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RISK MANAGEMENT IN LARGE-SCALE CONSTRUCTION PROJECTS: IDENTIFYING KEY CHALLENGES AND EFFECTIVE MITIGATION STRATEGIES

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ABSTRACT

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The economic need for mega-construction works including highways and airports results in multiple types of risks that produce both cost increases and construction delays with safety hazards. Despite frameworks like ISO 31000 and PMBOK, implementation challenges, stakeholder misalignment, and emerging risks persist. The research develops improvements in risk management by identifying fundamental risk types while analyzing project implementation obstacles and evaluating defense measures used in big construction projects. Using a qualitative approach grounded in constructivism, the research reviewed 38 empirical sources (2017–2025), including journals, case studies, and industry reports. Thematic analysis, supported by Python tools, was used to analyze 107 risk descriptions, 76 challenge descriptions, and 82 mitigation strategy descriptions. Findings indicate that "Other Risks" (29.0%) and Operational Risks (17.8%) dominate, with Technical Risks (10.3%) and Financial Risks (9.3%) interconnected, and Environmental Risks (7.5%) emphasizing sustainability. Challenges like poor coordination and complexity, marked by "hinder" (25 instances) and "complicate" (23 instances), impede risk management. Effective strategies include contingency planning, risk identification, systematic frameworks, and technology adoption (e.g., Building Information Modeling), addressing financial, operational, and technical risks while promoting sustainability. This study advocates for integrated risk management to enhance coordination and risk awareness. The findings might not apply to specific region projects or small projects because the research relied on literature-based data and lacked stakeholder feedback while also having a wide geographical scope. Future research should incorporate real-time data, conduct region-specific analyses, and use advanced NLP to capture emerging risks and refine strategies. This study offers actionable insights for resilient and sustainable construction project outcomes.

Keywords large-scale construction projects, mitigation strategies, risk categories, risk management, thematic analysis

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ABBREVIATIONS

Abbreviation	Full Form
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BERT	Bidirectional Encoder Representations from Transformers
BIM	Building Information Modeling
CMCPs	Cross-Regional Mega Construction Projects
CRM	Construction Risk Management
CSCRM	Construction Supply Chain Risk Management
ERM	Enterprise Risk Management
EWM	Entropy Weight Method
FMEA	Failure Mode and Effect Analysis
ISO	International Organization for Standardization
LCSA	Life Cycle Sustainability Assessment
LDA	Latent Dirichlet Allocation
MCDM	Multicriteria Decision-Making
MCRI	Multi-sentence Context-aware Risk Identification
MCRI	Multi-sentence Context-aware Risk Identification
MIPs	Megha Infrastructure Projects
NLP	Natural Language Processing
NLTK	Natural Language Toolkit
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
RAKE	Rapid Automatic Keyword Extraction
SMEs	Small and Medium-sized Enterprises
TF-IDF	Term Frequency-Inverse Document Frequency

1 INTRODUCTION

Airports alongside bridges and highways define essential elements for modern economies and social advancement according to Mok et al. (2015). These nationwide projects demand considerable capital injections while involving intricate design work along with protracted construction periods as well as essential coordination between officials and construction firms and residential groups (Mok et al., 2015). The Burj Khalifa reached its position as the world's tallest building by consuming more than $1.5 billion in funds with advanced engineering involved (Flyvbjerg, 2017). The historical project of Channel Tunnel serves as evidence for why proper risk management techniques must be combined with effective stakeholder coordination (Ametller et al., 2017). The successful completion of projects depends on effective management of economic interests along with social effects and regulatory requirements and high-quality construction practices (Mok et al., 2015). Nevertheless, they still face financial unstable (e.g. budget overruns), operational inefficiency (e.g. delays), regulatory change, environmental uncertainty, and socio-political challenges (Zou et al., 2007; Dirampaten & Griño, 2024). Cost overruns, delays and safety hazards occur from inadequate risk management.

While ISO 31000 as well as PMBOK frameworks exist, the insufficient implementation from practices such as resource constraint along liabilities of expertise ‘balloon’ projects to the deep end (Vargas & Campos, 2022; Kumar & Kumar, 2024). Innovative solutions are required for emerging risks including technological disruptions and climate change (Dirampaten & Griño, 2024). This paper adopts a qualitative approach where the empirical studies and case studies (e.g., Burj Khalifa) and industry reports from the Project Management Institute (PMI) on the subject are reviewed grounded in constructivist and interpretivism. Evidence based findings are provided using thematic analysis rooted with python libraries such as (NLTK, pandas) (Braun & Clarke, 2006; Loper & Bird, 2002; McKinney, 2010).

This study finds main hazards, makes implementation difficulties, and evaluates mitigation in large scale building projects. Previous works tend to pay less attention to environmental risks as well as issues such as stakeholder misalignment (Zou et al., 2007).

1.1 Research Problem

Risk management in major infrastructure developments remains problematic despite guidelines like PMBOK (Project Management Institute, 2021; Mansour et al., 2023), ISO 31000 (Abuyassin et al., 2018; Sousa et al., 2012). Guidelines can prove ineffective in handling actual issues in various project environments (Hillson & Murray-Webster, 2017). Unforeseen weather conditions, supply chain interruptions, and political unrest can influence timeliness and costs (Hillson & Murray-Webster, 2017). Poor stakeholder coordination and ineffective mitigation result in increased risks, such as cost overruns, delays, and safety issues (Hillson & Murray-Webster, 2017). Though widely reported risk avoidance, transfer, mitigation, and acceptance techniques (Project Management Institute, 2021), their efficacy is heterogeneous owing to situational limitations, particularly in low-income nations with weak countries (Flyvbjerg, 2017; Nawaz et al., 2019). The present study aims for risk management techniques custom-made for diverse project environments.

1.2 Research Objectives

The aims are:

- To identify important risk categories for large-scale building projects.
- To analyze challenges in risk management implementation.
- To evaluate effective risk mitigation strategies from the literature.

1.3 Research Questions

This study addresses:

- Which risk categories are most important for major building projects?
- What obstacles exist for efficient risk management?
- Which risk reduction techniques, according to the literature, are the most successful?

1.4 Significance of the Research

The significances are:

- **Advancing Knowledge:** Enhancing understanding of financial, operational, and environmental risks (Flyvbjerg, 2017).
- **Practical Impact:** providing direction to improve risk management practices and project efficacy (Osei-Kyei et al., 2022).
- **Improving Risk reduction Strategies:** Providing suggestions based on research to maximize risk reduction (Project Management Institute, 2021).

1.5 Limitations of the Study

The limitations are:

- **Methodological Constraints**: Relies on existing literature, lacking real-time data.
- **Geographical Focus**: Lacks a specific regional focus, limiting applicability.
- **Risk Categories:** New hazards, such technology disruptions, could not be adequately covered.

