency ratio calculations. Conversely, the qualitative data obtained from face-to-face interviews were analyzed manually through content analysis. As explained by Haggarty (1996), content analysis is a structured and reliable approach to interpreting qualitative data, enabling researchers to derive meaningful conclusions within defined categories. This method allowed for an in-depth examination of interview responses, ensuring that the qualitative insights were thoroughly explored and aligned with the study's objectives. By combining these quantitative and qualitative methods, the research achieved a holistic and balanced interpretation of the collected data.

To identify and rank critical risk factors in cost estimation practices within the Palestinian construction sector, three key indices were calculated: SI, FI, and IMPI. These indices quantified the relative significance and occurrence of various risk factors based on respondents' perceptions. The SI captured the perceived impact of each factor, which was calculated using Formula 3. The FI reflected how often each factor was encountered, which was calculated using Formula 4. The combined effect of these indices was measured through the IMPI to identify the most critical risk factors. The IMPI percentage was calculated using Formula 5.

$$SI(\%) = \frac{\sum a.(n/N) \times 100}{5} \tag{3}$$

$$FI(\%) = \frac{\sum a.(n/N) \times 100}{5} \tag{4}$$

$$IMPI(\%) = \frac{FI(\%) \times SI(\%)}{100} \tag{5}$$

where a is the scale assigned to each response, n is the count of responses corresponding to a particular scale, and N represents the total number of respondents.

MCS was employed in this study to quantify the uncertainty in construction cost estimation. The simulation was based on the probabilistic behavior of key risk factors affecting project costs. It is performed using 10,000 iterations to generate a range of potential cost risks and identify the probability distribution of total cost variations (Li et al., 2024). In this study, MCS was conducted using Python and Excel to ensure an accurate probabilistic risk assessment. The input variables for the simulation include eleven primary risk factors, each assigned a probability distribution derived from the IMPI values. A triangular probability distribution is also assumed using Eq. (6) (Suarez-Burgoa, 2023).

$$X = a + (b - a) \times (\frac{\sqrt{(r \times (c - a) + (1 - r) \times (b - c)} + c - a)}{b - a} \tag{6}$$

where a is minimum cost risk (90% of IMPI), b is maximum cost risk (110% of IMPI), c is most likely cost risk (IMPI), and r is random value between 0 and 1 (generated per iteration). The cumulative distribution function (CDF) analysis was conducted to gain insights into the probability of cost risk not exceeding a given threshold. The cumulative probability is computed using Eq. (7).

$$F(x) = P(X \leq x) = \sum P(X_i) \tag{7}$$

where X_i is estimated total risk values and $P_{(X_i)}$ is probability density values from the histogram.

3.5 Framework Design

Numerous studies (Abdel-Monem et al., 2022; Castro Miranda et al., 2022; Dandan et al., 2020; Goyal & Sharma, 2022; Mahamid, 2015; Ullah et al., 2021) have proposed various models to tackle risks in cost estimation. Despite their potential, these models are often characterized by intricate structures that require advanced mathematical computations, which makes them challenging to implement and less practical for regular use by professionals in the construction industry. In contrast, risk-based cost estimation approaches focus on developing models that balance simplicity and sophistication, thus leveraging probabilistic frameworks to systematically manage project risks. These approaches prioritize identifying critical risk factors and embedding them into baseline cost estimates to enhance accuracy and reliability (Seddeeq et al., 2019).

In this research, AHP was utilized as the basis for designing a risk-based cost estimation model specifically for the Palestinian construction sector. AHP is a renowned decision-making framework that facilitates prioritization and informed choices in scenarios involving multiple criteria. Its strength lies in the ability to address complexities related to benefits, costs, risks, and opportunities, prompting its wide application in various domains such as planning, resource allocation, conflict resolution, and forecasting (Akinshin, 2023). Hence, it was chosen in this study due to its adaptability, ease of use, and effectiveness in assessing both qualitative and quantitative factors. The development of the proposed risk-based cost estimation model involved the following systematic steps:

i. Defining the objectives of the model.
ii. Decomposing the risk factors into a hierarchical framework.
iii. Identifying and structuring criteria and sub-criteria relevant to the model within a hierarchical structure.
iv. Conducting pairwise comparisons of criteria and sub-criteria to establish their relative priority weights using Saaty's (Saaty & Kearns, 1985) 1–9 scale, as shown in Table 1.
v. Normalizing the pairwise comparison matrix and calculating the priority weights.
vi. Validating the consistency of judgments using the consistency index (CI), with values ≤0.10 deemed acceptable.
vii. Integrating the calculated weights with frequency and severity indices to estimate the cost of risk (CR).

To estimate the CR, the calculated weights were integrated with the Frequency Index (FI) and Severity Index (SI). This approach allows for a comprehensive evaluation of risk impact. The estimation process also incorporated measures of consistency to ensure reliability in the analysis. The CI was computed using Formula 8, while the Cost of Risk (CR) was then determined by the ratio of the CI to the Random Consistency Index (RCI), as shown in Eq. (9).

$$\mathrm{CI} = \frac{\lambda_{\mathrm{max}\,-\,\mathrm{n}}}{\mathrm{n} - 1} \tag{8}$$

$$CR = \frac{CI}{RCI} \tag{9}$$

where λ max represents the maximum eigenvalue of the pairwise comparison matrix, n is the number of criteria or the matrix dimension, CI is the consistency index, and RCI is the random consistency index. This adheres to the recommendation by Saaty & Kearns (1985), as shown in Table 2.

