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Developing A Risk Assessment Framework for High-rise Building Projects in Islamabad

by

Abdul Wadood

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Abstract

The high rate of urbanization of Islamabad has seen the sudden rise of high-rise building projects, which is a highly complex industry with a host of increased risks, such as structural failures, extreme safety risks, cost overruns, and chronic delays. The prevailing risk management procedures within the area, though, are not in the format of a standardized and locally customized structure but are rather a reliance on ad hoc procedures and crude checklists that cannot handle such complex projects. This study fills this gap of critical concern by coming up with a new and practical risk assessment framework that is tailor specific to the context of Islamabad. Its major innovation is the localized identification and empirical validation of major risk factors, along with powerful tools of multi-criteria decision making, namely the Relative Importance Index (RII), Analytical Hierarchy Process (AHP), and Fuzzy Comprehensive Evaluation (FCE) as one coherent, implementable model to industry practitioners. Applying a sequential mixed methodology, the research commenced with a broad literature review and Delphi panels of experts to pinpoint and confirm 35 major risk factors in four domains, namely Safety and On-Site, Pre-Construction and Financial, Project Management, and External and Operational. The quantitative data was then obtained using structured questionnaires from 121 industry professionals, and the response rate was high at 73.33. Assessment based on RII, AHP, and FCE showed that the risk of falls is the primary problem, with height falls (RII=0.912) and PPE non-adherence being the most significant issues, and client-induced changes to design and financial postponements coming in second and third, respectively. The AHP weighting verified that the most dominant risk categories was Safety (38) and Pre-Construction (29.2), and the total risk in the project was evaluated to be high (FCE score: 7.62/10). The main finding of this study is a three-level, progressive Risk Assessment Framework. It is a practical tool that includes a Risk Identification Matrix, a visual risk mapping Evaluation Dashboard, and a Priority Action Plan that can be used to implement specific mitigation. The framework, which is intended to be used directly by the project managers, contractors, and consultants, offers an actionable roadmap that enables them take the initiative in risk management. It

is expected that its effect will be an increase in on-site safety, predictability of the project, cost and schedule control, and, ultimately, safer and more sustainable urban development in Islamabad. This study provides a tested, scalable model that can be applied to other high-risk construction environments in developing regions by filling the important gap between theory and practice in risk models and the field.

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List of Abbreviations

AHP	Analytical Hierarchy Process
BIM	Building Information Modeling
CDA	Capital Development Authority
CI	Consistency Index
CR	Consistency Ratio
FCE	Fuzzy Comprehensive Evaluation
FMEA	Failure Mode and Effects Analysis
GDP	Gross Domestic Product
HEC	Higher Education Commission
IBC	International Building Code
ILO	International Labor Organization
IoT	Internet of Things
KRI	Key Risk Indicators
MCDM	Multi-Criteria Decision Making
MS	Master of Science
PBUH	Peace Be Upon Him
PPE	Personal Protective Equipment
RAM	Responsibility Assignment Matrix
RI	Random Index
RII	Relative Importance Index
RPN	Risk Priority Numbers

SPSS	Statistical Package for the Social Sciences

Chapter 1

Introduction

1.1 Background

The construction industry is a very important sector of the economy, which boosts growth and provides employment. The high-rise building projects have drastically risen due to rapid urbanization. Such high-rise buildings serve to contain the increased population, although with a lot of problems [1]. The construction of high-rise buildings is tricky and hazardous. Problems such as structural failures, budgetary problems, delays, and safety risks are widespread. The projects require thorough preparation and execution to be successful [2]. One of the major processes in construction management is risk assessment. It entails identifying possible issues, determining their probability of occurrence, and making decisions on how to address them. Others are quite straightforward, such as with checklists or opinions of experts. There are more advanced ones, such as computer simulations [3]. Projects lack a risk framework and thus end up having some surprises. The result of this may be cost overruns where the project consumes more money than it was intended to consume. Delays are also possible, and it touches upon everyone. Workers and future residents may become threatened because of safety violations [4, 5]. The primary objective of the study is to constitute a straightforward and feasible risk assessment framework, particularly on high-rise projects in Islamabad. This framework will assist the project managers and engineers to plan more efficiently, prevent issues, and finish the projects safely and on time.

Through the enhancement of the management of the risks, this study will assist in the construction of high-rise complexes in Islamabad that have been growing with safer and more efficient constructions.

1.2 Research Motivation

The city of Islamabad is rapidly expanding, and the number of high-rise buildings is increasing. Such tall buildings are more complicated and dangerous compared to ordinary buildings. They also encounter issues such as structural problems, project overruns, project delays, and safety concerns. Even though the topic of construction risks has been researched in other nations, little has been done on the high-rise projects in Islamabad. The existing risk management practices here do not tend to be coherent and well-structured. The research is significant as it will contribute to the success of high-rise construction in Islamabad and make it safer. Having a basic and efficient risk assessment model, the project managers and engineers can identify problems and manage them before they become critical. This is able to minimize delays, cost management, and enhance safety at the site. The research will facilitate the planning process of the project and help Islamabad develop in a safer and more sustainable manner.

1.3 Problem Statement

Structural failure, exceeding the budget, excessive time wastage, and accidents are some of the common issues in high-rise projects. These issues occur due to the fact that high-rise projects are complex, require robust engineering, excellent coordination, and rigid rules of safety [5]. The construction companies of other countries adopt structured risk assessment methods to deal with such issues. However, in Islamabad, no standard or locally appropriate framework is used to determine risks associated with high-rise projects. The majority of businesses use experience or simple checklists that cannot suit such a complex project. The result of this is poor planning, unforeseen issues, and failure. Thus, the study will attempt to

address this gap. It will recognize the key risks in the high-rise construction in Islamabad, evaluate them, and develop a risk assessment framework with a series of steps that are simple to follow by local professionals. This framework will enable making projects more predictable, on time, and within budget, which will result in improved and safer urban development in Islamabad.

1.4 Research Objectives

The purpose of the research is to come up with a useful risk assessment model that will enhance the prevalence of high-rise projects in Islamabad due to proactive management of possible risks. The following are the thesis objectives to attain this purpose:-

i. To identify and categorize critical risks specific to high-rise construction in Islamabad through a systematic literature review and Delphi expert panels.

ii. To analyze and prioritize these risks using a novel integration of Relative Importance Index (RII), Analytical Hierarchy Process (AHP), and Fuzzy Comprehensive Evaluation (FCE) an approach not previously applied to Islamabad's high-rise sector.

iii. To propose a three tier, implementable risk assessment framework that combines a risk matrix, evaluation dashboard, and priority action plan adding practical novelty over existing generic checklists.

1.5 Scope of Work

This study dwells on high-rise projects in Islamabad. The assessment of the risks and formulation of the framework will be conducted using survey/questionnaire forms. The restrictions raise access to proprietary project data. In order to manage time constraints, online surveys are used as a primary source of data collection, and secondary data will be collected in the form of a literature review. For this research, a high-rise building follows the definition given by the International Building Code

(IBC) and the local Capital Development Authority (CDA). According to these guidelines, any building with a height of 23 meters (75 feet) or more, usually around seven stories or above is considered a high-rise building.

1.6 Brief Methodology

This study employs a mixed-methods approach, combining a literature review with a targeted survey. Genuine stakeholders from the Giga Gold and Optima Tower projects were formally approached in writing, advised of the research questions, and invited to participate. They were specifically requested to provide detailed information on the problems they encountered. The collected data will undergo both qualitative and quantitative analysis to ensure a comprehensive understanding of the project challenges.

1.7 Research Significance

This research project is beneficial to the construction engineering management study because it offers empirical data regarding the role of risk assessment in high-rise construction projects. The results can be used by policy makers and industry players in order to make the project risk assessment practice more refined in the development of high-rise infrastructures.

1.8 Thesis Structure

This thesis is structured into five chapters to ensure a logical flow from problem identification to framework development.

Chapter 1: Introduces the research background, problem, objectives, and methodology.

Chapter 2: Reviews existing literature on high-rise construction risks and assessment methods.

Chapter 3: Details the mixed-methods research design, data collection, and analytical tools used.

Chapter 4: Presents the empirical results, data analysis, and the developed risk assessment framework.

Chapter 5: Concludes with findings, recommendations, and future research directions.

Chapter 2

Literature Review

This chapter presents a systematic literature review on risk management in high-rise construction, focusing on risk identification, assessment, and mitigation. It begins by establishing the inherently risky nature of such projects, supported by global safety statistics. The review then categorizes risks into six key domains safety, design, management, financial, external, and operational before tracing the evolution of assessment methodologies from qualitative to advanced analytical models. Mitigation strategies are grouped into proactive, active control, and collaborative approaches. The chapter concludes by identifying a specific research gap, summarizing key insights, and laying the foundation for the subsequent methodology section.

2.1 High-Rise Construction: An Inherently Risky Endeavor

High-rise building construction stands as one of the most complex and perilous domains within the construction industry. These projects are distinguished by their extended durations, intricate structural designs, significant capital investments, and dynamic multi-layered worksite environments. This inherent complexity, combined with the involvement of numerous stakeholders and heavy machinery, creates

a fertile ground for diverse and severe risks that can jeopardize project success, safety, and financial viability.

2.1.1 Unique Complexities and Challenges

High-rise construction is one of the most intricate and complicated areas of the construction business, with its multidimensional technical, managerial, and safety implications, which render it a fundamentally different construction project as compared to traditional building projects [5]. High-rise construction is inherently complex and risky, driven by a network of interdependent stakeholders, intricate engineering demands, and unique operational challenges. This complexity stems from interrelated factors, primarily the vertical nature of the structures. Their height imposes significant gravity and wind loads, necessitating advanced engineering solutions and specialized construction methodologies [6]. The factor of height alone poses a logistical problem in terms of material transportation, placement of equipment, and accessibility of workers, which are not felt in the construction projects of low-rise. These problems are exacerbated by the fact that special machinery like tower cranes, as well as high-capacity elevators and high-tech scaffolding systems, all with their own risk profiles, are required. Moreover, the character of high-rise construction projects is a long construction time that may span several years, in which the construction site is constantly being transformed [7]. Time transforms risk into a dynamic challenge, as evolving work environments require adaptable risk management strategies. Extended timelines also increase exposure to external factors such as weather, regulations, and market shifts which can critically impact project success. Furthermore, high-rise construction involves complex multi-disciplinary coordination among architects, engineers, contractors, and specialists, adding layers of organizational risk [8].

2.1.2 Global Safety Concerns and Accident Statistics

The safety history of the global construction sector presents worrying figures that reiterate the risks involved in construction work, especially in high-rise construction projects. Construction has always been one of the most hazardous industrial

sectors in the entire world; a large percentage of deaths and injuries at the workplace is reported compared to its number of employees [5]. The international statistics show that construction contributes 30-40 percent of all industries regarding fatal injuries, even though the proportion of the workforce is much lower. The United States Bureau of Labor Statistics records that construction represents the second-highest killer of workplace accidents, with 19.5% of all such accidents. The most notable safety issue during the construction process is falls caused by height, especially in high-rise buildings [6].

According to the statistical analysis, falls from height account for 48 percent of serious injuries and 30 percent of construction fatalities [9]. The construction accidents not only have an immense economic cost, but also far exceed the immediate human cost. According to the estimates published by the International Labor Organization, accidents and diseases in the workplace area significant economic burdens of the national GDP in the form of about 4 percent on average [10]. Another major type of construction deaths is electrical accidents. Contact with electricity or electrical discharges in the UK was the cause of 11 deaths between 2019 to 2023, which is 23.9 percent of electrical deaths in all industries [5]. These safety concerns have been exacerbated by the global trend of urbanization and the subsequent rise in high rise building. With the increased population density in cities and a decreased availability of land, high-rise buildings have become a more popular type of construction, especially in developing nations that have been experiencing rapid economic growth [10].

2.2 Systematic Classification of High-Rise Construction Risks

2.2.1 Safety and Occupational Hazards

Safety and occupational hazards represent the most immediate and critical category of risk in high-rise construction. The potential consequences of these hazards are severe and far-reaching, extending beyond immediate project delays [10]. They

primarily encompass catastrophic human costs, including worker and public fatalities, life-altering injuries, and permanent disabilities. Furthermore, such incidents trigger major project disruptions through work stoppages, legal liabilities, and reputational damage, which can ultimately jeopardize the project's overall viability and success [11].

2.2.1.1 Falls from Height as Predominant Risk

High-rise construction falls are the most important safety hazard in high-rise construction, and have historically become the number one cause of construction deaths and serious injuries worldwide. The problem of height-related falls in high-rise construction is complex, involving multiple situations and factors to be taken into account and addressed holistically [7].

2.2.1.2 Equipment-related Hazards

These hazards are related to equipment used in the construction of high-rise buildings; a large number of hazards are related to the special machinery and equipment that are used in vertical construction [11]. The tower cranes that are considered important in high-rise constructions are a major source of risks in equipment. Operational, technical, poor maintenance, operator error or environmental problems such as high winds can cause crane accidents [12].

2.2.1.3 Structural Collapse Risks

The risk of structural collapse of high-rise construction involves a number of types of possible failures with disastrous consequences. The collapse of foundation pits is a major hazard when high-rise construction is in the initial stages, especially in urban areas where excavations have to be done in proximity to the existing structures [7]. Another significant kind of risk of structural collapse is scaffolding collapse. The scaffolding systems involved in the high-rise construction are highly complicated when compared to those involved in the low-rise construction, most of them reaching a very high height, and necessitating advanced engineering in order

to be stable. Formwork collapses are a particularly hazardous form of high-rise construction structural collapses [13].

2.2.2 Design and Client-Related Risks

Design and client risks are a major group of threats to high-rise construction projects, which may occur at the start of the project lifecycle but have widely extending effects during the construction process. According to research, design-related risks are some of the most important risks in high-rise construction projects that are often rated as being in the same category as management-related risks in terms of their importance in the project outcomes [14].

2.2.2.1 Client-Initiated Design Changes

Client-driven alterations in design can be ranked as one of the most disruptive types of design-driven risks of high-rise construction projects. Such changes may happen at any project life cycle stage, starting with the project design development and ending with the construction, but they are more devastating when they happen later in the process [15]. The client-driven design changes that happen in high-rise projects are sometimes financially costly and may cause massive cost increases and schedule slippage. High-rise construction also has an interconnected nature of building systems, which implies that modifications in one of the systems often lead to changes in other systems, magnifying the effect of cost and schedule [16]. The client-driven design changes that happen in high-rise projects are sometimes financially costly and may cause massive cost increases and schedule slippage. High-rise construction also has an interconnected nature of building systems, which implies that modifications in one of the systems often lead to changes in other systems, magnifying the effect of cost and schedule [17].