- **Generalizability:** Smaller projects might not be able to use the results.
- Excludes stakeholder feedback, thereby restricting practical findings.

1.6 Report Organization

This thesis comprises seven chapters:

Chapter 1: Introduction

Introduces the research problem, aims, questions, significance, scope, limitations, and report structure (Sections 1.1 to 1.6).

Chapter 2: Theoretical Framework

Explores project and risk management theories, focusing on construction projects, risk processes, categories, challenges, and mitigation strategies (Sections 2.1 to 2.7).

Chapter 3: Methodology

explains the qualitative research type, data collection methods (empirical studies, case studies, industry reports), and Python-based theme analysis (Sections 3.1 to 3.3).

Chapter 4: Literature Review

Reviews empirical studies on risk management in construction, outlining the search strategy and findings (Sections 4.1 to 4.2).

Chapter 5: Results

summarizes the search approach and results of empirical research on risk management in the construction industry (Sections 4.1 to 4.2).

Chapter 6: Discussion

discusses the findings' ramifications, including risk categories, obstacles, ways to mitigate them, links, and wider effects (Sections 6.1 to 6.5).

Chapter 7: Conclusion

Summarizes findings, contributions, implications, limitations, and future research recommendations (Sections 7.1 to 7.6).

2 THEORETICAL FRAMEWORK

This chapter examines theoretical and empirical foundation of risk management in major building projects. First, we cover project management principles, then theories and procedures of risk management, the framework analysis, identification of important risk categories, implementation issues and research holes.

2.1 Project Management

Project

A project is “a temporary endeavor undertaken to create a unique product, service, or result” (Project Management Institute, 2017, p. 32) and it sizes range from little attempts like advertising campaigns to massive undertakings like the Burj Khalifa, which need careful planning (Mok et al., 2015). The distinct nature of each project brings uncertainties, requiring customized approaches to manage risks such as financial instability, changes in regulations, and conflicts among stakeholders (Kerzner, 2022; Malsam, 2024). Proper management ensures that projects achieve their goals while staying within limitations (Kerzner, 2022).

Project Management

According to (Project Management Institute, 2017, p. 570), "Project management is the application of knowledge, skills, tools, and techniques to project activities to meet project requirements". Large scale construction projects are often managed through this process of constraints including scope, time, cost and quality, thus in arising projects risks (Project Management Institute, 2017, p. 36). It uses methodologies like Agile and Waterfall, and frameworks like PMBOK and ISO 21500, to standardize processes (Project Management Institute, 2021).

The Project Triangle

"The project management triangle is made up of three variables that determine the quality of the project: scope, cost, and time" (Asana, 2025, para. 2). These factors are interconnected, meaning a change in one can impact the others (for example, reducing the timeline might raise costs) (Morris, 2013). Project management tries to achieve reduction of risks, satisfy stakeholder, use the resources efficiently, and follow the legality standards (Morris, 2013; Project Management Institute, 2017, p. 36).

Role of Project Manager

The project manager oversees the project’s entire lifecycle and serves as the main point of contact for stakeholders (Schwartz, 2024; Bornman & Frisa, 2024). Their duties include:

- **Planning:** Writing a great project plan that covers requirements, estimates, budgets, and risk management plans (Schwartz, 2024; LetsBuild, 2023).
- **Resource Management:** Ensuring resources are allocated efficiently to prevent delays or bottlenecks (Bika, 2022).
- **Risk Management:** Potential risks identification, assessment of impact and mitigation of such risks (Bornman & Frisa, 2024; LetsBuild, 2023b).
- **Communication:** Facilitating clear and consistent communication with stakeholders to avoid misunderstandings and conflicts (Bornman & Frisa, 2024; Bika, 2022).
- **Monitoring and Control:** Keeping track of progress and making adjustments to address any deviations from the plan (Bornman & Frisa, 2024; RIB Software, 2024).
- **Leadership:** Inspiring teams, encouraging collaboration, and maintaining morale (Bika, 2022).

2.2 Risk Management Theories for Construction Endeavors

In fact, it is risk management, as a very important aspect of the construction project management, as it seeks to identify, assess and manage risks that may act negatively towards the project outcomes. Sound risk management practices are essential to large scale construction projects in order to be cost effective, completed on time and in compliance with safety (Zou et al., 2007; Guevara, 2023; Shah, 2025). Theories on risk management highlight the importance of identifying risks early, systematically assessing their probability and potential impact, and developing customized strategies to address them (Cochrane, 2024; Ellis, 2024).

"ISO 31000" and "PMBOK" offer standardized approaches, promoting ongoing monitoring throughout the project's lifecycle (Project Management Institute, 2021; Malsam, 2024). Tools like Project Management Information Systems (PMIS) streamline risk management tasks, enhancing decision-making and improving project outcomes (Shah, 2025). By effectively managing risks, projects can reduce cost overruns, ensure timely delivery, improve safety, use resources efficiently, and boost stakeholder trust (Guevara, 2023; Cochrane, 2024; Ellis, 2024).

2.3 The Risk Management Process

Five steps make up the organized method to risk identification, assessment, and mitigation used in construction projects:

- **Risk Identification:** This step identifies possible hazards by using brainstorming, techniques such as checklists, historical data analysis, and so forth and identifies those hazards based on the operational, financial, environmental and the safety threats (Osipova, 2007; McKinnon, 2024).

- **Risk Assessment:** Likelihood and impact of risks are analyzed via qualitative methodology and quantitative methodology to prioritize them (Vincent, 2025).
- **Risk Mitigation:** Strategies like avoidance, reduction, transfer (e.g., via insurance), or acceptance are developed, tailored to the project’s context (Jones, 2024).
- **Risk Monitoring:** Continuous tracking of risks via the risk register ensures timely intervention and evaluates mitigation effectiveness (Cochrane, 2024).
- **Risk Control:** Corrective actions are implemented to address emerging risks, refining strategies based on monitoring to keep the project aligned with objectives (Graham, 2023).

2.4 Frameworks in Risk Management

Risk management in large-scale construction projects addresses uncertainties through structured theories and frameworks, crucial for managing complex, multi-stakeholder projects.

ISO 31000 Framework

The ISO 31000 provides the standardized approach of risk management which can be put to good use in the construction industry. Based on Abuyassin et al. (2018) and Sousa et al. (2012), it prioritizes early identification of risk, inclusion and consistency with decision making processes through inclusion of risk management. In construction, the use of ISO 31000 helps risk awareness due to which risk practices are matched with organizational objectives and thus delays and budget overrun are reduced (Alfreahat & Sebestyén, 2022; SMuthuveeran et al., 2019).