Table 1. Saaty's 1 to 9 scale of pairwise comparison

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
2	Weak or slight	Intermediate value.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
4	Moderate plus	Intermediate value.
5	Strong importance	Experience and judgment strongly favor one activity over another.
6	Strong plus	Intermediate value.
7	Very strong or demonstrated importance	One activity is strongly favored over another, with its dominance evident in practice.
8	Very, very strong	Intermediate value.
9	Extreme importance	Evidence strongly supports the dominance of one activity over another at the highest possible level.
Reciprocals of the above	Reverse comparison	If activity iii is given a certain value when compared to jjj, then jjj has the reciprocal value when compared to iii.
1.1 to 1.9	Close importance	Indicates slight differences between activities, but their relative importance can still be discerned.

Table 2. The RCI values for different matrix dimensions (n)

Matrix Dimension (n)	RCI
1	–
2	–
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

The CR must be less than or equal to 0.10 (CR ≤ 0.10CR) to ensure acceptable consistency in the judgments. If CR>0.10, the evaluations should be revisited and adjusted to improve their consistency. Using these principles, a risk-based cost estimation model was formulated based on Eq. 10.

$$CR = RW \times FI \times SI \tag{10}$$

where CR represents the Cost of Risk, a quantitative measure of the potential financial impact of a risk factor. RW denotes the Relative Weight of the factor or category, as determined through AHP, reflecting the factor's importance relative to others.

3.6 Sensitivity Analysis

A sensitivity analysis was conducted to evaluate the resilience and dependability of the proposed model. Pichery (2014) explains sensitivity analysis as a technique used to assess the extent to which uncertainties in one or more input variables affect the uncertainties in output variables. In this research, a sensitivity analysis was done to verify the reliability of the developed model. It investigated how changes in input parameters and foundational assumptions affected the model's results. By examining the influence of these variations, the process confirmed the model's practicality and suitability for addressing cost estimation risk factors in the context of the Palestinian construction sector.

4. Results and Discussion

4.1 Demographic Profile

Data were collected using self-administered questionnaires distributed to respondents across six distinct professional groups within the construction industry. Out of the 125 questionnaires distributed, 113 were completed and returned, resulting in an overall response rate of 90.3% (see Figure 2). Figure 3 presents the decomposition of risk factors within a hierarchical framework.