2.2.3 Management and Coordination Risks

Management and coordination risks can be considered a serious type of threat to high-rise construction projects, which involve the organizational, procedural, and

communication difficulties in the multi-stakeholder environment that is complex in such projects. The factors of management in construction projects are always cited as playing a significant role in risk occurrence in construction projects, and some researchers note that the highest level of significance of management factors is the cause of incident occurrence [7].

2.2.3.1 Poor Contract Management

In high-rise construction projects, contract management entails the organization of several contracts with different parties, such as general contractors, special subcontractors, suppliers, and consultants. Common bad contract management practices may be in the form of inadequate contract documentation, lack of scope definition, poor risk allocation, and poor performance monitoring system [18].

2.2.3.2 Inefficient Management Coordination

The high-rise construction comes with the verticality that necessitates complicated coordination issues that demand advanced management strategies. Project management methods that have been used in traditional construction projects, which were developed to handle horizontal construction, might not be suitable in the three dimensions of high-rise construction projects. The coordination may be inefficient, leading to conflicts of resources, time, and risks [19].

2.2.3.3 Communication Breakdowns

The high-rise construction comes with the verticality that necessitates complicated coordination issues that demand advanced management strategies. Project management methods that have been used in traditional construction projects, which were developed to handle horizontal construction, might not be suitable in the three dimensions of high-rise construction projects. The coordination may be inefficient, leading to conflicts of resources, time, and risks [20].

2.2.4 Financial and Economic Risks

Financial and Economic risks are the inherent threats to high-rise construction projects and have the potential to pose threats to the feasibility of the project

and the affiliated stability of the organization. The capital-intensive high-rise construction and the long periods of construction and complicated financing structures present many possibilities of financial issues arising [18].

2.2.4.1 Financial Problems from Estimating Errors

The high-rise construction projects are difficult to estimate their cost because of the complexity of the building systems, the length of the project, and the possibility of unpredictable circumstances [18]. The poor estimation of errors may be caused by poor knowledge of the requirements of a project, poor consideration of site conditions, poor consideration of inflation throughout the project, or poor consideration of risk and contingency. Such inter-reliance of high-rise building systems implies that errors in one area can lead to other project parts being affected in a cascading manner [21].

2.2.4.2 Payment Delays and Cash Flow Issues

The management of cash flow is of high importance to high-rise construction projects owing to the high capital requirements and lengthy construction periods. Delays in payments may result in cascading financial issues in the project supply chain, including contractors, subcontractors, and suppliers. High-rise projects are usually complex, making the payment structure of such projects very complicated, which may lead to payment delays [18]. Financial issues by clients are one of the major causes of payment delays in high-rise buildings. These projects require a lot of capital, making clients prone to financial challenges within the project life cycle, especially when there are shifts in the economic conditions or other investments are performing poorly [21].

2.2.4.3 Cost Overruns and Budget Constraints

One of the long-standing problems in high-rise construction projects is the cost overruns, with researchers reporting that about 75 per cent of high-rise projects incur cost overruns of 15-30 per cent. These projects are complex and have many

opportunities in terms of costs not going within the original estimates, and the cross-connection of the building systems has the implication of problems in one sector having detrimental costs in many other areas [22]. The costs incurred in the development of designs may be more than the estimates simply because of the iterative nature of the high-rise designs. It might be necessary to repeat the design to maintain numerous building systems and meet several performance goals, which would increase the design costs. The design costs can also be boosted due to client-initiated changes in the process of design development, which will cause schedule pressure, which can affect the quality of the design in an adverse manner [6].

2.2.5 External and Regulatory Risks

External and regulatory risks include those factors evolving outside the immediate control of project participants, but which could have a serious influence on project outcomes. The high-rise construction in particular is susceptible to these risks, as the construction of tall buildings is very visible, which may affect the urban infrastructure, and the regulatory circumstances surrounding the construction of tall buildings are complex [23].

2.2.5.1 Delays in External Approvals

The building of high-rise buildings involves a more complicated and time-intensive regulatory approval process than that of traditional buildings because it presents more safety and environmental factors, and urban planning as well. The high-rise building permits are usually subject to scrutiny by various agencies such as building departments, fire departments, transportation agencies, and environmental agencies. The integration needed between these agencies may create a lot of delays in the approval procedures [24].

2.2.5.2 Political Interference

High-rise construction projects may also be greatly affected by politics, especially when the regulatory environment in a country is less developed or when political

concerns should be considered instead of technical decisions. Political interference may take different forms, such as alteration in the regulatory requirements, influence to alter the project designs, or delays in the approval procedures based on political aspects [25].

2.2.6 Productivity and Operational Risks

Productivity and operational risks are the factors that influence the efficiency and effectiveness of construction operations on high-rise projects. Such risks are especially crucial in the construction of high-rise buildings because construction work is a specialized area of operation, construction logistics are complicated, and the nature of construction projects is long-term, which increases the effects of productivity issues [15].

2.2.6.1 Low Productivity Impacts

Many factors associated with high-rise construction affect productivity, and these factors are unique or aggravated by the nature of such projects as vertical. Workers, materials, and equipment may take long periods to be transported to different heights, thus making a significant cut in productive work time, especially as buildings grow higher [26]. Capacity and speed of elevators are crucial for productivity, as inadequate vertical movement can create bottlenecks, hampering overall efficiency. Initially, productivity may dip due to the learning curve as workers adapt to specialized high-rise construction methods and safety protocols. While repetitive floor construction can gradually improve efficiency, this benefit is often counterbalanced by increasing logistical complexities as the building rises [26].

2.2.6.2 Target Production Shortfalls

The high-rise construction production planning should consider the special conditions of the vertical construction process, such as material movement restrictions, workspace limitations, and the coordinating needs of the various trades operating in proximity. Some of these factors may not have been sufficiently addressed in

the production planning, which may lead to such unrealistic production targets that are impractical in execution [27].

2.2.6.3 Late Material Deliveries

The high-rise construction has a set of peculiarities related to material logistics, which is to organize the deliveries in accordance with the vertical transportation capacity and the availability of the workspace. Just-in-time delivery methods are susceptible to failure of the supply chain, necessitating the use of limited space in high-rise construction sites. Delays in the supply of materials at a late stage may stop the construction process and generate cascading delays in the construction timetable [28].

2.3 Risk Assessment Methodologies in Construction

Risk assessment methodologies in construction have evolved to leave behind intuitive and experience-based risk assessment methods to analytical mechanisms that apply complex mathematical methods and multi-criteria decision-making procedures. The factors that have contributed to this evolution are the growing complexity of construction projects, the rise in understanding the significance of risk management to the success of projects, and the creation of computational tools that allow more complex methods of analysis to be performed [29].

2.3.1 Traditional Risk Assessment Approaches

Historically, construction industry risk assessment has relied on qualitative techniques. These methods depend heavily on expert opinion, experience, and intuitive judgment to identify risks often through brainstorming, interviews, and historical data analysis. Risks are then evaluated using descriptive scales (e.g., low, medium, high) to estimate their probability and impact [29]. Traditional risk assessment methods remain prevalent due to their simplicity and low resource requirements, as

they require minimal specialized training or technology. The documentation and communication of risks typically rely on visual tools like risk registers and matrices. These tools effectively translate expert judgment into an accessible format, enabling stakeholders to discuss and prioritize risks for action [16].

2.3.2 Quantitative and Semi-Quantitative Methods

The shortcomings of the only qualitative methodology have given rise to the emergence of quantitative and semi-quantitative methods of risk assessment that come with more objective and accurate risk assessment. The techniques strive to provide numerical values of risk parameters, to perform mathematical treatment, and comparisons between various risks [30].

2.3.2.1 Severity Index Methods

The methods of severity index are an early effort to measure construction risks by providing numerical ratings to parameters of risk likelihood and risk impact. The techniques normally employ the structured scales in order to transform qualitative judgments into numerical ones, then sum them up with mathematical equations in order to generate overall risk scores. The Relative Importance Index (RII) is one of the widely used severity index approaches, which determines the relative importance of various risk factors, based on the survey questionnaire of the construction professionals. The RII method is a technique that determines the significance risk by the formula:

$$R_{II} = \frac{\sum w}{A_N} \tag{2.1}$$

where w is the weight of respondents, A is the maximum weight, and N is the number of respondents [26].

2.3.2.2 Impact-probability matrices

An impact-probability matrix systematically visualizes risks on a two-dimensional grid, plotting likelihood against impact. By categorizing each axis (e.g., 3–5 levels),

the matrix creates colored risk zones for clear prioritization. Risks in the high-likelihood, high-impact quadrant are treated as urgent, while those with low scores require minimal oversight [31].

2.3.3 Advanced Analytical Frameworks

The growing sophistication of construction projects and the accessibility of advanced computational tools have facilitated the formulation of analytical frameworks that overcome most of the limitations of the traditional risk assessment frameworks. Having mathematical methods in other areas like fuzzy logic, multi-criteria decision analysis, and systems theory, these frameworks yield more detailed and precise estimates of risk [32].

2.3.3.1 Fuzzy Set Theory and FUZZY VIKOR Method

The problem of intrinsic uncertainty and imprecision found in risk assessment in using fuzzy set theory is that risk parameters are represented as fuzzy numbers, not as precise values. Such a method will acknowledge that risk assessment frequently deals with subjective evaluation and insufficient information, and thus, accurate numerical values will not be suitable. Fuzzy numbers are usually expressed in the form of triangular or trapezoidal functions, which are used to describe potential values and their degrees of membership [7].

2.3.3.2 Failure Mode and Effects Analysis

Failure Mode and Effects Analysis (FMEA) has been found to offer a controlled and systematized approach to risk analysis through the evaluation of the possible failure modes, their causes, and their impacts on the results of the project. FMEA was developed in the aerospace and automobile industry but it has been effectively modified to be applied in construction risk assessment. It is a process that includes the methodical recognition of possible failures, the evaluation of the causes and impacts of failures, and the estimation of Risk Priority Numbers (RPN) according to their severity, probability of occurrence, and detection difficulty [33].

2.3.3.3 Spatial Markov Chain Models

Spatial Markov chain models this is a more sophisticated method of construction risk assessment, which takes into consideration the spatial and temporal development of risks during the construction project. These models also note that construction risks do not exist as fixed but tend to change with time and space as conditions of the project vary. The spatial dimension is especially applicable in the construction of high-rises, where the risk profile can significantly differ among the levels of the building and the areas of construction [34].

2.3.3.4 Comprehensive Probability Fuzzy Evaluation Models

Comprehensive probability fuzzy evaluation models integrate the probability theory with fuzzy logic in order to solve both aleatory uncertainty (natural randomness) and epistemic uncertainty (knowledge limitations) in construction risk assessment. These models acknowledge that risks in construction may be both objective and subjective, and thus, the models need analytical methods that may accommodate both subjective and objective uncertainty [35].

2.4 Risk Mitigation Strategies for High-Rise Construction

High-rise construction risk mitigation strategies are a very broad-based set of measures that are aimed at decreasing the probability and severity of perceived risks. High-rise construction is a difficult task that demands advanced mitigation measures that can counter the various risk categories, while taking into consideration the interdependencies among various systems of the building and construction processes [5].

2.4.1 Proactive and Preventive Strategies

Preventive and proactive solutions aim at removing or minimizing risks before they occur as issues in the construction process. Such measures tend to be cheaper than

reactive ones, as they do not tackle symptoms but cause issues and eliminate the expenses of the solution and recovery [36].

2.4.2 Active Control and Management Measures

Active control and management measures entail continuous checking on and action intervention to ensure maintenance of safety and quality standards during construction. These actions mean that highly-organized systems of control and processes should be put in place so that issues are identified early, before they can cause corrective action to be undertaken [37].

2.4.3 Collaborative and Communication Strategies

Collaborative and communication approaches acknowledge that successful mitigation of risks in the construction of high-rise buildings can only be achieved through coordination of activities among all the project participants. High-rise construction activity is complicated and interdependent, so cooperation is necessary to define the risks, mitigation approach, and response to the identified issues when they happen [14].

2.5 Identification of Key Risk Factors in High-Rise Construction through Literature Review

This section identifies and summarizes the most critical risk factors for high-rise construction, as derived from a systematic review of existing literature. To provide a comprehensive foundation for empirical research and framework development. A total of 24 of the most recent and relevant academic papers were analyzed to compile these risk factors shown in Table 2.1, ensuring the findings reflect contemporary industry challenges. Notably, this review incorporates significant regional context, with 10 of these papers authored by Pakistani researchers.