Enterprise Risk Management Framework

This approach is organization wide and addresses risk on an organizational level which includes financial, strategic, operational and compliance risk. It improves both internal (e.g., resources related problems) and external (e.g., regulatory changes) risks and enhances resilience and supports the long-term growth in construction (Alfreahat & Sebestyén, 2022; Bachtiar & Prasetya, 2024; Mansour et al., 2023).

Project Risk Management (PMBOK Guidelines)

These project risk management guidelines don’t just offer a framework but they are also quite detailed as far as how to manage the identified risk, this includes identification, analysis, response planning and monitoring. They are widely used in the construction business and they bring the continuous risk reassessment and stake holder behavior to ensure timely delivery, continuous delivery with no disturbances (Kara et al., 2023; Bachtiar & Prasetya, 2024; Bepari et al., 2022).

2.5 Key Risk Categories in Construction Projects

Large construction projects suffer from many risks that can threaten the success of such projects, and will be classified in terms of financial, operational, environmental and regulatory/legal.

- **Financial Risks:** They are because of budgeting errors, inflation or unexpected expenses that are soaring, it will kill the project’s viability. Such examples include inaccurate budget estimate, increasing material price and unexpected site conditions (Hou, 2024; Naik & Balapgol, 2019). There are such risks that lead to delays and lower profitability (Shibani et al., 2022).
- **Operational Risks:** Daily challenges in execution add to the operational risks, and what results is a delay and inefficiency. Included are material shortages, equipment failure, workforce ineffeciencies that lead to the reduction in productivity and timeline extension (Naik & SBalapgol, 2019; Khatleli, 2019).
- **Environmental Risks:** The risks implicit in environmental are natural disaster, changes in climate, and ecologic issues in their

ways affect the timeline and sustainability. Sites can be damaged by floods, extreme weather or regulatory compliance issues and progress is stymied (Naik & SBalapgol, 2019).

- **Regulatory and Legal Risks:** Such risks include complying with building codes, settling contractual disputes and adjusting to changes in policy that might result in legal disputes and project delay. Penalties and litigation can also occur due to non-compliance, contractual conflicts and policy shift (Khatleli, 2019).

2.6 Challenges in Risk Management Implementation

Implementing risk management in faces several challenges:

- **Stakeholder Misalignment:** Conflicting priorities among owners, contractors, and regulators hinder coordinated risk management, leading to inconsistent strategies (Gharaibeh, 2019).
- **Difficulties in Communicating and Making Decisions:** Coordinated risk management not only requires coordination among owners, contractors, and regulators, conflicting priorities among owners, contractors, and regulators make it difficult to implement a coordinated strategy (Gharaibeh, 2019).
- **Resource Constraints:** It is important because, if there is ineffective communication and delayed decision making this may damage risk management and may also delay the project (Gharaibeh 2019; Construction Link 2025).

2.7 Risk Mitigation Strategies in Construction

Various strategies to mitigate risks:

- **Contingency Planning:** Allocating reserves and resources to handle unforeseen risks ensures adaptability without major disruptions, often through a risk budget (Malsam, 2024; LetsBuild, 2023a).

- **Proactive Risk Management:** Identifying risks early and maintaining ongoing monitoring help reduce their effects, with success depending on strong collaboration among stakeholders (Lokeshwaran & Bharath, 2023; Malsam, 2024).
- **Technology Integration:** Technologies like BIM, AI, and IoT enhance risk prediction and monitoring. BIM aids in analyzing models, while AI automates tasks, keeping projects on track (Ishak et al., 2023; Aladayleh & Aladaileh, 2024; Manu, 2024).

3 METHODOLOGY

In this chapter the procedures used in carrying out this study are described. The figure below shows an outline of the research procedure that describes the methodical approach that was taken in this study. These procedures are frequently used by researchers in various domains to guarantee an organized inquiry.

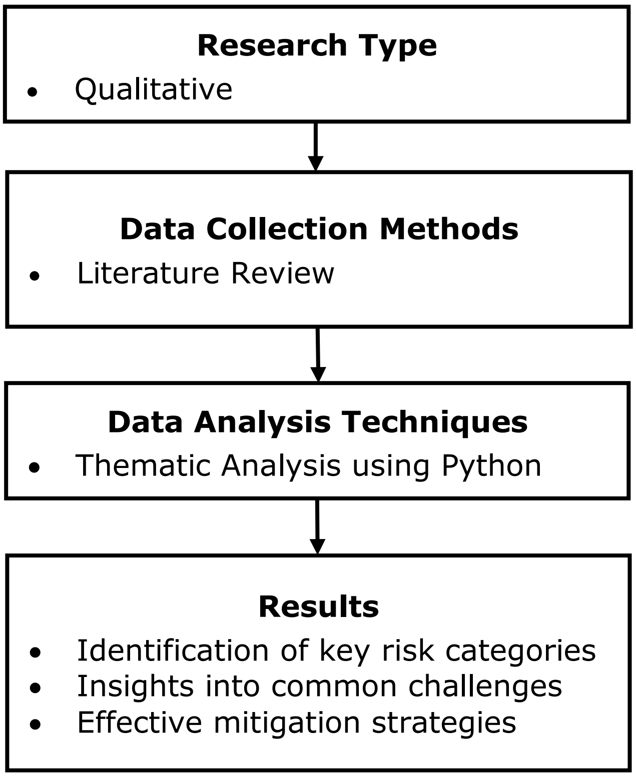

Figure 1. Block diagram of research methodology

3.1 Research Type

The approach used in this research is qualitative in nature which is used to explore the factors that influence the success or failure of risk management in large scale construction projects. It is grounded in constructivism and interpretivism (Creswell, 2007) and it looks at risks from the stakeholder perspective of project managers and contractors.

The contextual analysis, narrative inquiry and thematic exploration approaches (Braun & Clarke, 2006) are used to develop a detailed investigation of human, environmental and organizational factors. This is consistent with the study's aim of identifying risk types, assessing implementation challenges and assessing mitigation strategies, providing a more nuanced alternative to quantitative methods (Denzin & Lincoln, 2011).

3.2 Data Collection Methods

Data collection is done by reviewing the empirical study case studies and industry reports from peer-reviewed journals. Financial, operational, and mitigation focused risks are looked at from the peer reviewed articles such as Ramadhan and Waty (2025) on cost overruns and Hatefi et al. (2025) on fuzzy logic-based risk assessment. Case studies, such as "the Probolinggo-Banyuwangi Toll Road Project" (Amin et al., 2025) and "the Jragung Dam Construction" (Adriantama et al., 2025), offer practical, real-world insights. Industry reports of Vargas and Campos (2022) and Project Management Institute (2021) also offer up to date trends and better practices.