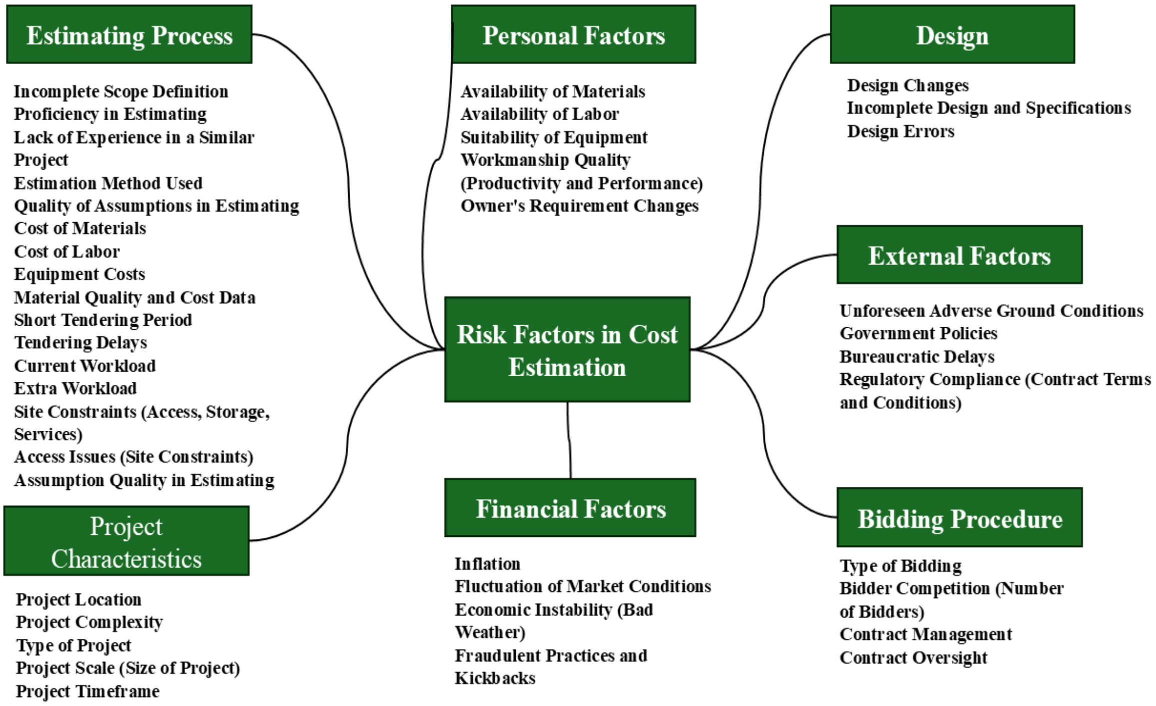

Figure 3. Key risk factors in construction cost estimation

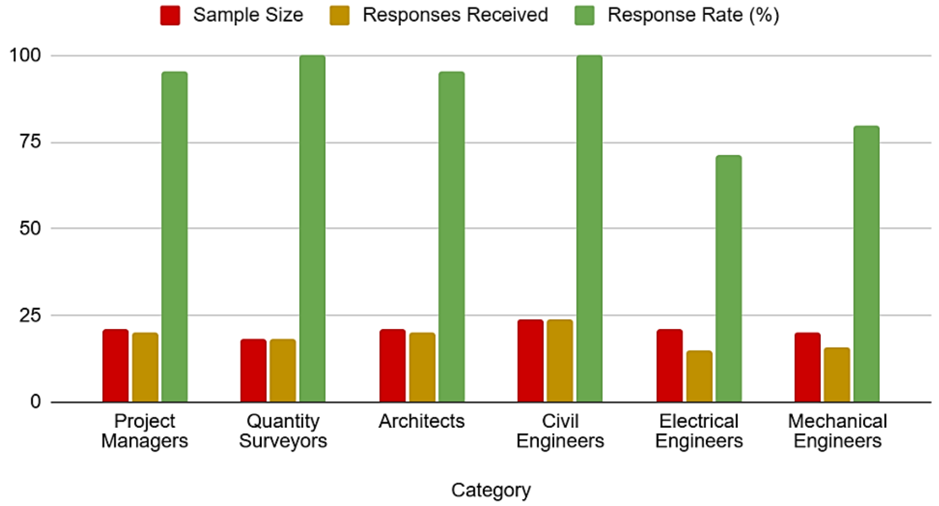

Figure 4. Comparison of sample size, responses received, and response rate (%) across professional categories

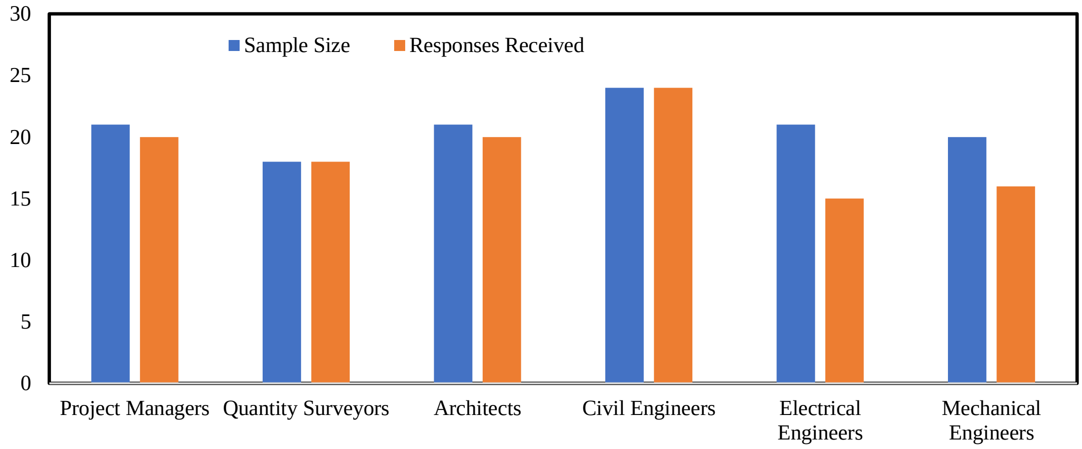

Figure 5. Sample size vs. responses received by professional categories

Figure 4 shows the response rates by category, with 100% for quantity surveyors and civil engineers, 95.2% for project managers and architects, 80% for mechanical engineers, and 71.4% for electrical engineers. The high participation levels across most professional groups underscore the strength and representativeness of the data. Meanwhile, Figure 5 summarizes the respondents' years of experience in the building construction industry. The majority of them had six or more years of professional experience (90.2%), ranging from 6 to 10 years (34.5%), 11 to 15 years (39.8%), and 16 years and above (15.9%). Finally, the cumulative percentage in Figure 6 demonstrates the substantial representation of experienced professionals in the sample.

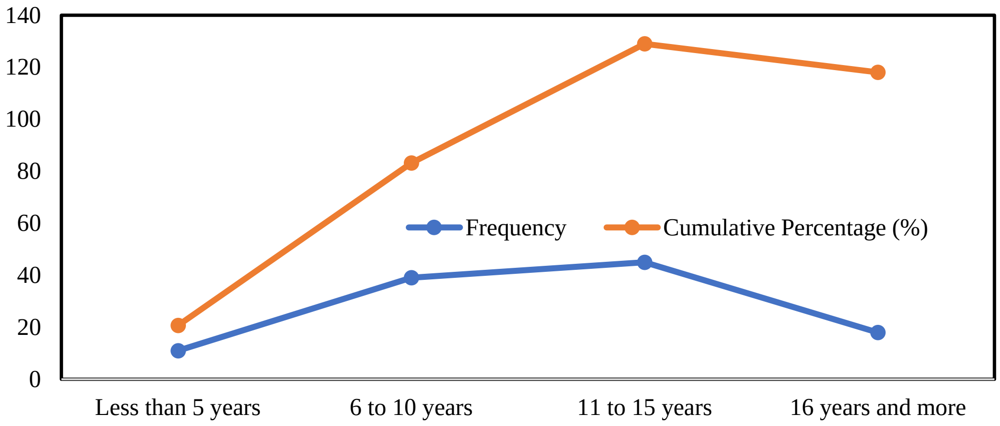

Figure 6. Experience levels by frequency and cumulative percentage

4.2 Risk Factors in Cost Estimation

4.2.1 Establishing risk factors in cost estimation

The nature of construction projects leads to considerable variability in potential risk factors, making it difficult to identify all risks comprehensively. Nonetheless, examining previous research (Riveros et al., 2022) offers a practical means of pinpointing critical risk factors. In this study, a thorough literature review was conducted to identify key risk factors in cost estimation, which formed the basis for designing the questionnaire. The questionnaire included a total of 39 risk factors, and respondents were invited to suggest additional factors based on their professional experience and expertise. Interestingly, no new risk factors were identified by the respondents, confirming that the 39 factors derived from the literature were comprehensive.