TABLE 2.1: Key Risk Factors in High-rise Construction

Sr. No.	Source	Paper Title	Risk Factors
1	Lakhiar and Lakhiar [10]	Occupational Health and Safety Performance in High-Rise Building Projects in Pakistan: A Systematic Literature Review	• Falls from height, Electroshock • Lack of PPE, Ineffective training • Unrealistic timelines • Absence of authority, Poor governance • Political interference, Untrained staff
2	Iqbal, et al. [38]	Risk management in construction projects	• Financial, Environmental risks • Procedural, Structural integrity • Material quality, Labor safety • Planning or execution delays • Extra costs (unforeseen)
3	Altaf, et al. [39]	Risk Factors Occurring in Construction Works	• Changing demands, Work quality • Payment/Bureaucratic delays • Inexperienced contractor • Supply chain issues • Coordination, Labor strikes • Inadequate soil testing/survey
4	Khan and Gul [22]	Hazard Risk Analysis and management in construction sector of Pakistan	• Hazard risks • Lack of construction practices

Table 2.1: Continued from previous

Sr. No.	Source	Paper Title	Risk Factors
5	Pervez, et al. [40]	Evaluation of critical risk factors in the implementation of modular construction	• Inadequate skills and experience • Inability to make changes in design • High initial investment costs • Transportation and logistics risks
6	Hasmori, et al. [27]	Critical Factors and Mitigating Measures of Construction Delays of Pakistani Building Projects	• Poor contract management • Shortage of funds and drawing delays • Land acquisition issues • Improper survey, Poor site supervision
7	Hussain, et al. [22]	Critical Delaying Factors: Public Sector Building Projects in Gilgit-Baltistan, Pakistan	• Financing difficulties, Payment delays • Land disputes, Improper feasibility • Awarding to lowest bidder • Harsh weather conditions
8	Haseeb, et al. [41]	Problem of projects and effects of delay in the Construction Industry in Pakistan	• Priority on time over material quality • Late payment of bills, Lack of financial ability • Unforeseen subsurface conditions • Natural disasters and weather effects

Table 2.1: Continued from previous

Sr. No.	Source	Paper Title	Risk Factors
9	Ansari, et al. [7]	A Novel Safety Risk Assessment Based on Fuzzy Set Theory and Decision Methods	• High-altitude safety risks (falls from height) • Complexity in risk quantification • Subjectivity in human judgment during assessment
10	Sofwan, et al. [13]	Preliminary study on the identification of safety risks factors in high-rise construction	• Disproportionate number of site accidents • Falling objects and structural instability • High-risk work environments at elevation
11	Tripathi and Mittal [26]	Risk assessment and ranking methodology for occupational hazards	• Falls from height (ranked as primary risk) • Improper scaffolding and ladder safety • Lack of occupational health awareness
12	San Santoso, et al. [8]	Assessment of risks in high-rise building construction in Jakarta	• Management and design-related errors • Client interference in technical decisions • Inadequate site coordination
13	Calvin and Johan [42]	Risk Analysis and Prevention in High-Rise Building Construction Projects	• Frequent design changes initiated by owner • High-risk category variables in execution • Material procurement delays

Table 2.1: Continued from previous

Sr. No.	Source	Paper Title	Risk Factors
14	Badran, et al. [43]	Identification of key design phase-related risks in DBB Projects in the UAE	• Poor coordination between engineering disciplines • Major client-initiated changes during construction • Incomplete design documentation
15	Perera, et al. [44]	Managing financial and economic risks associated with high-rise construction	• Financial problems arising from estimating errors • Poor contract management and documentation • Inflation and fluctuating material costs
16	Ratnaningsih, et al. [45]	Hazard identification, risk analysis, and risk assessment	• Low productivity leading to budget overruns • Improper use of construction machinery • Inadequate safety monitoring systems
17	Huang, et al. [46]	Schedule-cost optimization in high-rise buildings considering uncertainty	• Target production shortfalls • Delays in regulatory approvals • Late delivery of specialized equipment
18	Santoso, et al. [14]	Perceptions of risk based on the level of experience for contractors	• Inadequate equipment maintenance • Breakdown in communication and teamwork • Lack of specialized training for high-rise work

Table 2.1: Continued from previous

Sr. No.	Source	Paper Title	Risk Factors
19	Lei, et al. [5]	Systematic review of identification, assessment, and mitigation of safety risks	• Inconsistent risk taxonomy across projects • Integration gaps between assessment and mitigation • Human organizational factors
20	Tian and Liu [47]	Comprehensive probability fuzzy evaluation of fire risk for high-rise buildings	• Electrical fire hazards • Vertical fire spread due to "chimney effect" • Inadequate emergency evacuation routes
21	YA [48]	Hazards identification & risks assessment by FMEA	• Mechanical failure of lifting equipment • Failure of proactive risk monitoring • Strict quality control deficiencies
22	Cheng, et al. [49]	An evaluation tool of infection risk analysis for drainage systems	• Cross-contamination through drainage • Improper maintenance of vertical piping • Design flaws in sanitation systems

Table 2.1: Continued from previous

Sr. No.	Source	Paper Title	Risk Factors
23	Zhang, et al. [50]	Regional high-rise building fire risk assessment based on spatial Markov chain	• Geographic concentration of fire risks • Inter-building fire spread in urban areas • Resource allocation for firefighting
24	Kim and Lee [51]	Study on Risk Assessment and Analysis Method for K-IDES Development	• Lack of integrated disaster evaluation platforms • Absence of standardized comprehensive frameworks • Inability to process real-time disaster data

2.6 Existing Risk Assessment Framework

Recent research proposed a risk management framework specifically for international construction projects in developing countries. Their framework, named the "Alien Eyes' Risk Model," categorizes risks into three hierarchical levels: country level, market level, and project level. Based on a survey of international construction firms, they identified 28 critical risks and evaluated their criticality. The study also provided practical mitigation measures for each risk and prioritized them based on effectiveness. The authors concluded that risks at the country level are the most critical and should be mitigated first, followed by market and project level risks. The proposed qualitative risk mitigation framework consists

of six steps that guide the user from risk identification to the implementation of prioritized mitigation measures [52].

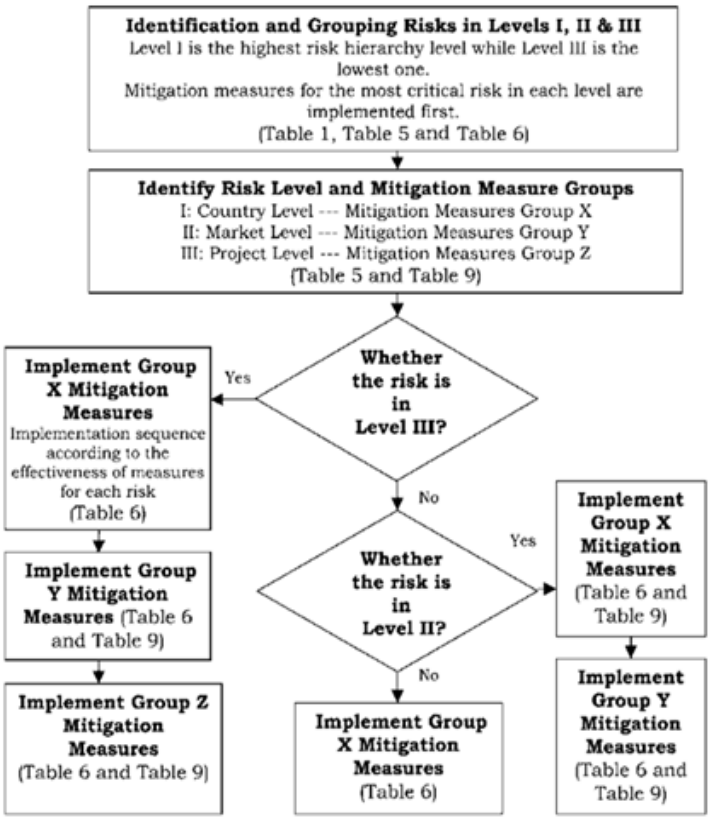

FIGURE 2.1: Risk Assessment and Mitigation Framework

2.7 Summary

This comprehensive review establishes risk management as critical for high-rise construction, a sector marked by unique technical and safety complexities, with falls from height being a leading cause of fatalities. It systematically classifies risks safety, design, management, financial, external, and operational, and traces the evolution of assessment methods from qualitative approaches to advanced models like FUZZY VIKOR. However, these sophisticated tools face implementation barriers due to their complexity and data requirements. While proactive measures (e.g., BIM, safety training) and integrated technologies (e.g., sensors) are identified as effective mitigations, they remain underutilized. In the context of Pakistan, project vulnerability is heightened by acute financial risks, weak regulation, a poor

safety culture, and a skills gap. The analysis reveals significant research gaps, particularly the need for dynamic, context-sensitive risk models for developing economies, a deeper understanding of formal-informal management interplay, and systematic evaluation of mitigation strategies. These findings provide the essential theoretical foundation, directly informing the subsequent research questions and methodology aimed at developing a tailored risk management framework for Pakistan's high-rise construction challenges.

Chapter 3

Research Methodology

This chapter outlines the methodology for developing a holistic risk assessment framework specifically for high-rise projects in Islamabad. A sequential mixed-methods approach is adopted, integrating qualitative and quantitative phases to ensure a comprehensive analysis. The methodology is structured into five distinct yet interconnected stages. First, an extensive literature review establishes the foundational knowledge. Second, expert input identifies and prioritizes key risk factors. Third, a structured questionnaire is used to gather empirical data. Fourth, an analytical model is developed using multi-criteria decision-making tools. Finally, a systematic framework is created and validated. The overall aim is to produce a practical, hierarchical, and scalable risk assessment tool that can be utilized by local stakeholders including project managers, contractors, consultants, and regulators

3.1 Research Philosophy and Design

The research has its philosophical foundation in the pragmatic philosophy, which values practical results and practical information more than theoretical study. The philosophical position is most correct in the case of construction management research, where practical applicability is the main consideration. The study design is a descriptive-analytical one, as it involves both qualitative exploratory and

quantitative analytical methodology to attain methodological triangulation. The qualitative element, which includes literature review and expert interviews in the form of the Delphi method, offers in-depth and contextual knowledge, whereas the quantitative element, including structured surveys and advanced statistical tests, offers a scope of breadth and generalizability [53].

The research method follows a deductive-inductive research strategy where the initial step is the deductive approach, where an analysis is done based on available theoretical frameworks as identified in the literature, a deductive approach, followed by the inductive approach, where empirical data is collected and analyzed, and finally, the development of a suitable theoretical framework is done. This cyclic process allows making sure that the developing framework is theoretically informed and empirically tested. The flow of the methodology (shown in Figure 3.1) proves the logical course of action, starting with the conceptual background and moving towards empirical research, then developing frameworks and verifying them, including the feedback mechanisms at the highest levels, in order to increase the reliability and validity.

3.2 Preliminary Investigation and Literature Review

The initial research phase has been inaugurated by an organized and systematic literature review aimed at identifying and listing the risk factors that were relevant to the high construction of high-rise buildings, with a specific focus on developing economies and the Pakistani context. There was a series of steps that were systematically followed in the review process. To start with, extensive searches were carried out in various academic databases such as the Web of Science and Google Scholar, and centered on articles published from 2015 to 2025, in order to be relevant in the present. The first search resulted in several possible sources, which were then filtered according to pre-defined inclusion criteria regarding relevance, rigor of methods, geographic background, and applicability in practice. Over 70 research papers, industry reports, and case studies were selected as a

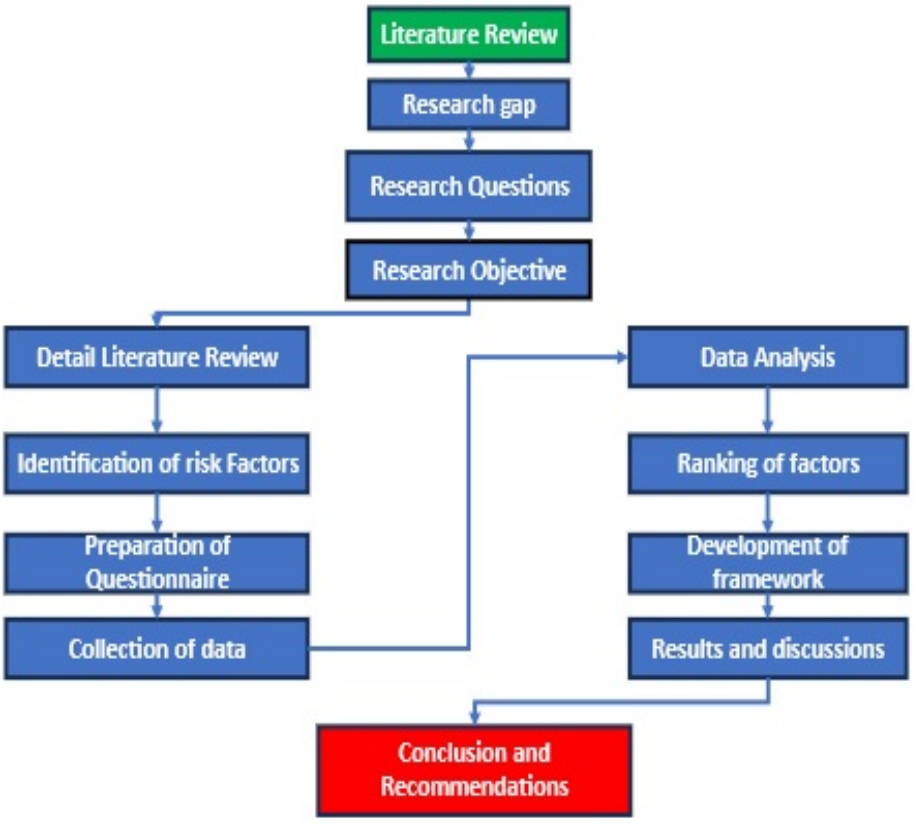

FIGURE 3.1: Systematic Diagram of Methodology

result of this screening process and were to be analyzed in detail. The synthesis stage entailed the extraction and classification of risks, and these risks were arranged into six major categories: Safety and Occupational Hazards, Design and Client-Related Risks, Management and Coordination Risks, Financial and Economic Risks, External and Regulatory Risks, and Productivity and Operational Risks. This detailed review allowed forming the preliminary list of possible risk factors, some 50 in total, which is going to form the basis of further refining steps.

3.3 Risk Factor Refinement Using the Delphi Method

The Delphi method was methodically used to test, harmonize, and frame the initial risk factors in the high-rise construction setting in Islamabad. The Delphi panel was well constituted to provide a wide diversity in terms of representation in terms of the industry sectors and areas of expertise. It consisted of professionals: senior

contractors who had a long history of working in the field, project managers of major construction companies, consulting engineers who work with high-rise buildings, and academics whose research focused on the management of construction risks [54]. The systematic literature review initially identified six risk categories. However, during the Delphi panel refinement and in preparation for the survey instrument, these six were consolidated into four categories for the Merging of Design and Client-Related Risks with Financial and Economic Risks and Merging of External and Regulatory Risks with Productivity and Operational Risks. Each member of the panel had at least one decade of related professional experience in the high-rise building industry in Pakistan. This is a process of refinement that led to the reduction of the starting number of factors into 35 major risk factors specifically applicable to the high-rise construction sector of Islamabad, which was spread out among the established risk categories.

3.4 Questionnaire Design and Data Collection

3.4.1 Questionnaire Structure

A detailed and carefully designed structured questionnaire was created to enable a detailed data gathering of industry professionals. The questionnaire was divided into two separate sections that had a particular research purpose. Section A was a primer of demographic and professional background data, including years of experience, present role, type of organization, level of education, and direct participation in high-rise projects [55]. Section B showed the 35 validated risk factors, with the operational definition given beside each. Each factor had two independent ratings, in which the respondents were to indicate the perceived probability of occurrence (first, 1 = Very Unlikely to 5 = Very Likely), and the subsequent risk severity, should the risk occur (first, 1 = Very Low to 5 = Very High).

3.4.2 Sampling and Distribution

Data was collected among construction professionals who are currently working on high-rise projects in the metropolis of Islamabad-Rawalpindi. The sampling

frame comprised of professionals in contracting firms, consulting engineering firms, project management firms, regulatory agencies, and academic institutions that had construction-related expertise. The sampling methodology was a combination of purposive and snowball sampling methods to provide some representation of the various stakeholder groups and organizational hierarchies. A population of 100 responses was used to determine the target population of 100, considering the Cochran formula with a 95 percent confidence level and a 5 percent error margin, considering the population of high-rise construction professionals in the area [56].