For relevance, empirical rigor, and agreement with study aims, 38 sources from 2017 to 2025 were chosen (see Table 1). Recent works ensure contemporary relevance, while foundational studies like Ahmed (2017) offer historical context. Data preparation involved three steps: First, sources were selected based on criteria like publication in reputable journals and focus on large-scale projects. Second, textual data on risk categories, challenges, and strategies were extracted from abstracts, findings, and discussions. Third, data was organized into a coded dataset using a thematic framework, with codes refined iteratively during analysis. An in-depth, fact-based investigation of construction risk management is supported by this multi-source methodology.

Table 1. Description of datasets

Dataset (CSV file)	Purpose	No of Instances	Variables	Example
risk_categories	Identifies primary risk categories in construction projects	107	Source, Text	"Ramadhan & Waty, 2025","Design changes contribute to 56.5% of cost overruns in large-scale projects."
common_challenges	Documents risk management implementation challenges	76	Source, Text	"Amin et al., 2025","Improved logistics coordination reduced delays in material supply."
mitigation_strategies	Records risk mitigation strategies	82	Source, Text	"Implementing BIM enhances planning accuracy" (Ramadhan & Waty, 2025)

Note. Dataset compilation and analysis conducted by the authors.

3.3 Data Analysis Techniques

The process entailed a thorough literature review, coding of relevant excerpts, and theme generation (financial risks due to budget overruns, barriers to implementation, and risk management strategies) that were subsequently refined for a better understanding of the implementation of risk management strategies in the major construction initiatives (Braun & Clarke, 2006). The themes were then iteratively refined based on the Braun and Clarke's (2006) methodology in order to align with the objectives of the study, for example obstacles to implementation of risk management.

For handling large datasets, libraries such as "scikit-learn" (Pedregosa et al., 2011), "pandas" (McKinney, 2010), "NLTK" (Loper & Bird, 2002) and “matplotlib/seaborn” (Hunter, 2007; Waskom, 2021) could be easily used to spot trends in the data. Python’s scripted workflows ensured reproducibility (Wilson et al., 2014), while its flexibility integrated qualitative insights with quantitative techniques (Guest et al., 2012). As an open-source language under permissive licenses, Python enabled accessible use (van Rossum & Drake, 2009).

3.3.1 Python for Thematic Analysis: Meeting Research Objectives

The study topics and objectives in Sections 1.2 and 1.3 were addressed using Python. The following subsections detail techniques used to identify risk categories, analyze challenges, and evaluate mitigation strategies.

Identification of Key Risk Categories

Using 107 risk descriptions from 38 research (2017–2025), Python expedited the process of identifying the main risk categories:

- **Text Preprocessing**: NLTK preprocessed text by lowercasing, tokenizing, removing stopwords (e.g., "and," "the," custom terms like "in," "of"), eliminating punctuation, and lemmatizing. For example, “Construction cost overruns threaten economic sustainability” became ['construction', 'cost', 'overrun', 'threaten', 'economic', 'sustainability'].
- **Keyword-Based Categorization**: A dictionary linked keywords to eight categories—Financial (e.g., "cost"), Operational (e.g., "delay"), Safety (e.g., "accident"), Technical (e.g., "design"), Environmental (e.g., "geological"), Political (e.g., "instability"), Contractual (e.g., "dispute"), and Supply Chain (e.g., "delivery"). Risks were assigned to categories by keyword matching, with unmatched risks labeled "Other Risks." For example, "Inflation rate volatility was identified as a critical risk" was classified as Political Risks due to "volatility."

- **Analysis and Visualization**: Risks were analyzed for distribution, visualized via a bar chart, and word clouds per category using Matplotlib and WordCloud, with a summary of distributions.

Insights into Common Challenges

Python analyzed 76 challenge descriptions from 38 studies (2017–2025) to explore risk management challenges (e.g., stakeholder misalignment, poor communication):

- **Frequency Analysis:** NLTK preprocessed text to lowercase, tokenize, stopwords (e.g., "the," custom terms like "risk"), and lemmatizing (e.g., "hinders" to "hinder"). Pandas computed term frequencies, and Matplotlib plotted the top 10 terms (e.g., "hinder" (25), "complicate" (23)) in a bar chart, uncovering barriers like resource constraints ("lack") and complexity.
- **Network Analysis:** NetworkX created a graph with challenges as nodes, linking those with shared terms (e.g., "complexity"). Degree centrality identified systemic challenges, like "Poor understanding of new risks hinders safety management" (centrality: 0.987). A graph visualized the top 5 central challenges, showing interconnections.
- **Word Cloud Visualization:** WordCloud displayed frequent terms (e.g., "hinder," "complicate"), emphasizing prevalent themes.

Effective Mitigation Strategies

Python evaluated 82 mitigation strategies from 38 sources (2017–2025) to identify effective approaches (e.g., contingency planning, technology adoption):

- **Text Preprocessing and Topic Modeling:** NLTK preprocessed text—lowercase conversion, tokenizing, removing stopwords (e.g., "the," custom terms like "mitigate"), and lemmatizing.

Scikit-learn’s LDA identified 5 topics using a TF-IDF matrix (300 features).

- **Keyword Extraction:** RAKE extracted phrases like "building information modeling," cross-referenced with examples like Adriantama et al. (2025), where technology mitigated operational risks.
- **Frequency Analysis:** Pandas identified frequent terms (e.g., "planning," "bim"), aligning with the question’s examples of contingency planning and technology adoption.
- **Visualization:** A bar chart displayed the top 10 terms; word clouds per topic emphasized key terms (e.g., "cost" in Contingency Planning).

4 LITERATURE REVIEW

The literature reviewed here establishes a foundation for understanding risk management in construction projects, employing a variety of research approaches and settings. These research, which range from 2017 to 2025, include quantitative analyses, mixed-method studies, systematic reviews, and case studies which focus on identifying, evaluating, and mitigating risks in major construction initiatives (e.g., Zou et al., 2007; Guevara, 2023; Shah, 2025).

4.1 Literature Search Strategy

This literature review searches the academic databases and industry sources to identify studies on risk management in construction project from 2017 to 2025. Search was done on the databases like Scopus, Web of Science, Google Scholar, and the website of PMI from where peer reviewed publications, case studies, and industry reports are available. Total and qualifying publications per source are summarized in Table 2 by criteria of relevance, empirical evidence and recent publication. Table 3 details the selected sources' impact, journal metrics, and geographical focus, showing the literature's quality and diversity. Section 3.2 contains data collection details.