4.2.2 Evaluation of risk factor indices in cost estimation

This study analyzed the effects of various risk factors on cost estimation in the Palestinian construction industry by utilizing severity, frequency, and importance indices. These indices were carefully computed to rank the significance of each factor. The results in Table 3 provide a comprehensive breakdown of the indices, offering valuable insights for evaluating and understanding the impact of these risks. Table 3 highlights the critical factors influencing cost estimation in construction projects in Palestine. Project Location stands out with the highest IMPI% of 88.41%, signifying its prominent impact on cost estimation. Among the challenges tied to project location include logistics, transportation costs, and access to resources. Project managers can reduce the risk of cost overruns by addressing location-specific issues, such as optimizing delivery routes or choosing more accessible locations. Availability of Materials is ranked second with an IMPI% of 83.39%. The availability of materials is crucial for maintaining the project schedule and budget, with delays in procurement and fluctuations in material supply often resulting in higher costs. Therefore, building strong supplier relationships and implementing effective sourcing strategies can help mitigate the risk of material shortages and price increases. Fluctuation of Market Conditions is ranked third with an IMPI% of 83.11%. Market volatility, including price fluctuations and supply chain disruptions, is a key risk factor in construction cost estimation. This can be managed through strategies such as forward contracts or bulk purchasing to lock prices and reduce the financial impact of market changes.

The fourth factor is Cost of Materials, which recorded an IMPI% of 82.58%. Material prices directly contribute to the overall project expenses as it can fluctuate and influence the project budget. This can be addressed through early price locking, negotiating better deals with suppliers, and exploring alternative material sources to provide cost stability and reduce unexpected expenses. Government Policies, with an IMPI% of 80.83%, play a significant role in shaping the financial landscape of a construction project. Changes in construction regulations and taxes can disrupt project planning and budgets. Project teams must stay informed about policy shifts and adjust their strategies accordingly to avoid unexpected financial strain. Another critical factor is Unforeseen Adverse Ground Conditions with an IMPI% of 80.35%. Unexpected site conditions, such as poor soil quality or environmental challenges, can cause delays and additional costs. To mitigate these risks, comprehensive geotechnical studies should be conducted before the project begins to ensure early detection of potential issues. Another significant contributor to overall project expenses is Cost of Labor with an IMPI% of 78.31%. Labor costs are influenced by worker productivity, wage rates, and availability. Improving labor productivity through training, better work practices, and efficient workforce management can reduce the financial burden of labor costs. Finally, Inflation, with an IMPI% of 77.60%, is an economic factor that can escalate project costs. Inflation can increase material, labor, and operational costs throughout the project. Construction projects can better withstand the effects of rising costs by incorporating early budgeting strategies and contingency plans for inflation.

Table 3. Key risk factors in cost estimation with corresponding severity, frequency, and importance indices (%)

Risk Factors in Cost Estimation	SI%	FI%	IMPI%
Project Location	89.63	87.19	88.41
Availability of Materials	84.59	82.19	83.39
Fluctuation of Market Conditions	84.26	81.96	83.11
Cost of Materials	83.89	81.26	82.58
Government Policies	82.96	78.70	80.83
Unforeseen Adverse Ground Conditions	82.59	78.11	80.35
Cost of Labor	81.81	74.81	78.31
Inflation	81.67	73.52	77.60
Availability of Labor	78.70	71.52	75.11
Fraudulent Practices and Kickbacks	77.41	71.74	74.58
Design Changes	75.93	68.33	72.13
Incomplete Scope Definition	74.81	66.67	70.74
Incomplete Design and Specifications	74.63	63.70	69.17
Proficiency in Estimating	73.52	62.44	67.98
Lack of Experience in a Similar Project	73.52	62.44	67.98
Regulatory Compliance (Contract Terms and Conditions)	71.48	60.11	65.80
Estimation Method Used	70.93	58.19	64.56
Type of Bidding	70.93	58.19	64.56
Short Tendering Period	70.74	57.41	64.08
Project Complexity	70.74	55.52	63.13
Site Constraints (Access, Storage, Services)	69.44	55.52	62.48
Current Workload	69.26	54.12	61.69
Extra Workload	68.33	54.12	61.23
Equipment Costs	67.78	50.23	59.01
Suitability of Equipment	64.07	48.76	56.42
Workmanship Quality (Productivity and Performance)	63.89	46.67	55.28
Project Timeframe	62.59	45.25	53.92
Economic Instability (Bad Weather)	61.30	44.52	52.91
Owner's Requirement Changes	60.00	43.11	51.56
Material Quality and Cost Data	60.00	43.59	51.80
Access Issues (Site Constraints)	59.22	42.48	50.85
Contract Management	54.81	40.22	47.52
Bidder Competition (Number of Bidders)	51.67	38.67	45.17
Project Scale (Size of Project)	50.19	36.44	43.32
Assumption Quality in Estimating	46.67	34.12	40.40
Tendering Delays	43.52	30.10	36.81
Design Errors	40.00	30.40	35.20
Bureaucratic Delays	35.00	28.45	31.73
Contract Oversight	30.00	25.32	27.66

4.2.3 Model development

The model was designed using the 15 most critical risk factors influencing cost estimation in the building construction sector, with a particular focus on the Palestinian context. These factors were identified through an in-depth analysis of region-specific challenges, such as geopolitical uncertainties, limited resources, and unique socioeconomic conditions. By concentrating on these key risks, the model is tailored to meet the distinct requirements of construction professionals in Palestine and improve the accuracy and dependability of cost estimation practices. This localized approach ensures the model's relevance and effectiveness in mitigating risks and enhancing project performance.