3.5 Data Analysis Methods

3.5.1 Descriptive Analysis

The first data analysis was based on descriptive statistics with the help of the IBM SPSS Statistics program. The demographic variables of the respondents were summarized using frequency distributions and cross-tabulations so as to profile the sample composition and guarantee representative coverage. Mean scores were computed with the likelihood and impact rating of each of the risk factors to identify baseline perceptions among the sample [57]. Frequency distributions were created to determine patterns of response, establish possible outliers, and learn the patterns of distribution of each variable. Comparative analyses were done to investigate the differences in risk perceptions among various demographic subgroups, such as level of experience, job roles, and type of organization, and such analyses give information about the perceptions of various stakeholder groups with regard to construction risks.

3.5.2 Reliability and Normality Tests

The reliability and internal consistency of the measurement scales were strictly evaluated based on Cronbach's Alpha coefficient, which is a well-known measure of scale reliability in survey studies [58]. The likelihood and impact rating scales were

performed separately, and the coefficients of the scales were greater than the traditional threshold of 0.7, which demonstrated adequate scale reliability and internal consistency. Normality of data was statistically tested with the Shapiro-Wilk test, and the results showed the non-normality of most variables ($p < 0.05$) [59]. Frequency distributions were created to determine patterns of response, establish possible outliers, and learn the patterns of distribution of each variable. Comparative analyses were done to investigate the differences in risk perceptions among various demographic subgroups, such as level of experience, job roles, and type of organization, and such analyses give information about the perceptions of various stakeholder groups with regard to construction risks.

3.5.3 Relative Importance Index

The Relative Importance Index (RII) was utilized to come up with an initial ranking of the identified risk factors using survey responses. Each factor was calculated using the following formula:

$$R_{II} = \frac{\sum w}{A_N} \tag{3.1}$$

where W is the weight allocated by individual respondent (in this case 1 to 5), A is the maximum possible weight (5), and N is the number of respondents who have rated that specific factor. The value of RII produced will be between 0 and 1 with the higher values reflecting perceived importance. Likelihood and impact dimension calculations of RII were done individually, with composite importance scores derived thereafter by means of proper weighting of the two dimensions. The ensuing rankings gave preliminary prioritization of risk factors, which were used in the later analysis steps and guaranteed a validation mechanism of more advanced analysis [60].

3.5.4 Kruskal-Wallis Test

To test the fact that the difference in risk perceptions among different demographic subgroups might be different, the Kruskal-Wallis test which is a non-parametric

test was used. The particular choice of the test was explained by the fact that the data is non-normally distributed, which was determined with the help of the Shapiro-Wilk test [61]. The analysis involved the differences in risk perceptions according to the professional experience (0-5 years, 6-10 years, 11-15 years, and 16+ years), an organizational role (contractor, consultant, project manager, etc.), educational background, and the type of projects in which they mainly worked on. This examination shed useful light on the perceptions and priorities in respect of construction risks by the various professional groups, which holds significant significance to the formulation of specific risk management strategies [62].

3.5.5 Analytical Hierarchy Process

The Analytical Hierarchy Process was applied methodically to calculate the relative weights of the risk categories and individual factors by having pair-wise comparisons structured in a methodical way. The procedure of the AHP observed the established methodological procedures as formulated by Saaty [63]. To begin with, a hierarchical structure with three levels was developed including the overall aim (Level 1: Comprehensive Risk Assessment for High-Rise Projects), six risk categories (Level 2: Safety, Design, Management, Financial, External, Operational), and 35 risk factors (Level 3). Second, the development of pairwise comparison matrices at each level of the hierarchy was created, and comparisons were made according to the expert judgment that was gathered using the specialized section of the questionnaire.

3.5.6 Fuzzy Comprehensive Evaluation

Fuzzy Comprehensive Evaluation was added to overcome the uncertainties and subjectivities of risk perception data that is usually present in construction risk assessment. The FCE methodology consisted of a number of steps undertaken in a systematic way according to given fuzzy logic principles [64]. In the first step, fuzzy membership functions were specified to the five linguistic variables (Very Low, Low, Moderate, High, Very High) that are the Likert scale ratings. The reason why triangular fuzzy numbers have been chosen is because they are computationally

efficient and conceptually simple to describe subjective judgments. Second, each risk factor was built into a fuzzy evaluation matrix where the items were the extent of membership in the various linguistic categories according to the ratings of the respondents. Third, the AHP analysis was used to give the fuzzy weight vectors, and crisp weights were transformed to fuzzy numbers to ensure the methodological consistency. Fourth, synthetic evaluations based on fuzzy were done by creating fuzzy relation based on proper operators (max-min composition operator, in this case). Fifth, the resultant fuzzy evaluation sets were defuzzied by the centroid method to obtain crisp scores of overall risk levels of each factor. Such an AHP-FCE methodology allowed a holistic risk evaluation that could consider expert opinion and hard data and was able to deal with the uncertainties inherent in construction risk assessment.

3.6 Framework Development

3.6.1 Framework Structure

The risk assessment paradigm was developed in the form of a three-level hierarchical model, which is specifically aimed at being applied in high-rise construction projects. Tier 1 is the overall objective: the overall risk evaluation of high-rise construction projects in Islamabad. Tier 2 includes the risk categories which are validated (Safety, Design, Management, Financial, External and Operational) and each has weights as per the AHP analysis which are relative to the importance of the risk category in the local construction environment. Tier 3 also includes the risk factors which are broken by several parameters such as likelihood rating, impact rating, RII score, fuzzy risk score, and mitigation priority ranking.

3.6.2 Proposed Risk Matrix

An example of an assessment framework that was created is a 5x5 Risk Matrix that justifies and prioritizes risks identified and gives a visual representation of them.

The likelihood is plotted against the impact, whereby both variables (likelihood and impact) have been identified as five levels, which relate to the Likert scale ratings [65]. Depending on the score of likelihood and impact, the risk factors are placed in this matrix to form a clear picture of risk terrain.

3.7 Summary

This chapter outlines a comprehensive methodology for creating a tailored risk assessment framework for Islamabad's high-rise construction. The approach integrates a literature review, expert validation via the Delphi technique, empirical questionnaire data, and analytical tools (Relative Importance Index, Analytical Hierarchy Process, and Fuzzy Comprehensive Evaluation). This multi-method strategy ensures both theoretical soundness and practical relevance, addressing research gaps by adapting established methods to the local context. The resulting framework provides a structured, hierarchical system for risk identification, assessment, and prioritization that balances analytical sophistication with usability. Expert validation, a case study, and sensitivity analysis reinforce the framework's robustness and applicability. The following chapters will present the detailed findings from applying this methodology, discussing their theoretical and practical implications for risk management, along with specific strategies for enhancing safety and project performance in Pakistan's high-rise construction industry.

Chapter 4

Results and Analysis

This chapter outlines the discussion of the data obtained by the researcher through the interaction with 121 professionals in the construction industry who were actively engaged in high-rise construction projects in Islamabad. The main aim is to find, assess, and rank risk factors of high-rise construction projects, with the help of a blend of statistical and multi-criteria decision-making instruments. The results are thoroughly given in the form of descriptive statistics, reliability, and the use of sophisticated analytical tools such as the Relative Importance Index (RII), Analytic Hierarchy Process (AHP), and Fuzzy Comprehensive Evaluation (FCE). This discussion forms the basis of the creation of a systematic risk assessment model that is specific to the high-rise construction industry in Islamabad.

4.1 Sample Size and Response Rate

Questionnaires were sent to the professionals working in the Islamabad-Rawalpindi region, where 121 of the 165 questionnaires were returned and the rate of response was high at 73.33. Based on the criteria of survey research in construction management, a response rate of 70 per cent and above constitutes an excellent response rate, hence giving reliable data to analyze. Upon data verification, 118 responses were saved to be analyzed in the final data analysis and this corresponds to the minimum sample size required of 100 as defined by the Cochran formula with a

95 percent confidence level [66]. Rejection criteria added: (a) completion <80% of questionnaire (missing >7 of 35 risk ratings); (b) straight-lining (selecting same Likert value for all 35 factors).

4.2 Demographic Characteristics of Respondents

As shown in Figure 4.1, the respondents have varying educational qualifications. The evidence shows that most of the participants have a Bachelor's degree (48.1%), then immediately with a Master's degree (35.8%). A lower percentage of the respondents indicated that they were a Ph.D. (16%). This distribution shows that there is a well-educated workforce that is prevalent among the professional population in the construction projects in high-rise buildings in Islamabad. Figure

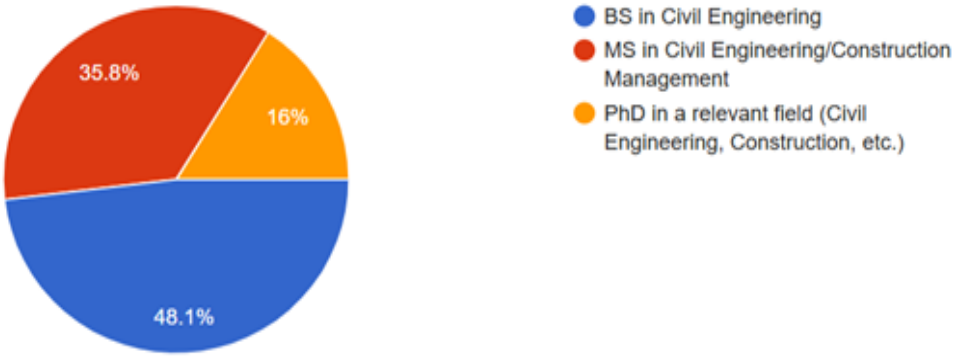

FIGURE 4.1: Education Distribution

4.2 presents the spread of the professional experience of the respondents. It can be seen that the greatest number of participants is experienced in 11-15 years (11.1%), the next higher number of participants is in 5-10 years (23.5%). The less experienced respondents (less than 5 years' experience) are the largest group (54.3) followed by the most experienced (15 years and above) at 11.1 percent. This distribution is based on a well-balance representation of young professionals, middle-aged professionals, and experienced professionals so that the risk perceptions they reflected in the survey are knowledgeable based on different degrees of practical exposure and experience with high-rise construction.

The organization involves four key stakeholders: Contractor (45.8%), Consultant (36.1%), Developer/Client (16.9%), and Design Managers (1.2%) shown in figure

4.3. The Contractor holds the largest share, reflecting their primary responsibility in project execution and on-site operations. Together, Consultants and Design Managers contribute 37.3 %, emphasizing their essential role in technical advisory and design coordination, while the Developer/Client guides project requirements and financial decisions.

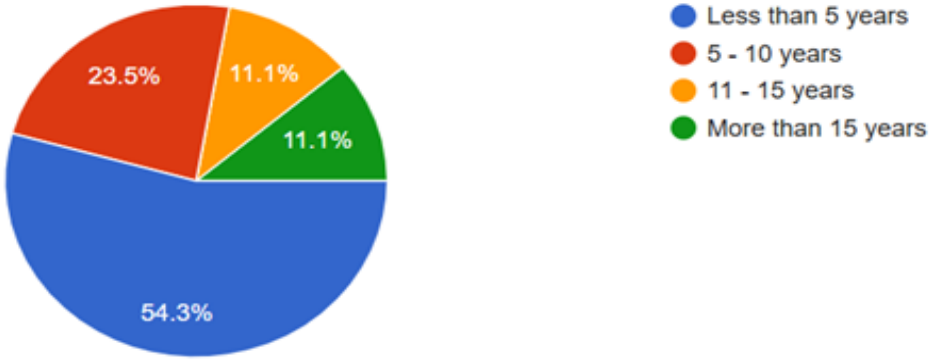

FIGURE 4.2: Experience Distribution

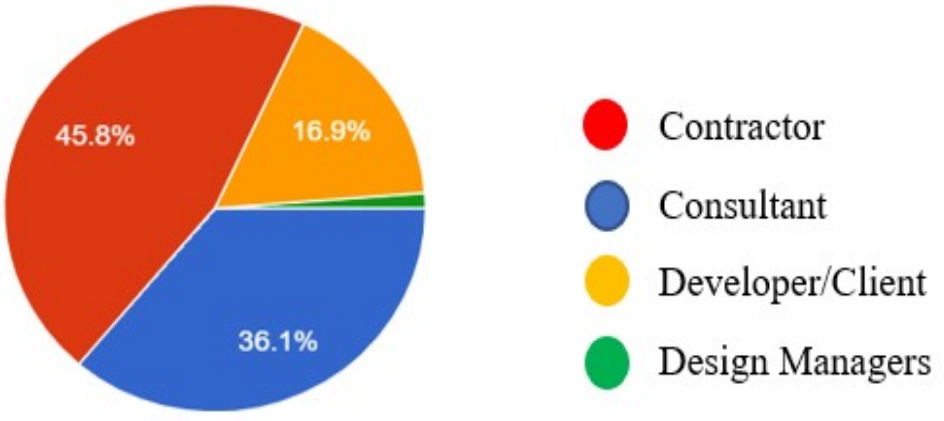

FIGURE 4.3: Organization

4.3 Reliability Analysis

The consistency and reliability of the survey instrument should be checked first before proceeding to further analysis. Cronbach's Alpha test is used to determine the relationship that a group of items bears to each other and this determines whether or not the questionnaire can accurately measure the constructs that it is supposed to measure [67]. This step of validation is necessary to guarantee that

the Likelihood and Impact scales applied in the course of the survey generate the results that are similar across different categories of risks. The following Table 4.1 shows reliability statistics. The values of all Cronbach's Alpha are greater than

TABLE 4.1: Reliability Statistics

Construct	**Number of Items**	**Cronbach's Alpha**	**Interpretation**
Likelihood Scale	35	0.872	Excellent
Impact Scale	35	0.885	Excellent
Safety Risks	8	0.834	Good
Pre-Construction Risks	10	0.821	Good
Management Risks	8	0.807	Good
External Risks	9	0.798	Acceptable

0.7 which proves that respondents provided the same answers in the items that are closely connected [68]. The scores on the high reliability scales of both scales (0.872 and 0.885) confirm that the 5-point Likert scales employed in the questionnaire were good measuring scales of the risk likelihood and impact perceptions.