Table 2. Documents from search results

Database/Platform	**Total Publications**	**Qualifying Publications**
Scopus	450	20
Web of Science	300	10
Google Scholar	600	5
PMI (Industry Reports)	50	4

Table 3. Source impact

Source Type/ Journal Name	H-Index	Articles	Publication Period	Geographical Areas
Journal of Construction Engineering and Management	85	12	2017–2025	Global, North America, Asia
International Journal of Project Management	92	8	2017–2024	Europe, Asia, Australia
Construction Management and Economics	67	6	2018–2025	Global, Middle East, Europe
Engineering, Construction and Architectural Management	55	5	2017–2023	Asia, Africa, Europe
Industry Reports (e.g., PMI)	N/A	4	2021–2022	Global
Case Studies (e.g., Probolinggo-Banyuwangi Project)	N/A	4	2025	Asia (Indonesia)

4.2 Empirical Studies

A chronological analysis of empirical studies emerges from the literature search starting from 2025 up to 2017.

Ramadhan and Waty's (2025) study surveyed 120 professionals on the risk faced to the cost overrun on major Indonesian construction projects and used project data to examine the problems. The methods and simulations were used to identify design and planning errors as the main causers of cost overrun and showed that Building Information Modeling (BIM) and structured change protocols reduced those risks largely, proving a practical and data driven strategy to improve cost management in such projects.

Hatefi et al. (2025) used mixed methodology to acquire data and use sophisticated analytics to assess associated risks in mass housing projects. The study used fuzzy ranked as risks such as import/export limitations, changes in the inflation rate. Results of these empirical data showed that they were substantive factors affecting the costs and deadlines, and fuzzy logic afforded a quantifiable framework improving allocation efficiency of resources to high volume building situations.

In an extensive review and analysis of the existing literature for considering the supply chain challenges faced by small and medium sized enterprises (SME) in construction projects, Chen et al, (2025) observed that there are multiple risks in the domain of management, operations and sustainability, including delays in materials, budget constraint. It provided a tool for assessing the level of risk and to highlight the gaps for next research, which improve SME project's resilience level.

Amin et al. (2025) used surveys, document analysis, and interviews to look into the dangers associated with Indonesia's Probolinggo-Banyuwangi Toll Road Project Package 2. The assessment of risks targeting delayed delivery together with rising material prices relied on probability and impact assessment to develop mitigation strategies which stakeholders validated through feedback monitoring systems. Results demonstrate that the focus mitigation is vital in the sustainable way of managing complex infrastructure projects.

Ahmad et al. (2025) presented a bridge project sustainability risk assessment framework which united risk analysis and BIM together with Life Cycle Sustainability Assessment (LCSA). The Pareto Principle helped identify 38 out of 55 risks that were responsible for 80% of lifecycle impact through survey results. The framework achieved effective implementation during real-world application on a bridge project which demonstrated that supervision and construction phases will be key to sustainable development compliance with ISO guidelines.

In Senić et al. (2025), the Delphi method was used as a tool for soliciting 37 multidisciplinary experts’ feedback to classify the 56 risks and 302 preventive measures for mitigating risk in road infrastructure projects. An MCDM approach was used to evaluate measures in terms of implementation cost, time, complexity and success probability and this was validated using fuzzy logic. The framework prioritized preventive strategies, providing actionable guidance for resource allocation and enhancing risk management effectiveness.

In the Jragung Dam Construction Project Package 2, Adriantama et al. (2025) implemented a combination of lack construction and risk management with brainstorming, Borda and FMEA. The study identified key waste types, such as defects (20.05%), and critical risks like incomplete diversion channels (RPN = 108). Empirical results confirmed the effectiveness of a genetic-algorithm-based K-means clustering method, providing a structured approach to minimize waste and enhance project efficiency.

Ullah et al. (2024) examined factors analysis for risk identification methods in international contracting projects using survey method. Politicial risks such as expropriation and policy changes were strongly highlighted in the data collected from construction experts. Systematic risk management was shown to help in delaying problems and how contractors operating in politically unstable locations can benefit from a practical approach of this.

Tang et al. (2024) used text mining to find safety risk factors in the construction of the metro, building toward safety risk factors from the safety risk information of the Metro Project Safety Risk Early Warning System. Both high frequency danger phrases were retrieved using Jieba word segmentation and TF-IDF analysis and complications such as nearby structures were exposed. This resulted in data driven approach to improve on-site safety management against the issues that stand with the traditional methods.

The comprehensive literature review and bibliometric analysis was done by Shishehgarkhaneh et al. (2024) based on the articles of Construction supply chain risk management (CSCRM) from 1999 to 2023. The study started from 2016 when the research changing from surveys to the AI techniques using Gephi and VOSviewer. The expanded CSCRM stages introduced by Insights included risk allocation and recovery which provided complete understanding of emerging patterns.

Jackson and Priya (2024) employed structural equation modeling and questionnaire survey of 462 Ghanaian professionals to find out such poor resource planning that is important in terms of risk variables. The model determines that outcome determinants are resource planning, conflict resolution and technological expertise and recommends obligatory conflict resolution boards in order to improve project performance.

Gao et al. (2024) based on natural language processing (NLP), design a Multi-sentence Context aware Risk Identification (MCRI) model for risk event extraction from news article. The model was tested on a supervised dataset and it delivers with an F1-score of 87.1% outperforming the baselines. Threshold approach automated the risk identification enabling infrastructure projects to undertake early-stage risk assessment from today.

In Al-Mhdawi et al. (2024), a FMEA model based on fuzzy was applied to the oil and gas construction risk assessment in many ways like the questionnaire and interview with the project managers in the United States. The study lists 41 factors causing risk and non-compliance with PPE regulations was ranked as the most vital factor. Mitigation solutions using open ended questionnaires were used to validate in order to improve risk understanding for project success.

The study by Zhao (2023) examined 2034 publications about construction risk management (CRM) through document co-citation and bibliographic coupling analysis of the publications from 2000 to 2021. Themes such as advanced risk analysis as well as ICT driven CRM were identified and their trends of adoption that were identified by the analysis. The research brought together theoretical and practical CRM development to provide practitioners complete knowledge.

Yousri et al. (2023) assessed risks in Egyptian building construction through a pilot survey with 15 experts and a broader survey of 95 participants, using a Likert scale. Funding issues and material price variations surfaced as major risk considerations. The findings redefined risks based on economic shifts, providing a model to control critical risks and enhance project performance.

The ZW high-speed railway in China served as the basis for Xiang et al. (2023) to verify their integrated risk assessment method targeting cross-regional mega construction projects (CMCPs). Drawn from AHP and cross-impact analysis data identified 12 threat and vulnerability factors with local government conflicts being one of them. The results emphasized coordination mechanisms, offering transferable strategies for CMCPs.

System dynamics combined with the AHP-EWM method was used to analyze tunnel security risk management efficiency in Chinese megaprojects by Liu et al. (2023). Simulations with Vensim software pinpointed real-time risk adaptation as a key factor. The approach demonstrated that comprehensive risk awareness networks improve efficiency, guiding tunnel security management.

Khodeir (2023) reviewed 43 Scopus-indexed papers from 2000 to 2021 to identify risks in fast-track construction projects. The synthesis highlighted risks, such as unfair risk distribution due to contract terms, recommending scope assessment. This study clarified risk management’s role in accelerating delivery under high complexity.