4.2.4 Determining priority and relative weights of criteria and sub-criteria

The priority and relative weights of each criterion and sub-criterion are detailed in Table 4, providing insights into their significance and influence within the model. Priority weights indicate the overall importance of each criterion, while relative weights demonstrate the contribution of each sub-criterion within its specific category. These calculations ensure a balanced representation of factors in the analysis.

Table 4. Priority and relative weights of risk evaluation criteria and sub-criteria

Criteria	Weight	Risk Factor	Risk Factor Weight	Relative Weight (Wr)
Cost estimation	0.15	Project Location	0.50	0.0750
	0.15	Availability of Materials	0.45	0.0675
	0.15	Fluctuation of Market Conditions	0.60	0.0900
	0.15	Cost of Materials	0.40	0.0600
	0.15	Government Policies	0.35	0.0525
Project duration	0.09	Unforeseen Adverse Ground Conditions	0.50	0.0450
	0.09	Cost of Labor	0.55	0.0495
	0.09	Inflation	0.50	0.0450
Risk factors	0.07	Availability of Labor	0.60	0.0420
	0.07	Fraudulent Practices and Kickbacks	0.50	0.0350
	0.06	Design Changes	0.45	0.0270
	0.06	Incomplete Scope Definition	0.50	0.0300
	0.05	Incomplete Design and Specifications	0.45	0.0225
	0.05	Proficiency in Estimating	0.50	0.0250
	0.04	Lack of Experience in a Similar Project	0.40	0.0160

4.2.5 Cost of risk

The CR for the highest-priority factors was calculated using the assigned values of relative weight, FI, and SI for each factor. Table 5 presents these calculations, offering a detailed representation of the financial impact of the identified critical risks. The total cost of risk for the assessed sub-criteria accounts for approximately 39.96% of the overall project cost, with the average cost of risk per sub-criterion estimated at around 2.66% of the project cost.

Table 5. Risk factors in cost estimation and their weights, FI, SI, and CR

Risk Factor	Wr	FI (%)	SI (%)	CR
Project Location	0.1000	87.19	89.63	0.078148
Availability of Materials	0.0600	78.70	82.96	0.039174
Fluctuation of Market Conditions	0.0400	55.52	69.44	0.015421
Cost of Materials	0.0900	82.19	84.59	0.062572
Government Policies	0.0375	54.12	68.33	0.013868
Unforeseen Adverse Ground Conditions	0.0225	43.59	60.00	0.005885
Cost of Labor	0.0750	81.96	84.26	0.051795
Inflation	0.0450	73.52	81.67	0.027020
Availability of Labor	0.0300	44.52	61.30	0.008187
Fraudulent Practices and Kickbacks	0.0400	60.11	71.48	0.017187
Design Changes	0.0350	42.48	59.22	0.008805
Incomplete Scope Definition	0.0250	38.67	51.67	0.004995
Incomplete Design and Specifications	0.0750	71.52	78.70	0.042215
Proficiency in Estimating	0.0450	50.23	67.78	0.015321
Lack of Experience in a Similar Project	0.0300	46.67	63.89	0.008945

Table 6. Factors affecting construction risk costs with cost percentage, cumulative cost percentage, and rank

Risk Factor	CR	Cost %	Cumulative Cost %	Rank
Project Location	0.078148	19.55977	19.55977	1
Cost of Materials	0.062572	15.66117	48.88551	2
Cost of Labor	0.051795	12.96368	66.79297	3
Incomplete Design and Specifications	0.042215	10.56591	93.92649	4
Availability of Materials	0.039174	9.804791	29.36456	5
Inflation	0.027020	6.762763	73.55573	6
Fraudulent Practices and Kickbacks	0.017187	4.301648	79.90656	7
Fluctuation of Market Conditions	0.015421	3.859782	33.22434	8
Proficiency in Estimating	0.015321	3.834607	97.7611	9
Government Policies	0.013868	3.470916	52.35642	10
Lack of Experience in a Similar Project	0.008945	2.238904	100	11

Table 6 presents the factors affecting construction risk costs, highlighting their respective cost percentages, cumulative cost percentages, and rankings based on their impact. Project Location is the most significant factor and contributes 19.56% to the total cost of risk, followed by Cost of Materials at 15.66% and Cost of Labor at 12.96%. Together, these three factors account for 66.79% of the total risk cost, underscoring their critical influence on construction projects. Other notable factors include Incomplete Design and Specifications (10.57%), Availability of Materials (9.80%), and Inflation (6.76%), which further contribute to the cumulative risk cost. Less significant but still impactful factors include Fraudulent Practices and Kickbacks (4.30%), Fluctuation of Market Conditions (3.86%), and Proficiency in Estimating (3.83%). Government Policies (3.47%) and Lack of Experience in Similar Projects (2.24%) round out the list, with the latter being the least impactful among the identified risk factors.