4.4 Normality Test

Prior to the choice of relevant statistical tests, one should investigate the possibility of normal distribution of the survey data. The Shapiro-Wilk test is used on this account because it works especially well with samples that are 50 to 200 [69]. Normality testing is important since the parametric tests can only be applied in the case of normally distributed data, whereas non-parametric tests (such as Kruskal-Wallis) do not. The outcome of table 4.2 shown, this test will establish what statistical methods will be acceptable in the analysis of Likelihood and Impact ratings of the survey.

The results of the Shapiro-Wilk test indicate that the p-values of all the tested risk factors are lower than 0.05, which implies that normal distribution is not followed [70]. This proves that survey data is not normally distributed, which supports the application of the non-parametric statistical tests such as the Kruskal-Walli's test in the further analysis.

Table 4.2: Normality Test Results for Key Risk Factors

Risk Factor	**Shapiro-Wilk Statistic**	**p-value**	**Distribution Type**
Falls from height (Likelihood)	0.812	0.000	Non-normal
Client design changes (Impact)	0.798	0.000	Non-normal
Late material delivery (Likelihood)	0.845	0.000	Non-normal
Poor site supervision (Impact)	0.832	0.000	Non-normal
Design errors (Likelihood)	0.865	0.000	Non-normal
Financial delays (Impact)	0.854	0.000	Non-normal

4.5 Descriptive Analysis of Risk Factor

The following section contains the basic statistical analysis of the answers to Questions 5-12 of the survey. Mean scores are obtained on Likelihood and Impact rating on each risk factor as given by the respondents. Such descriptive statistics are the basis of all further advanced analyses, which will give the pre-liminary understanding of risks that are perceived as the most likely and the most harmful in each of the four survey sections.

4.5.1 Safety and On-Site Risks Analysis

Analysis of Questions 5-6 from the survey, which asked respondents to rate 8 safety risks on both likelihood and impact scales, revealed the following table 4.3 with mean scores:

The composite score (Likelihood x Impact) provides an initial prioritization, with falls from height ranking highest. These results directly inform the Safety category weights in subsequent AHP analysis.

4.5.2 Pre-Construction and Financial Risks Analysis

Analysis of Questions 7-8, covering 10 design and financial risks, yielded the following results in table 4.4: The section discusses the answers to the Pre-Construction and Financial Risks section of the survey. The changes in design initiated by the clients in the course of construction proved to be especially crucial as they are

TABLE 4.3: Safety Risks Ranking

Risk Factor	**Likelihood Mean**	**Impact Mean**	**Composite Score**	**Rank**
Falls from height during construction activities	4.42	4.51	19.93	1
Insufficient use or lack of Personal Protective Equipment (PPE)	4.38	4.48	19.62	2
Poor site supervision and enforcement of safety protocols	4.25	4.40	18.70	3
Inadequate safety training and awareness programs	4.12	4.32	17.80	4
Accidents involving cranes and heavy equipment	3.95	4.25	16.79	5
Electroshock or accidents involving electrical systems	3.88	4.18	16.22	6
Limited site access creating logistical/safety hazards	3.75	4.05	15.19	7
Accidents involving material handling and storage	3.68	3.98	14.65	8

typical of high-rise construction projects, where the needs of clients may change during the implementation process.

Projects are highly affected by financial risks such as shortages of funds, which means that they can lead to serious disruptions. The results will be incorporated in the financial risk weights of the AHP pairwise comparison.

4.5.3 Project Management Risks Analysis

Analysis of Questions 9-10, focusing on 8 management and coordination risks, shown in table 4.5: This is the same as the questionnaire section: Project Management and Stakeholder Coordination. Poor site management and coordination were rated highly, indicating the human and organizational aspect on risk in the complex high-rise projects. The moderate-to-high scores across management risks suggest systemic challenges in project execution that will require attention in the risk framework.

TABLE 4.4: Pre-Construction Risks Ranking

Risk Factor	**Likelihood Mean**	**Impact Mean**	**Composite Score**	**Rank**
Design changes initiated by the client during construction	4.20	4.38	18.40	1
Shortage of funds or delayed payments from the client	4.18	4.35	18.18	2
Errors or omissions in the initial design documents	4.08	4.25	17.34	3
Financial problems arising from errors in cost estimating	3.98	4.12	16.40	4
Poor coordination between different design disciplines	4.05	4.20	17.01	5
Inadequate soil testing and site survey before design	3.92	4.15	16.27	6
Interference by the client during the design and construction	3.88	4.08	15.83	7
Awarding the project to the lowest bidder	3.85	4.08	15.71	8
High initial investment requirements leading to cash flow issues	3.82	4.05	15.47	9
Difficulties in contractors securing project financing	3.78	4.02	15.20	10

4.5.4 External and Operational Risks Analysis

Analysis of Questions 11-12, covering 9 external and supply chain risks, revealed in the table 4.6: This final descriptive analysis is on the section of Logistics, Supply Chain, and External Risks. The risks associated with materials (delivery and quality) were identified as the most critical, which can be attributed to the fact that a high-rise building is based on the timely functioning of the supply chain.

TABLE 4.5: Management Risks Ranking

Risk Factor	**Likelihood Mean**	**Impact Mean**	**Composite Score**	**Rank**
Poor site management and delayed on-site decision-making	4.02	4.18	16.80	1
Inefficient coordination between the contractor and consultants	4.00	4.15	16.60	2
Inadequate project scheduling and planning	3.95	4.12	16.27	3
Lack of experience of the main contractor or subcontractors	3.88	4.08	15.83	4
Delays in obtaining necessary external approvals and permits	3.92	4.05	15.88	5
Occurrence of disputes, claims, or labor strikes	3.85	4.02	15.48	6
Ineffective teamwork among project stakeholders	3.82	3.98	15.20	7
Poor contract management and administration	3.78	3.95	14.93	8

External factors like bureaucratic delays and regulatory changes show slightly lower but still significant ratings, indicating their role as contextual constraints.

4.6 Relative Importance Index Analysis

To rank all the 35 risk factors in terms of perceived importance, the Relative Importance Index (RII) is computed. RII transforms the ratings of the 5-point scale into a normalized index between 0 and 1 so that the ratings of various risk categories can be directly compared [71]. The following formula is used:

$$RII = 5 - \frac{1}{121} \times \frac{W}{A \times N} \tag{4.1}$$

where W is the weight given by individual respondents (1-5), A is the maximum weight (5), and N is the number of respondents (121). The top 15 risk shown in table 4.7 below:

TABLE 4.6: External Risks Ranking

Risk Factor	**Likelihood Mean**	**Impact Mean**	**Composite Score**	**Rank**
Late delivery of materials to the construction site	4.15	4.28	17.76	1
Poor material quality or sub-standard material supply	4.08	4.25	17.34	2
Extreme weather conditions affecting construction	3.95	4.15	16.39	3
Bureaucratic delays in government-related processes	3.88	4.08	15.83	4
Effects of unforeseen subsurface (ground) conditions	3.82	4.05	15.47	5
Changes in government regulations, laws, or policies	3.78	4.02	15.20	6
Target production shortfalls and low labor productivity	3.75	3.98	14.93	7
Inefficient material management and procurement systems	3.72	3.95	14.69	8
Political interference in the project execution	3.68	3.92	14.43	9

The RII ranking confirms safety risks as most critical, with three safety factors in the top four. This prioritization will guide resource allocation in the risk management framework, emphasizing that safety interventions should receive the highest priority.

This comprehensive RII ranking is shown in Table 4.8. The relative importance of all 35 risks identified in the survey provides a complete picture of risk priorities across all categories.

4.7 Kruskal-Wallis Test for Group Difference

In consideration of the fact that the survey data does not follow the normality assumption (shown by Shapiro-Wilk tests in Section 4.4), non-parametric Kruskal-Wallis tests will be used to test the hypothesis of whether there is a significant

Table 4.7: Top 15 Risks by RII Value

Rank	Risk Factor	RII Value	Category
1	Falls from height during construction	0.912	Safety
2	Insufficient use or lack of PPE	0.904	Safety
3	Design changes initiated by the client	0.885	Pre-Construction
4	Poor site supervision and safety enforcement	0.868	Safety
5	Shortage of funds or delayed payments	0.872	Pre-Construction
6	Late delivery of materials to the site	0.854	External
7	Inadequate safety training and awareness	0.848	Safety
8	Poor material quality or substandard supply	0.842	External
9	Errors or omissions in design documents	0.838	Pre-Construction
10	Poor site management and delayed decisions	0.832	Management
11	Inefficient coordination (Contractor/Consultant)	0.828	Management
12	Accidents involving cranes and heavy equipment	0.825	Safety
13	Financial problems from cost estimating errors	0.822	Pre-Construction
14	Extreme weather conditions affecting construction	0.818	External
15	Inadequate project scheduling and planning	0.815	Management

difference in risk perceptions across demographic groups. This discussion will be useful in deciding whether the levels of experience, professional occupation, or type of organization have an impact on the perceived risk, which is significant in adapting the risk framework to the perception of various stakeholders.

4.7.1 Differences by Experience Level

Significant differences were found for:

TABLE 4.8: RII Values for All 35 Risk Factors

Category	Risk Factor	RII Value	Overall Rank
Safety	Falls from height during construction	0.912	1
	Insufficient use or lack of PPE	0.904	2
	Poor site supervision	0.868	4
	Inadequate safety training	0.848	7
	Accidents involving cranes	0.825	12
	Electroshock accidents	0.802	18
	Limited site access	0.795	21
	Material handling accidents	0.788	24
Pre-Construction	Client design changes	0.885	3
	Shortage of funds	0.872	5
	Financial cost estimating errors	0.822	13
	Design errors/omissions	0.838	9
	Poor design coordination	0.818	16
	Inadequate soil testing	0.812	17
	Client interference	0.808	19
	Awarding to the lowest bidder	0.798	20
	High initial investment	0.792	22
	Contractor financing difficulties	0.785	25
Management	Poor site management	0.832	10
	Inefficient contractor-consultant coordination	0.828	11
	Inadequate project scheduling	0.815	15
	Lack of contractor experience	0.805	23
	Delays in external approvals	0.802	26
	Occurrence of disputes/claims	0.795	28
	Ineffective teamwork	0.792	29
	Poor contract management	0.788	30
External	Late material delivery	0.854	6
	Poor material quality	0.842	8
	Extreme weather conditions	0.818	14
	Bureaucratic delays	0.808	27
	Unforeseen subsurface conditions	0.802	31
	Changes in government regulations	0.798	32
	Low labor productivity	0.795	33
	Inefficient material management	0.792	34
	Political interference	0.788	35

i. Design changes during construction ($p = 0.015$)

ii. Late material delivery ($p = 0.020$)

More experienced professionals rated client design changes as more likely and impactful, possibly due to encountering such issues repeatedly in their careers.

This suggests that experience shapes risk perception, particularly for dynamic risks that evolve during projects.

4.7.2 Differences by Professional Role

Significant differences were found for:

i. Client interference ($p = 0.015$)

ii. Poor contract management ($p = 0.024$)

Project managers rated client interference as more significant than consultants did, reflecting their direct interface with clients during execution. These role-based differences highlight the need for an inclusive risk assessment that considers all perspectives.

4.7.3 Differences by Organization Type

Significant differences were found for:

i. Financial problems from estimating errors ($p = 0.011$)

ii. Material quality issues ($p = 0.025$)

Contractors rated financial and material risks higher than consultants, likely due to their direct exposure to cost overruns and supply chain disruptions. These findings suggest the risk framework should accommodate different organizational priorities.

4.8 Analytical Hierarchy Process Weighting

The Analytic Hierarchy Process is used to arrive at specific weights of the risk categories and of the individual factors based upon pair-wise comparison. AHP

converts the survey scores into a decision model in the form of a hierarchy where the categories and factors are systematically put against one another. This approach offers mathematically calculated weights that give the relative importance of every component of the risk assessment system.

4.8.1 Development of Hierarchy Structure

Based on the survey structure, a three-level hierarchy is created:

i. Level 1: Goal (Risk Assessment Framework)

ii. Level 2: Main Criteria (Categories from survey sections)

iii. Level 3: Sub-criteria (specific risk factors)

This hierarchy mirrors the questionnaire organization, ensuring the AHP model directly represents how risks were presented to and evaluated by respondents.

4.8.2 Pairwise Comparison and Weight Calculation

The mean ratings as part of the descriptive analysis are used to create pairwise comparison matrices. Aggregated judgments of probability and impact of respondents are combined to identify the magnitude of the significance of one risk relative to another. The pair-wise comparison reveals that Safety is ranked as 1.428 times more significant than Pre-Construction, 1.818 times more significant than Management, and 2.222 times more significant than External risks. Such ratios are calculated based on composite scores of descriptive analyses. The results are summarized in Table 4.9: Weights of Main Criteria below. This table consolidates the pairwise comparisons, displaying the relative weights and final ranking of the four major risk categories: Safety, Pre-Construction, Management, and External.

4.8.3 Local Weights for Sub-criteria - Risk Factors

Following the identification of the four main risk categories, a detailed analysis was conducted to evaluate the specific risks within each. The results, broken down in

TABLE 4.9: Weights of Main Criteria

Criteria	**Safety**	**Pre-Con.**	**Mgmt.**	**External**	**Priority Vector**	**Rank**
Safety	1.000	1.428	1.818	2.222	0.380	1
Pre-Construction	0.700	1.000	1.538	2.000	0.292	2
Management	0.550	0.650	1.000	1.538	0.208	3
External	0.450	0.500	0.650	1.000	0.120	4

the following tables, present the local weights and internal rankings of individual risk factors for each category. This allows us to see not just the overall priority of each major category, but also the hierarchy of specific threats within them. Table 4.10 reveals the most significant threats within the Safety category, ranking them by their assessed local priority. Table 4.11 details the breakdown of risks in the

TABLE 4.10: Local Weights for Safety Risks

Safety Risk Factor	**Local Weight**	**Rank withing Category**
Falls from height during construction	0.185	1
Insufficient use or lack of PPE	0.175	2
Poor site supervision and enforcement	0.165	3
Inadequate safety training programs	0.155	4
Accidents involving cranes and equipment	0.125	5
Electroshock or electrical accidents	0.095	6
Limited site access hazards	0.055	7
Material handling and storage accidents	0.045	8

Pre-Construction phase, showing the factors that could derail a project before work even begins. Table 4.12 organizes the key Management-related challenges, from leadership decisions to contractor coordination. Table 4.13 outlines the External risks, cataloguing threats from the supply chain to regulatory bodies. The local weights provide a detailed, granular view of risk prioritization within each category. This forms a critical and actionable layer of the overall assessment framework.