Developed by Coskun et al. (2023), RAMSCOM risk assessment method for megaprojects is tested on a real case by using AHP and cross impact analysis. Social, environmental, and economic critical hazards were identified and decisions regarding mitigation decisions were supported by visualization. Adding sustainability made this strategy work towards megaprojects long term success.

Canesi and Gallo (2023) applied the ANAC risk assessment tool to the SSv-51 road variant project, forecasting a 7.53% cost increase. Validation showed a 1.34% deviation from actual costs, demonstrating the tool's accuracy in mitigating cost overruns and supporting sustainable infrastructure planning.

Shibani et al. (2022) surveyed Lebanese construction experts to identify financial risks, such as currency fluctuation, amid an economic crisis. The study validated the advantage of risk management by reducing overruns, but few are implementing it, and it offers limited advice in areas traumatized by crises.

Osei-Kyei et al. (2022) performed a scientometric review on 1,635 publications indexed on Scopus from 1979 to 2022 through their analysis with VOSviewer and Gephi. Emerging themes that indicate heightened attention as the sector transitions to sector 5.0 include risk-integrated planning. Future research is guided by the findings of this study.

Nguyen et al. (2022) employed factor analysis to identify seven risk factors, including financial risks, in the selection of joint venture contractors after surveying 100 Vietnamese professionals. The findings linked effective risk ranking to project success, aiding decision-making in complex infrastructure projects.

Khairullah et al. (2022) identified risks in EPC projects through questionnaires with construction professionals. Design and contract risks were shown to be crucial, and the findings linked delays to a lack of risk management, which helped to guide risk reduction strategies.

Santarsiero et al. (2021) used data from Google Street View and OpenStreetMap to test the Italian Guidelines on Bridge Risk Management. When applied to a Basilicata bridge stock, conservative risk classifications were found, and approaches for prioritizing evaluations for in-depth analyses were suggested.

Li et al. (2021) used fuzzy set theory and interviews to identify 75 risk factors in mega infrastructure projects (MIPs). Validation provided a framework for MIP risk management that was expanded for sustainability, and coordination and economic risks were crucial.

An analytical network process (ANP) model was developed by Erol et al. (2021) to measure risks in megaprojects. A two-round Delphi study was used to validate the model across 11 projects. The findings ranked risk sources, improving the accuracy of risk assessments for practitioners.

Banerjee Chattapadhyay et al. (2021) surveyed experts on 63 risk factors in megaprojects, applying GA–K-means clustering and SMOTE. The approach offered a predictive paradigm to enhance megaproject performance by identifying time and cost issues as crucial.

Zhang et al. (2020) identified environmental and technological risks as safety-critical after conducting expert interviews and surveying 399 Chinese subway professionals. The number of accidents in subway projects was reduced as a result of better safety management.

Shaktawat and Vadhera (2020) reviewed the risks related to hydropower projects and proposed synthesis-based sensitivity analysis. Cost-estimating methods for sustainable development in developing countries were presented by emphasizing the risks related to the building phase.

Aarthipriya et al. (2020) used Primavera software to perform sensitivity analysis and Monte Carlo simulation to examine the hazards associated with residential development in Bangalore. The results quantified time and cost impacts, improving decision-making through effective risk management.

Sharma and Gupta (2019) reviewed the literature to determine 67 risk variables and ranked them using questionnaire surveys. Early risk assessment in construction projects was aided by the validation of top risks, such as funding unavailability.

After surveying 22 Pakistani contractor companies on 100 projects, Nawaz et al. (2019) discovered a connection between risk management and project performance. The importance of organized risk strategies in developing nations was highlighted by insights.

Through a review of the literature, Bahamid et al. (2019) found 111 risk variables in building projects in developing nations, of which 56 were deemed essential. The plan provided the framework for achieving schedule, cost, and quality goals.

In an online poll of construction experts, Saeed (2018) found that time and expense overruns were the most common hazards. Suggestions like better planning lessened the effects of subpar company performance.

Rachid et al. (2018) surveyed 52 Algerian construction experts, identifying owner-related delay causes, such as slow change orders. Improvements in scheduling procedures were guided by the findings.

Chang et al. (2018) grouped 27 "political risk management techniques" for multinational projects using factor analysis after surveying 155 experts. The findings provided useful methods at all stages of the project.

Ahmed (2017) reviewed risk mitigation in innovative projects, proposing a conceptually tested framework. Insights from autonomous vehicle projects emphasized step-by-step strategies, aligning risk management with business goals.

5 RESULTS

The research findings and their implications are presented in this section in relation to the goals and inquiries of the study. Objectives are: (1) to identify key risk categories in large-scale construction projects, (2) to analyze challenges in risk management implementation, (3) to evaluate effective mitigation strategies from the literature. The research questions were: RQ1: What are the primary risk categories, such as financial, operational, and environmental risks, in large-scale projects? RQ2: What challenges, like stakeholder misalignment, hinder risk management? RQ3: What are the most effective mitigation strategies, such as contingency planning, in the literature? The conclusions are based on three datasets: risk_categories.csv (107 dangers), common_challenges.csv (76 problems), and mitigation_strategies.csv (82 strategies) obtained from 38 studies between 2017 and 2025. The results answer all topics, followed by comments that integrate the data to convey overall knowledge of risk management dynamics. Table 4 (Appendix 1) summarizes the 38 sources, aligning their contributions with results in Sections 5.1, 5.2, and 5.3.

5.1 Identification of Key Risk Categories

The analysis of the "risk_categories.csv" dataset, with 107 risk descriptions from 38 studies (2017–2025), addressed the question RQ1. A Python-implemented keyword-based approach categorized risks into eight predefined groups—Financial, Operational, Safety, Technical, Environmental, Political, Contractual, and Supply Chain Risks—with unmatched risks labeled "Other Risks." Analysis and Visualization, including a bar chart, and word clouds, offered a detailed risk distribution overview.

The data revealed a variety of risk categories, with "Other Risks" appearing the most frequently at 31 times (29.0%). This category included emerging risks like "Lack of knowledge of new technology slows project efficiency" (Jackson & Priya, 2024) and "Unidentified risks from past projects threaten early-stage planning" (Gao et al., 2024). Operational risks were followed by 19 occurrences (17.8%), commonly associated with "delay" and "schedule," as in "Delays of 40% in project timelines were driven by design modifications" (Ramadhan & Waty, 2025). Technical Risks had 11 instances (10.3%), while Financial Risks had 10 (9.3%). Technical Risks involved design and equipment failures, such as "Design revision led to defects and financial losses" (Adriantama et al., 2025), while Financial Risks were linked to cost overruns, as in " Construction cost overruns threaten economic sustainability" (Li et al., 2021).