4.2.6 Monte Carlo simulation

A Monte Carlo simulation with 10,000 iterations was conducted to evaluate the uncertainty and variability in construction cost estimation. This simulation generated a probabilistic distribution of total cost risk, offering insights into the range of possible cost variations. By leveraging repeated random sampling, the analysis quantifies the impact of key risk factors identified through the SI, FI, and IMPI. This approach enhances the reliability of risk-based cost estimation by accounting for potential fluctuations in project costs, allowing for more informed financial decision-making. Figure 7 illustrates the probability distribution function of total cost risk, represented by a histogram with a kernel density estimate curve. The distribution follows a near-normal pattern with slight right skewness, indicating that while most cost estimates cluster around a central value, there is a possibility of higher-than-expected cost risks. The median total cost risk was approximately 850%, with the 10th percentile at 820% and the 90th percentile at 880%. These percentiles help in understanding cost variability and assessing risk exposure. The shape of the distribution indicates that the most probable total cost risk falls between 820% and 880%, covering most simulated outcomes. The peak of the probability curve suggests that cost estimates around the median value are the most frequently occurring. However, the right tail of the distribution implies a possibility of extreme cost overruns, highlighting the need for proactive risk mitigation strategies. These findings emphasize the importance of implementing robust cost management techniques to ensure financial stability in construction projects.

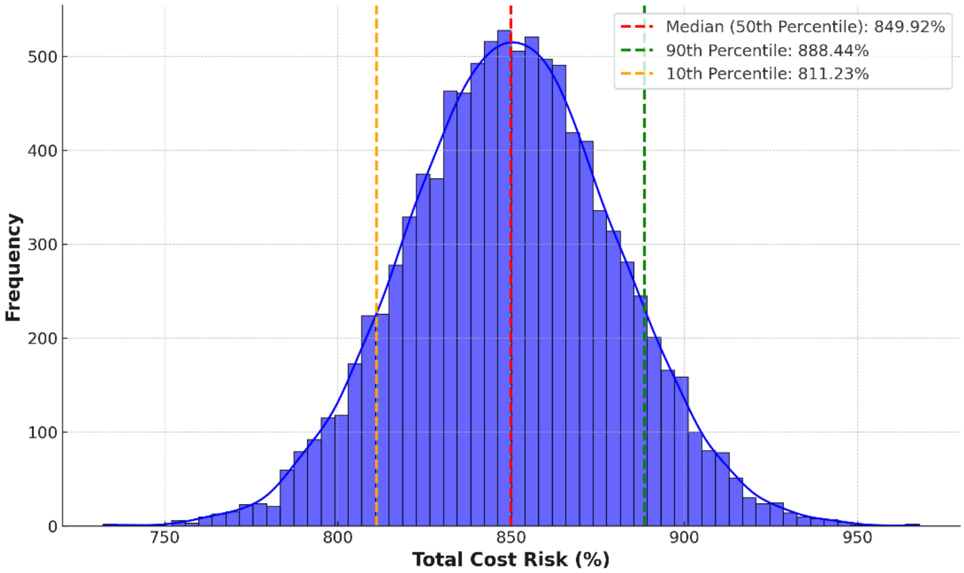

Figure 7. Probability distribution of Monte Carlo simulation for cost risk

Figure 8 presents the cumulative distribution function (CDF) of total cost risk, which depicts the probability that cost risk remains below a given threshold. The S-shaped curve represents a gradual increase in cumulative probability, with the steepest section indicating the range where most values fall. This visualization is essential for understanding cost risk exposure and establishing financial safeguards. CDF enables a percentile-based risk assessment, allowing construction managers to estimate the likelihood of different cost risk scenarios. The 50th percentile (median) cost risk is approximately 850%, indicating the most probable scenario. Meanwhile, the 90th percentile threshold suggests a 10% probability of exceeding 880%, suggesting that cost risk surpasses this critical threshold in 10% of simulated cases. The 10th percentile (820%) represents the best-case scenario with the lowest cost risks. These insights are crucial for setting contingency reserves and ensuring financial preparedness for worst-case scenarios, particularly in high-risk construction environments. By incorporating Monte Carlo simulations into cost estimation models, project managers can develop data-driven strategies to mitigate financial uncertainties and enhance decision-making in construction projects.