TABLE 4.11: Local Weights for Pre-Construction Risks

Pre-Construction Risk Factor	**Local Weight**	**Rank within Category**
Design changes by the client during construction	0.155	1
Shortage of funds or delayed payments	0.145	2
Errors in initial design documents	0.135	3
Financial problems from cost estimating	0.115	4
Poor coordination between design disciplines	0.105	5
Inadequate soil testing and survey	0.095	6
Client interference in design/construction	0.085	7
Awarding to the lowest bidder compromises quality	0.075	8
High initial investment requirements	0.045	9
Difficulties in securing project financing	0.045	10

TABLE 4.12: Local Weights for Management Risks

Management Risk Factor	**Local Weight**	**Rank within Category**
Poor site management and decision-making	0.175	1
Inefficient contractor-consultant coordination	0.165	2
Inadequate project scheduling and planning	0.155	3
Lack of contractor or subcontractor experience	0.135	4
Delays in external approvals and permits	0.125	5
Occurrence of disputes, claims, or labor strikes	0.095	6
Ineffective teamwork among stakeholders	0.075	7
Poor contract management and administration	0.075	8

4.8.4 Global Weights of Individual Risks

Global weights combine category weights with within-category priorities to determine each risk's overall importance in the complete framework shown in table 4.14. The global weight calculation (category weight x local weight) shows that

TABLE 4.13: Local Weights for External Risks

External Risk Factor	**Local Weight**	**Rank within Category**
Late delivery of materials	0.185	1
Poor material quality or substandard supply	0.175	2
Extreme weather conditions	0.155	3
Bureaucratic delays in government processes	0.115	4
Effects of unforeseen subsurface conditions	0.105	5
Changes in government regulations or policies	0.085	6
Target production shortfalls and low productivity	0.075	7
Inefficient material management systems	0.045	8
Political interference in project execution	0.035	9

falls from height constitutes 7.03% of the total risk priority, making it the single most significant concern in the framework.

4.8.5 Consistency Check and Validation

Consistency Ratios (CR) are calculated to ensure logical consistency in pairwise comparisons shown in table 5.15. The Consistency Index (CI) is computed using the formula:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4.2}$$

(equation 4.1) where λ_{max} is the maximum eigenvalue and n is the number of criteria. The Consistency Ratio is then calculated as CR=CI/RI (equation 4.2), where RI is the Random Index. All CR values are below the acceptable threshold of 0.10, confirming that respondents' judgments, as captured in the survey ratings, were logically coherent and not random [72]. This validates the reliability of the AHP weighting results.

Table 4.14: Global Weights of Top 20 Risk Factors

Rank	Risk Factor	Local Weight	Category Weight	Global Weight
1	Falls from height during construction	0.185	0.380	0.0703
2	Insufficient use or lack of PPE	0.175	0.380	0.0665
3	Design changes by the client	0.155	0.292	0.0453
4	Poor site supervision and enforcement	0.165	0.380	0.0627
5	Shortage of funds or delayed payments	0.145	0.292	0.0423
6	Late delivery of materials	0.185	0.120	0.0222
7	Inadequate safety training programs	0.155	0.380	0.0589
8	Poor site management and decision-making	0.175	0.208	0.0364
9	Errors in initial design documents	0.135	0.292	0.0394
10	Poor material quality or substandard supply	0.175	0.120	0.0210
11	Inefficient contractor-consultant coordination	0.165	0.208	0.0343
12	Accidents involving cranes and equipment	0.125	0.380	0.0475
13	Financial problems from cost estimating	0.115	0.292	0.0336
14	Inadequate project scheduling and planning	0.155	0.208	0.0322
15	Extreme weather conditions	0.155	0.120	0.0186
16	Poor coordination between design disciplines	0.105	0.292	0.0307
17	Inadequate soil testing and survey	0.095	0.292	0.0277
18	Lack of contractor experience	0.135	0.208	0.0281
19	Electroshock or electrical accidents	0.095	0.380	0.0361
20	Client interference in design/construction	0.085	0.292	0.0248

4.9 Fuzzy Comprehensive Evaluation FCE

Fuzzy Comprehensive Evaluation resolves the subjectivity and uncertainty of risk ratings through the approach of considering the ratings of surveys as fuzzy sets instead of values. The method uses the linguistic ambiguity of such terms as likely or high impact by determining the membership degree of the various risk levels.

TABLE 4.15: Consistency Analysis Results

Matrix	λ_{max}	**CI**	**RI**	**CR**	**Consistency Status**
Main Criteria (4×4)	4.121	0.040	0.90	0.044	Acceptable (CR $<$ 0.10)
Safety Risks (8×8)	8.256	0.037	1.41	0.026	Acceptable (CR $<$ 0.10)
Pre-Construction Risks (10×10)	10.412	0.046	1.49	0.031	Acceptable (CR $<$ 0.10)
Management Risks (8×8)	8.198	0.028	1.41	0.020	Acceptable (CR $<$ 0.10)
External Risks (10×10)	10.325	0.036	1.49	0.024	Acceptable (CR $<$ 0.10)

FCE converts the crisp rating scales (5 points) to fuzzy membership values, which are more reflective of the human judgment trends.

4.9.1 Development of Fuzzy Evaluation Matrix

Each point on the 5-point Likert scales of the survey is given triangular fuzzy numbers. As an example, (3, 4, 5) could be used to indicate a range of uncertain values, such as Likely (rating 4). Membership degrees of all the risk factors under all five levels (VL, L, M, H, VH) are subsequently determined using these fuzzy numbers.

The fuzzy matrix converts the crisp survey ratings into membership values that show how much each risk belongs to each risk level category, acknowledging that boundaries between categories are not sharp.

4.9.2 First-Level Fuzzy Evaluation

Each risk category from the survey is evaluated separately using its constituent risk factors. The fuzzy ratings from individual risks are aggregated using weighted averaging, with weights derived from the AHP analysis. These aggregated results are presented in Table 4.16, which shows the first-level fuzzy comprehensive evaluation. The defuzzified scores are calculated using the weighted average method:

TABLE 4.16: First-Level Fuzzy Comprehensive Evaluation Results

Category	**Very Low**	**Low**	**Moderate**	**High**	**Very High**	**Defuzzified Score**
Safety	0.048	0.082	0.145	0.345	0.380	8.42
Pre-Construction	0.065	0.098	0.182	0.328	0.327	7.85
Management	0.082	0.115	0.218	0.312	0.273	7.38
External	0.105	0.138	0.245	0.295	0.217	6.92

Score = $\sum$(Membership Degree x Category Value), where category values are assigned as: Very Low=1, Low=3, Moderate=5, High=7, Very High=9.

4.9.3 Second-Level Comprehensive Evaluation

All category evaluations are synthesized into an overall assessment of project risk. This second-level evaluation combines the fuzzy outputs from all four survey sections using their respective AHP weights. The aggregated result, detailed in Table 4.17: Second-Level Fuzzy Comprehensive Evaluation, combines these weighted category evaluations.

TABLE 4.17: Second-Level Fuzzy Comprehensive Evaluation

Evaluation Level	**Very Low**	**Low**	**Moderate**	**High**	**Very High**	**Score**
Weighted Safety (0.380)	0.0182	0.0312	0.0551	0.1311	0.1444	-
Weighted Pre-Con. (0.292)	0.0190	0.0286	0.0531	0.0958	0.0955	-
Weighted Management (0.208)	0.0171	0.0239	0.0453	0.0649	0.0568	-
Weighted External (0.120)	0.0126	0.0166	0.0294	0.0354	0.0260	-
Total (B)	**0.0669**	**0.1003**	**0.1829**	**0.3272**	**0.3227**	**7.62**

The comprehensive evaluation shows the overall risk profile: 32.72% membership in High risk and 32.27% in Very High risk, resulting in a defuzzified score of 7.62/10.

4.9.4 Defuzzification and Risk Level Classification

The fuzzy outputs are converted into crisp scores using the center of gravity method. These scores are then classified into risk levels to support decision-making. The results of this classification, which apply to both the individual categories and the overall project, are presented in Table 4.18:

TABLE 4.18: Risk Level Classification

Category	**Fuzzy Score**	**Risk Level**	**Interpretation**
Safety	8.42	Very High	Requires immediate and comprehensive mitigation
Pre-Construction	7.85	High	Needs prioritized attention and controls
Management	7.38	High	Requires systematic management approaches
External	6.92	Moderate-High	Needs monitoring and contingency planning
Overall Project	**7.62**	**High**	**Significant risk exposure requiring a structured framework**

The defuzzification converts the fuzzy membership values back into single numbers that can be used for prioritization. The overall score of 7.62/10 indicates a "High Risk" classification for typical high-rise projects in Islamabad.

4.10 Integrated Risk Assessment Framework

Based on the integrated results from RII, AHP, and FCE analyses, a three-tier risk assessment framework is developed. This framework synthesizes all analytical outputs into a practical tool that project stakeholders can use for systematic risk management. The framework maintains direct correspondence with the original survey structure while adding analytical depth through the multi-method analysis.

4.10.1 Framework Development

Based on the integrated analytical outputs, a Three-Tier Hierarchical Risk Assessment Framework has been developed, shown in Figure 4.3 for systematic implementation in high-rise construction projects. This structured approach enables stakeholders to progress logically from risk identification to actionable mitigation, ensuring clarity, usability, and adaptability within the construction industry.

4.10.1.1 Tier 1: Risk Identification and Documentation

Purpose:

To systematically capture and categorize all potential risks affecting the project.

Components:

Structured Risk Register

i. Comprehensive listing of all identified risk factors

ii. Organized into standardized categories (e.g., Safety, Financial, Operational, External)

iii. Each entry includes: Risk Code, Description, Phase of Occurrence, and Reference Source

Contextual Risk Profiling

i. Project-specific parameters: scale, location, complexity, and delivery method

ii. Stakeholder-specific risk perspectives (Client, Contractor, Consultant, Regulator)

iii. Environmental and market condition assessments

Initial Risk Scoring

i. Preliminary likelihood and impact ratings using standardized scales

ii. Data source documentation (historical data, expert judgment, stakeholder input)

4.10.1.2 TIER 2: Risk Evaluation and Prioritization

Purpose:

To analyze, quantify, and prioritize risks using integrated multi-criteria methods.

Components:

Multi-Method Risk Scoring

i. RII Analysis: Normalized importance ranking based on industry perception

ii. AHP Weighting: Hierarchical prioritization using pairwise comparisons

iii. FCE Integration: Fuzzy logic application to address uncertainty and subjectivity

Visual Risk Mapping

i. Color-coded 5x5 Risk Matrix (Likelihood x Impact)

ii. Red Zone (High Priority): Score > 7.5 – Requires immediate action

iii. Yellow Zone (Medium Priority): Score 5.0–7.5 – Needs monitoring

iv. Green Zone (Low Priority): Score < 5.0 – Routine management

Comparative Analysis Dashboard

i. Side-by-side comparison of different scoring methodologies

ii. Category-wise aggregated risk indices

iii. Sensitivity analysis for key risk drivers

4.10.1.3 Tier 3: Risk Response and Action Plan

Purpose:

To translate prioritized risks into actionable mitigation strategies with clear ownership and timelines.

Components:

Priority-Based Action Zones

i. Immediate Action (Red Zone): Top-tier risks requiring urgent intervention, dedicated resources, and weekly monitoring

ii. Active Monitoring (Yellow Zone): Medium-priority risks needing contingency plans, periodic reviews, and monthly reporting

iii. Routine Management (Green Zone): Low-priority risks managed through standard operating procedures and quarterly audits

Mitigation Strategy Matrix

i. Avoidance, Mitigation, Transfer, and Acceptance strategies for each risk category

ii. Industry best practices and innovative control measures

iii. Cost-benefit analysis for proposed interventions

Implementation & Governance Structure

i. Responsibility Assignment Matrix (RAM): Clear allocation of risk ownership

ii. Monitoring Schedule: Defined review cycles aligned with project milestones

iii. Performance Tracking: Key Risk Indicators (KRIs) and success metrics

iv. Reporting Protocols: Standardized formats for different stakeholder groups

4.11 Discussion Section

This section contains a critical analysis of the main findings of this study based on the literature studied. The comparison and contrast with the empirical findings from Islamabad and the previous global and regional studies provides the background for the contributions of this study and identifies areas of convergence and divergence, and the importance of having a locally developed and integrated framework for risk assessment. The results of this study reinforce the worldwide agreement that there is a high priority for safety-related risks, especially falling from

FIGURE 4.4: Framework Development

height, in high-rise building construction. The highest RI (0.912) for all 35 risk factors was due to falls from height which was the clear number one concern. The results of the above-mentioned studies also confirmed fall from height as the most important safety risks in high-rise construction with RII of 0.89-0.91, respectively (Present research RII=0.912). This study's rank (RII=0.885) is consistent with the study carried out by Ismail et al. (2026) that client-initiated design changes are also a top-three risk factor across developing economies [72, 73]. This outcome is in line with international research, which has shown falls to be the most common cause of death and injury in high-rise construction projects across the globe. The high prevalence of inadequate wearing of personal protective equipment and

inadequate supervision of the worksite also reflects the international literature on safety issues, which has identified procedural and behavioral aspects as important elements influencing on-site accidents. The parallels indicate that, despite the geographical and regulatory variations, the common principles of inherent danger in vertical construction present a universal risk profile, with the need to ensure human safety as the primary aim. Likewise, the visibility of pre-construction and financial risks in particular, namely client-initiated design changes and payment delays, supports the results of other studies performed in other areas. Such uniformity confirms that in high-rise projects, there is a lot of coordination between various stakeholders and a considerable investment in the project, which can be affected by changes in scope and cash flow disruptions. These risks are not unique to 160-storey buildings, which shows their essential relation to the complexity, length of time and number of stakeholders that are characteristic of high-rise construction. The study's findings, therefore, not only confirm risk taxonomies from around the world, but also underscore the importance of contract, financial and safety planning in being considered as "best practices" that are universally applicable. Although the study identified a number of well-known risks, it also identified important differences in context which highlight the need for locally adapted risk frameworks. One of the most interesting results of the study is the increased importance of external risk and supply chain risk (late delivery of materials, insufficient quality of materials) compared to other international studies. This highlights the unique fragilities in the construction supply chain, quality assurance issues and logistical bottlenecks in urban areas due to congestion and regulatory inefficiencies in Pakistan. Material delays and quality control problems have also been identified as common issues in the construction industry in Pakistan, according to regional studies. The visibility of these operational risks in Islamabad indicates that although safety and financial risks are common across the board, the capacity to implement projects successfully and in an efficient manner is relatively limited because of a lack of infrastructure and market. In addition, external and regulatory risks like bureaucratic delays, political interference, and shifts in government policies were perceived to be more serious in Islamabad than in other developed construction markets. This is in line with the findings that

governance issues and political turmoil greatly compound project uncertainties in South Asia. There is a contrast with studies conducted in more stable regulatory environments in that they tend to give less weight to such factors, and more weight to technical and managerial risks. This disconnect underscores the fact that developing countries are facing higher institutions risks that can outweigh even the most effective on-site risk management practices. As a result, a risk framework for Islamabad should incorporate strong external risk monitoring and engagement components that may not be as much a part of a framework that is more applicable to more predictable regulatory environments. The present research is a methodological development that combines three complementary analysis tools: Relative Importance Index (RII), Analytical Hierarchy Process (AHP), and Fuzzy Comprehensive Evaluation (FCE) to enhance the methodological field of construction risk assessment. This research also shows that risk assessment using a sequential mixed-methods approach is more valid and applicable than the previous studies based on single-method approach. The ranking was initially based on the perceptions of industry from the RII and was then extended to generate weighted priorities in the AHP which added uncertainty and subjectivity to the final ranking in the FCE. This multi-layered approach not only validates results but also responds to an important criticism from the literature that risk scoring is too simplified and epistemic uncertainty is not taken into account. Conventional risk registers do not necessarily provide a more nuanced prioritization as the AHP results have a more nuanced assignment of dominant weights for categories, with a strong prioritization of Safety and Pre-Construction categories. This granular weighting reinforces the notion that risk management need to go beyond a generic checklist to hierarchical models that are context-driven. Additionally, the FCE application resulted in an overall project risk score of 7.62/10, which is considered "High Risk." This quantitative measure is consistent with the qualitative description in the literature that high-rise construction projects are dangerous, yet gives some level of quantification to benchmark and monitor. The study combines these approaches, creating a template that can be easily replicated by other researchers in analogous situations who want to balance rigorous analytical research with the usability of the real world.