Supply Chain and Environmental Risks each had eight incidences (7.5%). Supply Chain Risks included "Delays in material delivery disrupt timelines for SMEs" (Chen et al., 2025), while Environmental Risks involved geological issues, like "Geological challenges increased costs" (Adriantama et al., 2025). Political and Safety Risks each had 7 instances (6.5%), with Political Risks tied to instability (e.g., "Political unpredictability delays projects" by Ullah et al., 2024) and Safety Risks to concerns like "High accident rates threaten worker safety" (Zhang et al., 2020). Contractual Risks were least frequent, with 6 instances (5.6%), as in "Contract-related risks increase costs in EPC projects" (Khairullah et al., 2022).

Figure 2 depicts the “distribution of risk categories”, with "Other Risks" (31 occasions) and Operational Risks (19 times) taking the lead and word clouds are in Appendix 2.

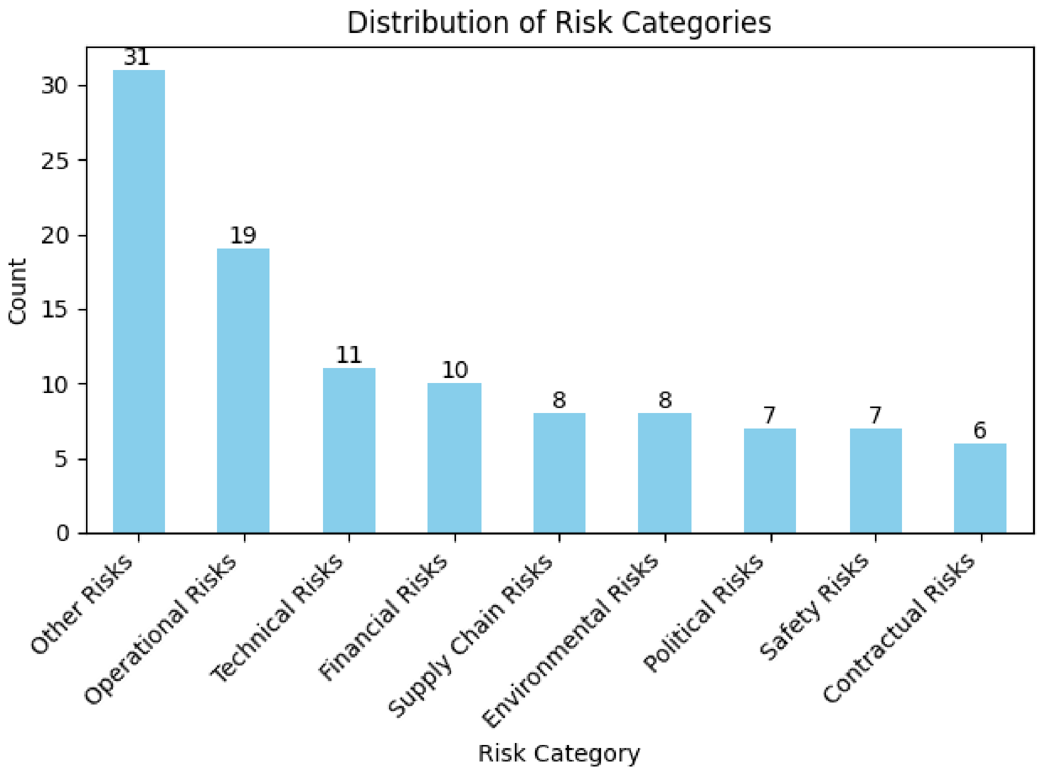

Figure 2. Distribution of risk categories across 107 risk descriptions

The high incidence of "Other Risks" (29.0%) implies that many hazards are context-specific or do not fit into specified categories, such as technology hurdles (Jackson & Priya, 2024) or historical risk carryovers (Gao et al., 2024). This aligns with Nawaz et al. (2019), who noted unmanaged risks threaten project success in Pakistan.

Construction businesses employ a variety of ways to address these "other" hazards. First, they keep dynamic risk registers and hold workshops to identify hazards such as "lack of skilled labor" (Amin et al., 2025). Second, firms consult experts to assess technological risks, such as BIM, as demonstrated by Ramadhan and Waty (2025). Third, scenario planning anticipates risks like "Uncertainties in Industry 5.0" (Osei-Kyei et al., 2022). Fourth, real-time monitoring adapts to evolving risks, as in Amin et al. (2025). Fifth, firms learn from historical data, using lessons from "Scattered historical risk events" (Gao et al., 2024). Finally, flexible frameworks with AI-driven analytics (Shishehgarkhaneh et al., 2024) identify risks like "Complexity of megaprojects" (Erol et al., 2021). Because of the presence of "other" risks, classifications should be refined to encompass technical and sustainability issues, with sophisticated methods used for uncategorized hazards.

Operational Risks (17.8%) as the second most frequent category highlight delays, echoing Ramadhan and Waty (2025) and Saeed (2018). The share of Technical (10.3%) and Financial Risks (9.3%) reflects the challenge of managing cost overruns and design issues, as design changes often cause both (Adriantama et al., 2025; Ramadhan & Waty, 2025). Environmental Risks (7.5%) emphasize sustainability and geological concerns, especially in megaprojects (Ahmad et al., 2025). According to Ullah et al. (2024) and Zhang et al. (2020), “political risks” and “safety risks” (6.5% each) reflect external and human variables that disrupt deadlines and safety. The lower frequency of Contractual Risks (5.6%) suggests they are less pervasive, though significant in contexts like EPC projects (Khairullah et al., 2022). These findings indicate that risk management must prioritize operational delays and developing hazards while resolving financial and technological issues.

5.2 Insights into Common Challenges

The analysis of the “common_challenges.csv” dataset, with 76 challenge descriptions from 38 studies (2017–2025), addressed the question RQ2. Python-based text analysis, using NLTK and NetworkX for frequency and network analysis, identified patterns in challenges. Visualizations like a bar chart, network graph, and word cloud offered insights into their thematic distribution and interconnections.

Frequency analysis showed "hinder" as the most frequent term (25 instances), followed by "complicate" (23 instances). Other terms included "risk" (10 instances), "complexity" (8 instances), "limit" and "effective" (7 instances each), "poor," "lack," and "delay" (6 instances each), and "plan" (5 instances). These words emphasize resource restrictions and complexity as major hurdles. For example, "Poor understanding of new risks hinders safety management" (Zhang et al., 2020) and "Complexity of 63 risk factors hinders analysis" (Banerjee Chattapadhyay et al., 2021) show how understanding and analytical complexity impede risk management. Figure 3 illustrates the top 10 frequent terms, confirming the prevalence of "hinder" and "complicate."