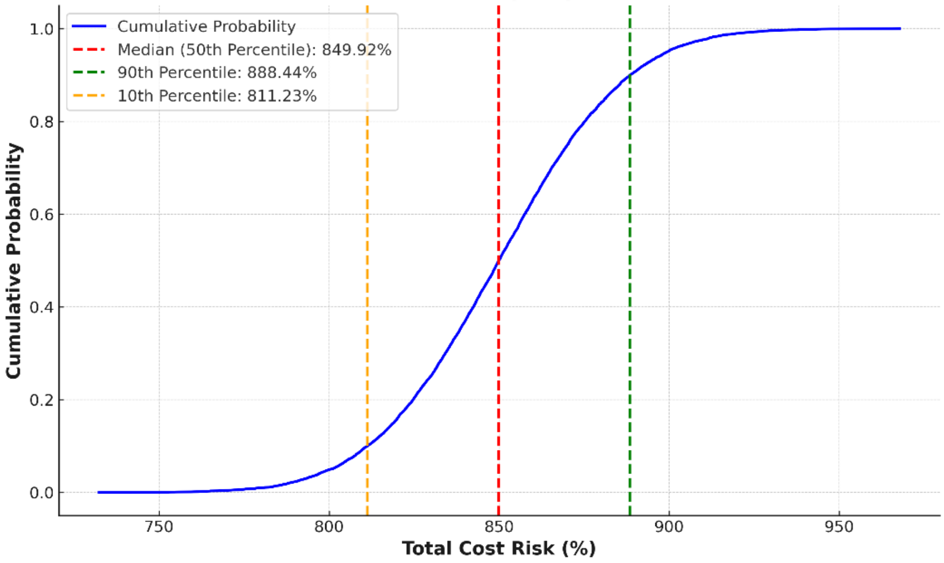

Figure 8. Cumulative distribution of Monte Carlo simulation for cost risk

4.2.7 Model verification

Sensitivity analysis was conducted by following the approach outlined by Salciccioli et al. (2016) to evaluate how changes in input parameters affect the model's outputs (Figure 9). This technique is essential for quantifying uncertainty, assessing model accuracy, and understanding parameter sensitivity. In this study, Microsoft Excel was employed to perform sensitivity analysis, ensuring a detailed examination of the developed model’s robustness and reliability. The analysis identified Project Location, Cost of Materials, and Cost of Labor as the most influential factors, demonstrating the largest sensitivities on project costs. Conversely, factors such as Incomplete Scope Definition, Unforeseen Adverse Ground Conditions, and Design Changes had comparatively lower sensitivities, indicating a lesser impact on cost fluctuations. The results confirmed that while changes in input values lead to observable variations in model outputs, these variations are relatively minor, indicating the model's robustness and consistency.

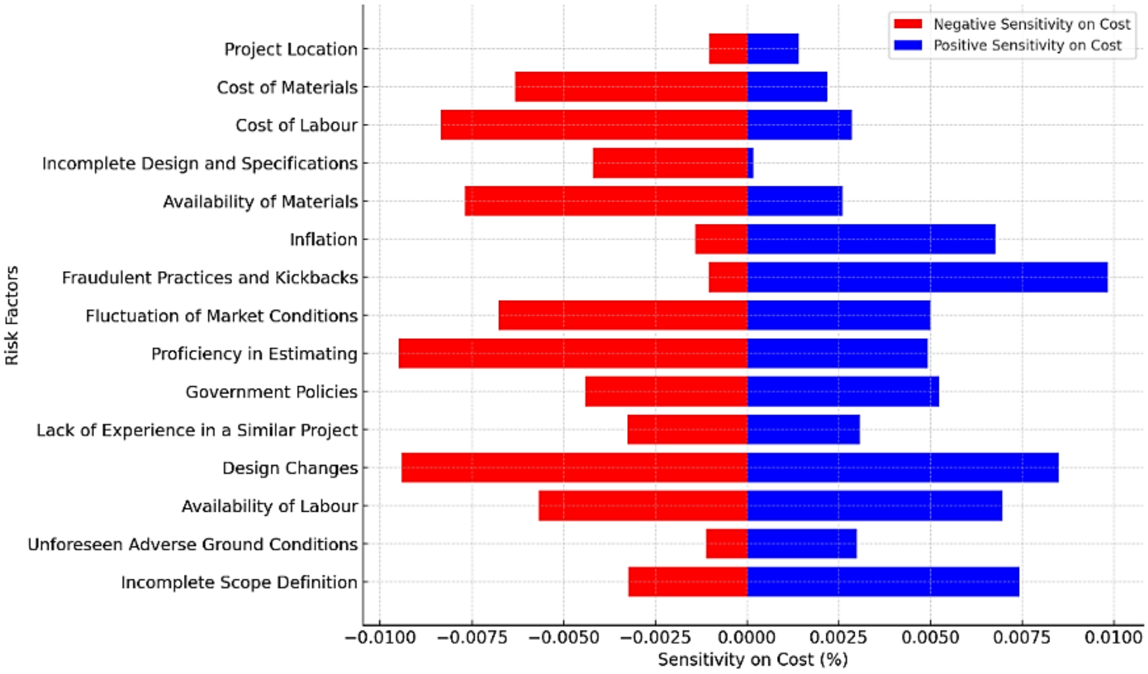

Figure 9. The sensitivity analysis of the model

4.3 Discussion

This study provides a detailed analysis of the critical risk factors influencing cost estimation in construction projects within the Palestinian context. The findings highlight the challenges faced by the construction industry and offer actionable insights for mitigating cost-related risks to improve project outcomes. The research achieved a high response rate of 90.3%, with data collected from six professional categories. This strong participation underscores the relevance of the research and the willingness of industry professionals to address cost estimation challenges. The diverse range of respondents ensures a comprehensive representation of the construction industry, while the high level of professional experience—90.2% of respondents having six or more years of experience in the field—further strengthens the reliability of the findings. The study identified 39 critical risk factors and no additional factors were suggested by the respondents, indicating the comprehensiveness of the initial list. The significance of each factor was quantified using severity, frequency, and importance indices. The results identified Project Location, Availability of Materials, and Fluctuation of Market Conditions as the most influential risk factors, contributing to 88.41%, 83.39%, and 83.11% of the IMPI, respectively. These findings align with industry trends, emphasizing the need to address logistical challenges, stabilize material supply chains, and manage market volatility to mitigate their impact on cost estimation.

The CI analysis revealed that the top five risk factors accounted for 68.56% of the total cost of risk, with Project Location, Cost of Materials, and Cost of Labor identified as the most critical contributors, representing 19.56%, 15.66%, and 12.96% of the total cost of risk, respectively. This distribution highlights the concentrated impact of several significant factors and the importance of targeted risk management strategies. The total cost of risk for all assessed factors represents approximately 39.96% of the total project cost, demonstrating the substantial financial implications of risk factors in construction projects. Monte Carlo simulation results further substantiate these findings, demonstrating that cost risks follow a near-normal distribution with a slight right skew. The presence of this skew suggests that while most cost risks are clustered around the median, there is a higher likelihood of extreme cost overruns compared to cost savings. This indicates that construction projects in Palestine are more prone to cost escalations rather than reductions, reinforcing the need for robust risk mitigation strategies. The median cost risk of approximately 850%, with a 90% confidence interval ranging from 820% to 880%, provides a realistic expectation of cost variations. While this range encompasses most cost risk scenarios, the potential for exceeding 880% remains a notable concern. In high-risk construction environments, such deviations can result in significant budget overruns, financial instability, and project delays. This study highlights that without adequate risk assessment and financial safeguards, stakeholders may struggle to manage unforeseen expenses, leading to disruptions in project execution.