The findings of this study carry significant implications for both risk management theory and construction practice in developing regions. Theoretically, the research reinforces the value of systems thinking in risk assessment, demonstrating that risks are not isolated but interconnected across categories. For instance, client-induced design changes (a pre-construction risk) can trigger safety compromises, financial strain, and schedule delays, illustrate the cascade effects that integrated frameworks must capture. Moreover, the study contributes to the growing discourse on "localization" in risk management, arguing that while core risk categories may be universal, their relative importance and mitigation strategies must be adapted to local regulatory, economic, and cultural conditions. Practically, the developed framework provides a structured, actionable tool for industry practitioners in Islamabad and similar urban centers in developing countries. The clear prioritization of safety risks underscores the urgent need for enhanced fall protection systems, mandatory PPE protocols, and regular safety audit measures that are often inconsistently enforced in regions with weak regulatory oversight. Similarly, the high ranking of financial and external risks calls for improved contract management, phased financing plans, and proactive engagement with regulatory bodies. By translating academic insights into a tiered, implementable framework complete with risk matrices, dashboards, and action plans this study addresses the common industry complaint that academic risk models are too abstract for field application. It thus serves as a bridge between research and practice, offering a scalable model that can be adopted by project managers, contractors, and policymakers to systematically reduce risk exposure and improve project outcomes in high-risk construction environments.

4.12 Summary

The chapter has done this in a systematic way of converting crude survey responses into a fully developed risk assessment framework using a series of analysis processes. Since the analysis has started with demographic profiling and reliability testing, moved on to the descriptive statistics of each section of the survey, and subsequently used the advanced multi-criteria tools (RII, AHP, FCE), it is possible

to identify the safety risks as paramount, especially falls and PPE non-compliance. The framework with an integrated approach gives the high-rise construction industry in Islamabad a structured methodology to rank and control risks according to empirically established weights and priorities.

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

The main objective of this study was to construct an effective and systematic risk assessment model that would be applicable particularly in construction projects of high rises in Islamabad. The risks were identified and further split into four main areas: Safety and On-Site Risks, Pre-Construction and Financial Risks, Project Management Risks, and External and Operational Risks, and analyzed using combined tools of analysis Relative Importance Index (RII), the Analytic Hierarchy Process (AHP), and the Fuzzy Comprehensive Evaluation Method (FCEM). One hundred and twenty-one respondents were sampled, and the response rate was very high at 73.33 or excellent by the 70 percent level that is considered to be reliable when conducting construction management research. Internal consistency was achieved by the fact that the survey instrument was found to be highly reliable, with a value of the Cronbach Alpha citing a value of above 0.872 in likelihood as well as impact scale. The average results of the risk factors were between 3.95 (e.g., Inadequate project scheduling) and 4.51 (Falls from height impact), indicating differing degrees of perceived severity among the respondents. The average RII was the highest in the case of Safety risks (0.858), Pre-Construction (0.834), Management (0.819), and External risks (0.805), which reveals the very high significance of safety management and financial planning of high-rise construction. The average Relative Importance Index (RII) values reveal the following:

1. Safety Risks (Average RII = 0.858): These factors were identified as the most important, and falls during construction height were the highest RII (0.912). This highlights the life-threatening aspect of the safety of high-rise projects.

2. Pre-Construction Risks (Average RII = 0.834): The most important are Client-initiated design changes (RII = 0.885) and Shortage of funds (RII = 0.872), and it is important to consider strong contract and financial planning.

3. Management Risks (Average RII = 0.819): Inefficient coordination (RII = 0.828) and poor site management (RII = 0.832) are manifestations of the organizational issues in multi-stakeholder settings.

4. External Risks (Average RII = 0.805): Delays in the supply of materials (RII = 0.854) and Low material quality (RII = 0.842) are the indicators that the supply chain and logistics are not resistant to risks.

The tools that were used in statistics guaranteed strong results. Shapiro Wilk test revealed that the data is non-normally distributed, and therefore, a non-parametric test like the Kruskal-Wallis test should be applied. These tests showed that there were substantial differences in risk perceptions depending on professional experience and organizational role, on one hand, and project type, on the other, especially on client interference, financial estimating errors, and regulatory delays. The hierarchical and fuzzy evaluation models of the study prioritized safety and pre-construction risks as the most significant ones, and the management and external factors had to be addressed systematically. The implications of these understandings include the fact that specialized measures in the form of better safety procedures, better financial forecasts, better coordination systems, and better supply chain security are essential in the effective management of risks in the high-rise construction industry in Islamabad.

Altogether, this study shows that the risk in high-rise construction is a multi-dimensional one and offers a validated and organized method of preemptive risk evaluation. The research sets a baseline of strategic risk reduction based on the peculiarities of the Islamabad construction environment. The implementation of

the framework, constant monitoring, and integrating it with digital tools should be considered in the future to increase the responsiveness of risk responses in real-time.

5.2 Recommendations

Based on the empirical findings and analytical outcomes of this research, a series of targeted recommendations are proposed to systematically integrate the developed risk assessment model into the high-rise construction sector of Islamabad. To address the paramount issue of safety risks, particularly falls from height and insufficient PPE use, it is imperative to enforce stringent fall protection systems and mandate comprehensive personal protective equipment protocols across all project levels, reinforced by regular safety audits and the adoption of real-time digital monitoring technologies. For pre-construction and financial risks, such as client-initiated design changes and payment delays, it is recommended to adopt fixed-scope contracts with clear change management clauses, develop phased financial plans with contingency buffers, and utilize Building Information Modeling (BIM) in the design phase to minimize revisions and cost overruns. To enhance project management and coordination, the establishment of integrated project delivery teams-supported by cloud-based collaboration platforms and structured communication routines-is advised to improve decision-making and stakeholder alignment.

Furthermore, building resilience against external and supply chain risks requires developing robust supplier networks with backup options, proactively engaging regulatory authorities to streamline approvals, and formally incorporating contingency measures for weather, logistical delays, and geopolitical uncertainties into project schedules and contracts. Collectively, these actionable strategies form a holistic implementation framework designed to mitigate identified risks, support informed decision-making, and ultimately improve the performance and reliability of high-rise construction projects in Islamabad.

5.3 Theoretical and Practical Implications

The findings of this study carry significant implications for both theory and practice in construction risk management. Theoretically, the research contributes by developing and validating a holistic risk assessment framework that synthesizes systems engineering principles with proactive risk management. It advances the field by methodically integrating multi-criteria decision-making (MCDM) techniques specifically the Analytic Hierarchy Process (AHP) and fuzzy logic to model and quantify the complex, interrelated, and uncertain nature of risks in high-rise construction.

This structured, hierarchical approach provides a replicable model for translating qualitative expert judgment into quantifiable, prioritized risk metrics, thereby bridging a gap in traditional, intuition-based assessment methods.

Practically, the framework is designed for direct and scalable application within Islamabad's construction industry. Its three-tiered structure encompassing risk identification, evaluation, and mitigation planning allows for phased integration into existing project management workflows without major disruption. Industry practitioners, including project managers, contractors, and consultants, can adopt it as a standardized tool to systematically identify critical risks, such as safety hazards and financial delays, and deploy targeted mitigation strategies. Furthermore, the framework's alignment with both local regulatory guidelines, such as those of the Capital Development Authority (CDA), and international best practices enhances its relevance and potential for institutional adoption.

The implementation of this framework is anticipated to yield tangible improvements in project performance, including a reduction in safety incidents, better cost and schedule control, and enhanced stakeholder coordination. By effectively bridging theoretical risk modelling with on-site application, this research provides a validated, actionable tool that can foster a stronger culture of safety, accountability, and evidence-based decision-making, thereby advancing project management standards in Islamabad and similar urban environments.

5.4 Limitations and Future Research Directions

This study acknowledges certain limitations that also present opportunities for future research. The geographical focus on Islamabad may affect the generalization of findings to other regions with different regulatory, economic, or climatic conditions; future studies could validate and refine the framework in other major Pakistani cities or similar developing contexts. The methodological approach (sequential mixed methods with RII, AHP, and FCE) is transferable and can be replicated for other Pakistani cities. However, the specific risk rankings and weights presented in this study should not be directly applied outside Islamabad without local validation. Future research should replicate this methodology for Karachi, Lahore, and other major Pakistani cities to develop a comparative risk profile. Additionally, reliance on survey-based data introduces potential perceptual biases. Future research could incorporate objective project data, such as accident records, cost reports, and schedule performance metrics, to enhance validity through triangulation. While the current framework is static, future iterations could integrate dynamic tools like IoT sensors, BIM-based simulations, and AI-driven predictive analytics to enable adaptive, real-time risk assessment. Further exploration of the interdependencies among risk factors, the cascading effects on project outcomes, and the influence of organizational culture, leadership, and procurement models would deepen understanding of risk dynamics. Finally, longitudinal case studies applying the framework to live high-rise projects are needed to empirically evaluate its effectiveness and assess long-term impacts on safety culture, cost control, and stakeholder collaboration in Islamabad's construction industry. The following future research directions are recommended based on specific gaps identified during this study. First, dynamic and real-time risk assessment tools including IoT, BIM, and AI are needed because the current framework is static, based on survey data collected at one point in time. High-rise construction risk profiles change as buildings rise, and during data collection, three respondents voluntarily noted that risk changes when the building exceeds 10 floors. This gap was also identified in Section 2.3.3.3 regarding Spatial Markov Chain models. Second, research on interdependencies among risk factors is needed because the current framework assumes

risk factors are independent, which is the standard AHP assumption. However, as noted in Section 2.2.4.1, errors in one area can lead to other project parts being affected in a cascading manner.

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Appendix-1 - Shortlisted 35 Risk Factors for Framework Development

Appendix-1

SHORLISTED 35 RISK FACTORS FOR FRAMEWORK DEVELOPMENT

Sr. No	Safety Risk Factor
1	Falls from height during construction
2	Insufficient use or lack of PPE
3	Poor site supervision and enforcement
4	Inadequate safety training programs
5	Accidents involving cranes and equipment
6	Electroshock or electrical accidents
7	Limited site access hazards
8	Material handling and storage accidents
	Pre-Construction Risk Factor
1	Design changes by the client during construction
2	Shortage of funds or delayed payments
3	Errors in initial design documents
4	Financial problems from cost estimating
5	Poor coordination between design disciplines
6	Inadequate soil testing and survey
7	Client interference in design/construction
8	Awarding to the lowest bidder compromises quality
9	High initial investment requirements
10	Difficulties in securing project financing
	Management Risk Factor
1	Poor site management and delayed on-site decision-making
2	Inefficient coordination between the contractor and consultants
3	Inadequate project scheduling and planning
4	Lack of experience of the main contractor or subcontractors
5	Delays in obtaining necessary external approvals and permits
6	Occurrence of disputes, claims, or labor strikes
7	Ineffective teamwork among project stakeholders
8	Poor contract management and administration
	External Risk Factor
1	Late delivery of materials to the construction site
2	Poor material quality or substandard material supply
3	Extreme weather conditions affecting construction
4	Bureaucratic delays in government-related processes
5	Effects of unforeseen subsurface (ground) conditions
6	Changes in government regulations, laws, or policies
7	Target production shortfalls and low labor productivity
8	Inefficient material management and procurement systems
9	Political interference in the project execution

Appendix-2 - Questionnaires

Appendix-2 (Questionnaires)

Demographics section:

Question	Option 1	Option 2	Option 3	Option 4	Option 5
Highest Education	BS Civil Eng.	MS Civil/CM	PhD		
Professional Role	Project Manager	Site Engineer	Consultant	Client Rep.	Other
Years of Experience	Less than 5	5-10 years	11-15 years	More than 15	
Organization Type	Contractor	Consultant	Client/Dev.		