The CDF further illustrates the likelihood of exceeding different cost thresholds, providing valuable insights for decision-makers. This function enables project managers to quantify the probability of exceeding certain cost limits, allowing them to adjust contingency budgets accordingly. For instance, if the probability of surpassing 880% is significant, it implies that a larger contingency reserve should be allocated to accommodate unexpected cost variations. On the other hand, if the probability of staying below 820% is high, decision-makers may consider reallocating financial resources to optimize efficiency. Sensitivity analysis further validated the robustness and reliability of the developed model by assessing how variations in input parameters influenced overall cost estimation outcomes. The results confirmed that the model remained stable and consistent, as changes in key variables only caused minor fluctuations in the output, demonstrating its suitability for practical applications in real-world construction projects. This stability is particularly crucial in the Palestinian construction sector, where project cost estimation is often complicated by economic instability, material price fluctuations, and labor market uncertainties. The analysis identified Project Location, Cost of Materials, and "Cost of Labor" as the most influential factors, exhibiting the highest sensitivities in the model. This means that even small changes in these variables can significantly impact overall project costs, reinforcing their critical role in risk-based cost estimation. Project location has a significant influence due to logistical constraints, transportation costs, and accessibility challenges. Material costs also emerge as a dominant cost driver, which are often subject to market price volatility and supply chain disruptions. Labor costs further contribute to cost variations as it can be affected by availability and skill level. The findings suggest that prioritizing risk mitigation strategies for these factors—such as securing fixed-price contracts for materials, improving supply chain resilience, and optimizing labor management—can substantially reduce cost uncertainties.

Conversely, factors such as Incomplete Scope Definition and Design Changes exhibited lower sensitivity, indicating that while they contribute to cost variations, their overall impact is comparatively smaller. This suggests that minor fluctuations in project scope or design modifications do not drastically alter the cost structure, provided that effective project controls are in place. However, while their immediate impact on cost estimation is relatively low, cumulative effects may lead to inefficiencies, rework, and prolonged project durations if left unaddressed. These findings highlight the importance of prioritizing high-impact risk factors in cost estimation while maintaining a balanced approach to managing lower-impact risks. They also reinforce the necessity of continuous monitoring and adaptive risk management strategies to accommodate dynamic changes in construction projects. By integrating sensitivity analysis into decision-making frameworks, project managers can enhance financial planning, allocate contingency funds more effectively, and optimize resource utilization. Future studies could explore advanced statistical techniques, such as machine learning-based sensitivity analysis or probabilistic modeling, to further refine cost risk assessments, enabling more data-driven decision-making and reducing uncertainties in large-scale construction projects.

5. Conclusions

This study presents a comprehensive risk-based cost estimation model tailored to the Palestinian construction industry by addressing the unique challenges posed by geopolitical instability, resource limitations, and market volatility. It identifies and prioritizes key risk factors affecting cost estimation in construction projects through a combination of qualitative and quantitative methodologies, including surveys, focus group discussions, Monte Carlo simulations, and sensitivity analyses. The findings highlight that Project Location, Cost of Materials, and Cost of Labor are the most influential risk factors, collectively accounting for a substantial portion of cost overruns. The analysis further confirms that geopolitical constraints, supply chain disruptions, and economic fluctuations significantly impact cost estimations. The Monte Carlo simulation results reinforce the probabilistic nature of cost risks, emphasizing the necessity of incorporating uncertainty management strategies into construction planning.

The developed risk-based cost estimation model integrates the AHP and probabilistic techniques to offer a structured and data-driven approach in quantifying and mitigating cost uncertainties. Sensitivity analysis validates the robustness of the model, demonstrating that while external risks exert significant influence, structured risk mitigation strategies can enhance cost estimation accuracy and improve project outcomes. This research underscores the importance of proactive risk management, urging construction professionals in Palestine to adopt advanced quantitative methods for cost estimation. By leveraging Monte Carlo simulations, AHP-based prioritization, and statistical modeling, project managers can improve financial planning, reduce cost overruns, and enhance the resilience of the construction sector. Future studies should explore integrating machine learning and artificial intelligence into risk-based cost estimation to further refine predictive accuracy and adaptability to evolving industry conditions. Ultimately, insights from this study provide practical recommendations for construction stakeholders, emphasizing the need for improved project planning, stakeholder collaboration, and the adoption of technology-driven risk management frameworks. These strategies are essential for ensuring sustainable growth and financial stability in Palestine's construction industry.

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The authors declare no conflicts of interest.

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Sameh Fuqaha (Formal analysis; Project administration; Writing - original draft)
Ibrahim Farah (Conceptualisation, Formal analysis)
Muhammad Heri Zulfiar (Resources; Methodology)

Availability of Data and Materials

The data collected for this research can be made available upon request and will be shared in accordance with applicable data protection and privacy regulations.

Ethics Declarations

This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations

The authors claim that artificially intelligent-assisted technologies in the form of generative AI were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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