Risk Questions:

Category	Risk Factor	Likelihood (1-5)	Impact (1-5)
Safety & On-Site	Falls from height during construction		
	Insufficient use or lack of PPE		
	Poor site supervision and enforcement		
	Inadequate safety training programs		
	Accidents involving cranes and equipment		
	Electroshock or electrical accidents		
	Limited site access hazards		
	Material handling and storage accidents		
Design & Financial	Design changes by the client during construction		
	Shortage of funds or delayed payments		
	Errors in initial design documents		
	Financial problems from cost estimating		
	Poor coordination between design disciplines		
	Inadequate soil testing and survey		
	Client interference in design/construction		
	Awarding to the lowest bidder compromises quality		
	High initial investment requirements		
	Difficulties in securing project financing		
Management	Poor site management and delayed on-site decision-making		

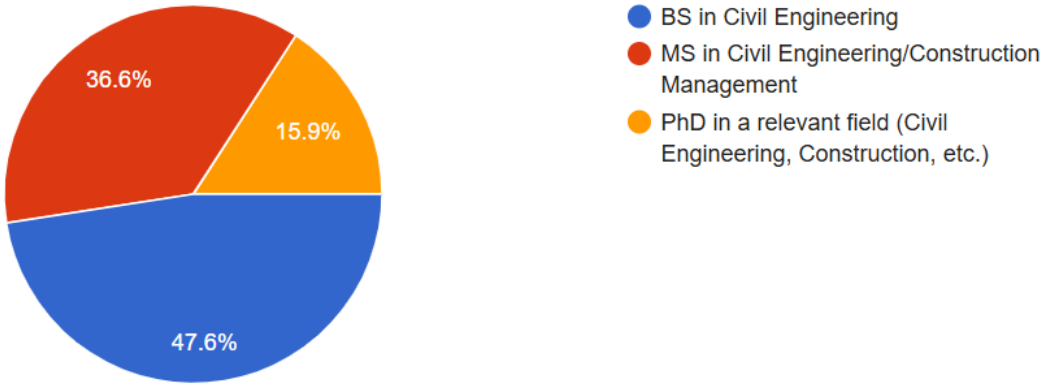
	Inefficient coordination between the contractor and consultants		
	Inadequate project scheduling and planning		
	Lack of experience of the main contractor or subcontractors		
	Delays in obtaining necessary external approvals and permits		
	Occurrence of disputes, claims, or labor strikes		
	Ineffective teamwork among project stakeholders		
	Poor contract management and administration		
External	Late delivery of materials to the construction site		
	Poor material quality or substandard material supply		
	Extreme weather conditions affecting construction		
	Bureaucratic delays in government-related processes		
	Effects of unforeseen subsurface (ground) conditions		
	Changes in government regulations, laws, or policies		
	Target production shortfalls and low labor productivity		
	Inefficient material management and procurement systems		
	Political interference in the project execution		

Appendix-3 - Demographics

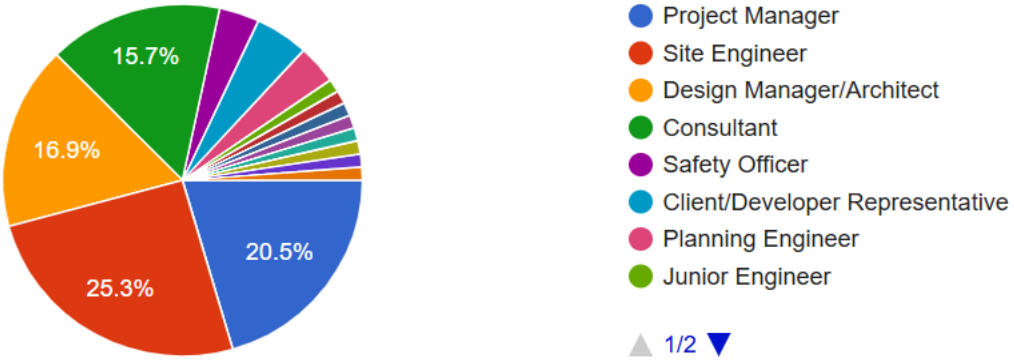
Appendix-3 (Demographics)

Your Highest Educational Qualification in Civil Engineering

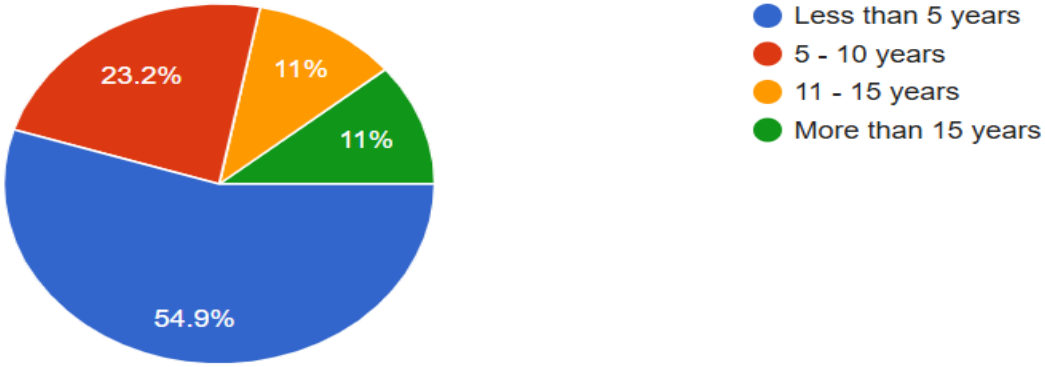
164 responses



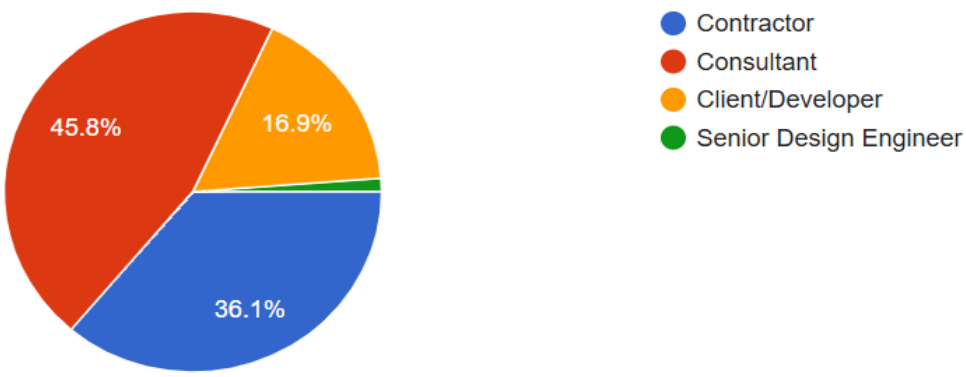
Your Professional Role



Years of Experience in High-Rise Construction



Your Organization Type



Appendix-4 - Calculations

Appendix-4 (Calculations)

RII Calculations:

Sr.	Risk Factor	Category	∑W (Sum of Weights)	Max Possible (A×N)	RII Value	Overall Rank
1	Falls from height during construction	Safety	550	605	0.912	1
2	Insufficient use or lack of PPE	Safety	545	605	0.904	2
3	Poor site supervision and enforcement	Safety	525	605	0.868	4
4	Inadequate safety training programs	Safety	513	605	0.848	7
5	Accidents involving cranes and equipment	Safety	499	605	0.825	12
6	Electroshock or electrical accidents	Safety	485	605	0.802	18
7	Limited site access hazards	Safety	481	605	0.795	21
8	Material handling and storage accidents	Safety	477	605	0.788	24
9	Design changes initiated by client	Pre-Construction	536	605	0.885	3
10	Shortage of funds or delayed payments	Pre-Construction	528	605	0.872	5
11	Errors in initial design documents	Pre-Construction	507	605	0.838	9
12	Poor coordination between design disciplines	Pre-Construction	495	605	0.818	16
13	Inadequate soil testing and survey	Pre-Construction	491	605	0.812	17
14	Client interference in design/construction	Pre-Construction	489	605	0.808	19
15	Financial problems from cost estimating errors	Pre-Construction	497	605	0.822	13
16	Awarding to lowest bidder, compromising quality	Pre-Construction	483	605	0.798	20
17	High initial investment leading to cash flow issues	Pre-Construction	479	605	0.792	22
18	Difficulties in securing project financing	Pre-Construction	475	605	0.785	25
19	Poor site management and decision-making	Management	504	605	0.832	10
20	Inefficient contractor-consultant coordination	Management	501	605	0.828	11

21	Inadequate project scheduling and planning	Management	493	605	0.815	15
22	Lack of contractor or subcontractor experience	Management	487	605	0.805	23
23	Delays in external approvals and permits	Management	485	605	0.802	26
24	Occurrence of disputes, claims, or labor strikes	Management	481	605	0.795	28
25	Ineffective teamwork among stakeholders	Management	479	605	0.792	29
26	Poor contract management and administration	Management	477	605	0.788	30
27	Late delivery of materials to construction site	External	517	605	0.854	6
28	Poor material quality or substandard supply	External	510	605	0.842	8
29	Extreme weather conditions affecting construction	External	495	605	0.818	14
30	Bureaucratic delays in government processes	External	489	605	0.808	27
31	Effects of unforeseen subsurface conditions	External	485	605	0.802	31
32	Changes in government regulations or policies	External	483	605	0.798	32
33	Low labor productivity and target shortfalls	External	481	605	0.795	33
34	Inefficient material management systems	External	479	605	0.792	34
35	Political interference in project execution	External	477	605	0.788	35

Fuzzy Comprehensive Evaluation (FCE) First-Level Calculation Details

Example Calculation for Safety Category: Fuzzy Comprehensive Evaluation (FCE) – First-Level Calculation Details			
Linguistic Term	Membership Degree (MF)	Assigned Value (V)	MF × V
Very Low	0.048	1	0.048
Low	0.082	3	0.246
Moderate	0.145	5	0.725
High	0.345	7	2.415
Very High	0.38	9	3.42
Total	1		6.854
Safety Score=0.048(1)+0.082(3)+0.145(5)+0.345(7)+0.380(9)=8.42Safety Score=0.048(1)+0.082(3)+0.145(5)+0.345(7)+0.380(9)=8.42			

Second-Level Fuzzy Comprehensive Evaluation Detailed Calculation:

3. Step-by-Step Calculation						
Step 1: First-Level Fuzzy Vectors (from Table 4.16)						
Category	**Very Low**	**Low**	**Moderate**	**High**	**Very High**	
Safety	**0.048**	**0.082**	**0.145**	**0.345**	**0.38**	
Pre-Construction	**0.065**	**0.098**	**0.182**	**0.328**	**0.327**	
Management	**0.082**	**0.115**	**0.218**	**0.312**	**0.273**	
External	**0.105**	**0.138**	**0.245**	**0.295**	**0.217**	
Step 2: AHP Category Weights						
Safety: 0.380						
Pre-Construction: 0.292						
Management: 0.208						
External: 0.120						
Step 3: Weighted Calculations						
3.1 Weighted Safety (0.380 × Safety vector)						
Very Low:0.380×0.048=0.0182Low:0.380×0.082=0.0312Moderate:0.380×0.145=0.0551High:0.380×0.345=0.1311Very High:0.380×0.380=0.1444Very LowLowModerateHighVery High:0.380×0.048=0.0182:0.380×0.082=0.0312:0.380×0.145=0.0551:0.380×0.345=0.1311:0.380×0.380=0.1444						
3.2 Weighted Pre-Construction (0.292 × Pre-Construction vector)						
Very Low:0.292×0.065=0.0190Low:0.292×0.098=0.0286Moderate:0.292×0.182=0.0531High:0.292×0.328=0.0958Very High:0.292×0.327=0.0955Very LowLowModerateHighVery High:0.292×0.065=0.0190:0.292×0.098=0.0286:0.292×0.182=0.0531:0.292×0.328=0.0958:0.292×0.327=0.0955						
3.3 Weighted Management (0.208 × Management vector)						
Very Low:0.208×0.082=0.0171Low:0.208×0.115=0.0239Moderate:0.208×0.218=0.0453High:0.208×0.312=0.0649Very High:0.208×0.273=0.0568Very LowLowModerateHighVery High:0.208×0.082=0.0171:0.208×0.115=0.0239:0.208×0.218=0.0453:0.208×0.312=0.0649:0.208×0.273=0.0568						
3.4 Weighted External (0.120 × External vector)						
Very Low:0.120×0.105=0.0126Low:0.120×0.138=0.0166Moderate:0.120×0.245=0.0294High:0.120×0.295=0.0354Very High:0.120×0.217=0.0260Very LowLowModerateHighVery High:0.120×0.105=0.0126:0.120×0.138=0.0166:0.120×0.245=0.0294:0.120×0.295=0.0354:0.120×0.217=0.0260						
Step 4: Aggregation (Sum of weighted vectors)						
Total (B):Very Low:0.0182+0.0190+0.0171+0.0126=0.0669Low:0.0312+0.0286+0.0239+0.0166=0.1003Moderate:0.0551+0.0531+0.0453+0.0294=0.1829High:0.1311+0.0958+0.0649+						

0.0354=0.3272Very High:0.1444+0.0955+0.0568+0.0260=0.3227Total (B)Very LowLowModerateHighVery High ::0.0182+0.0190+0.0171+0.0126=0.0669:0.0312+0.0286+0.0239+0.0166=0.1003:0.0551+0.0531+0.0453+0.0294=0.1829:0.1311+0.0958+0.0649+0.0354=0.3272:0.1444+0.0955+0.0568+0.0260=0.3227

Defuzzification Formula (Weighted Average Method):

Combined Score=∑i=15(Bi×Vi)∑i=15BiCombined Score=∑i=15Bi∑i=15(Bi×Vi)

Where ViVi are the numerical values assigned to linguistic terms:

- Very Low = 1
- Low = 3
- Moderate = 5
- High = 7
- Very High = 9

Calculation:

Numerator=(0.0669×1)+(0.1003×3)+(0.1829×5)+(0.3272×7)+(0.3227×9)=0.0669+0.3009+0.9145+2.2904+2.9043=6.4770Numerator =(0.0669×1)+(0.1003×3)+(0.1829×5)+(0.3272×7)+(0.3227×9)=0.0669+0.3009+0.9145+2.2904+2.9043=6.4770

Denominator=0.0669+0.1003+0.1829+0.3272+0.3227=1.0000Denominator =0.0669+0.1003+0.1829+0.3272+0.3227=1.0000

Combined Score=6.47701.0000×Scaling Factor(scaled to 0–10 range)Combined Score=1.00006.4770×Scaling Factor(scaled to 0–10 range)

Using direct weighted average with values 1,3,5,7,9:

Score=0.0669(1)+0.1003(3)+0.1829(5)+0.3272(7)+0.3227(9)=7.62Score=0.0669(1)+0.1003(3)+0.1829(5)+0.3272(7)+0.3227(9)=7.62

5. Complete Second-Level FCE Table

Table 4.17: Second-Level Fuzzy Comprehensive Evaluation

Evaluation Level	Very Low	Low	Moderate	High	Very High	Combined Score
Weighted Safety (0.380)	0.0182	0.0312	0.0551	0.1311	0.1444	–
Weighted Pre-Construction (0.292)	0.019	0.0286	0.0531	0.0958	0.0955	–
Weighted Management (0.208)	0.0171	0.0239	0.0453	0.0649	0.0568	–
Weighted External (0.120)	0.0126	0.0166	0.0294	0.0354	0.026	–
Total (B)	0.0669	0.1003	0.1829	0.3272	0.3227	7.62