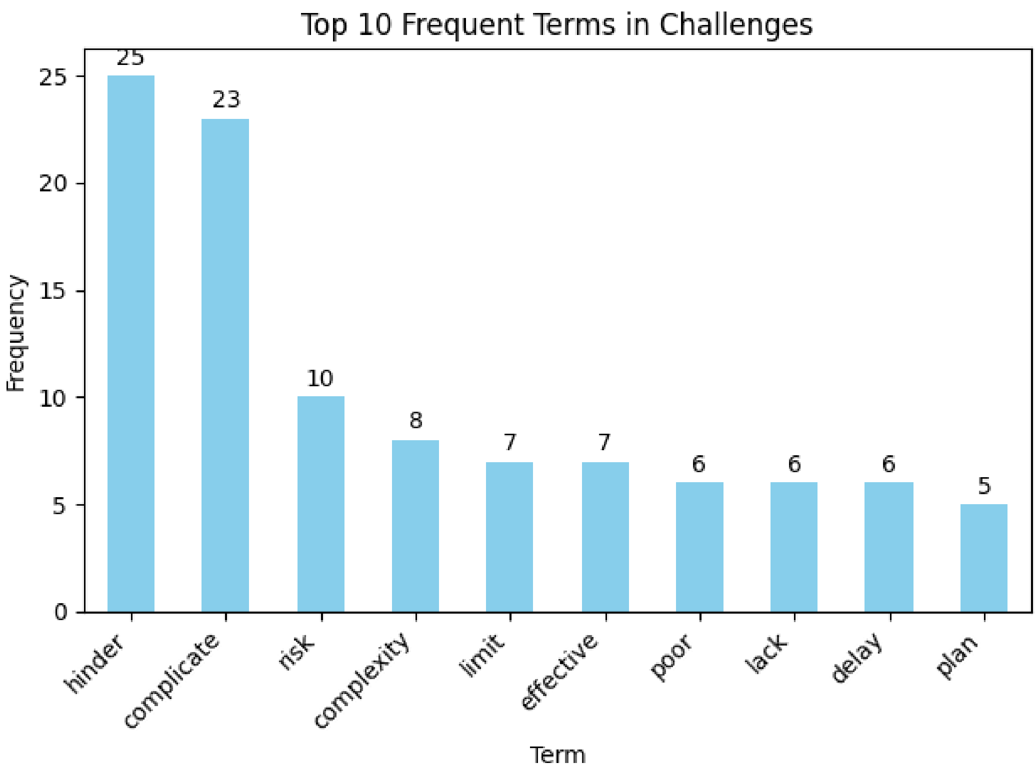

Figure 3. Top 10 frequent terms in challenges across 76 challenge descriptions.

The directed graph created using NetworkX was first implemented with challenges as nodes and having shared lemmatized terms as edges. Degree centrality identified "Poor understanding of new risks hinders safety management" (Zhang et al., 2020) as the most interconnected (centrality: 0.987), followed by "Complexity of 63 risk factors hinders analysis" (Banerjee Chattapadhyay et al., 2021; centrality: 0.907) and "Legal risks in joint ventures hinder contract enforcement" (centrality: 0.880). Two others, "Poor logistics coordination complicated timely material delivery" (centrality: 0.853) and "Limited data on low-risk factors like unpredictable fire hinders assessment" (centrality: 0.853), were also highly connected. These top 5 issues are visualized in Figure 4, which provides linkages through phrases like "complicate" and "hinder." For example, "complicate" links supply chain recovery (Challenge 5) and coordination difficulties (Challenge 9), while "hinder" links safety management (Challenge 57) and contract enforcement (Challenge 46). A word cloud emphasizing "hinder" and "complexity" is in Appendix 3.

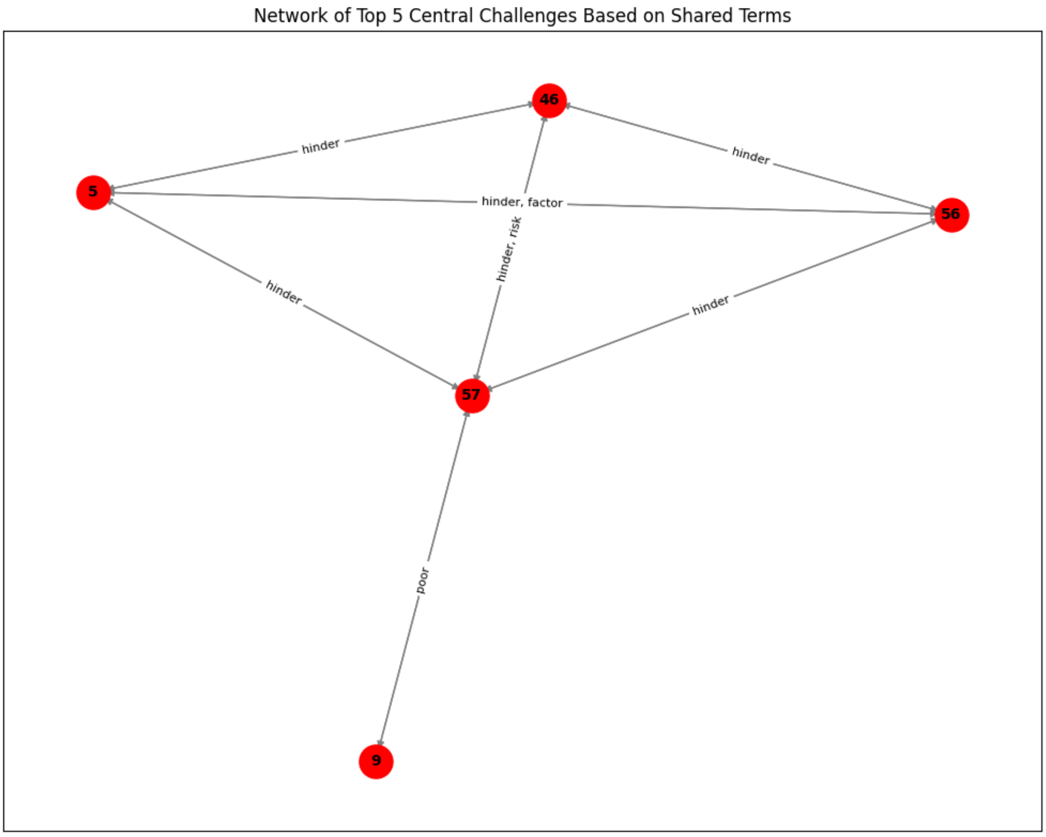

Figure 4. Network of top 5 central challenges based on shared terms.

The prevalence of "hinder" (25 instances) and "complicate" (23 instances) underscores barriers to risk management, especially in understanding risks. The high centrality of "Poor understanding of new risks hinders safety management" (0.987) indicates that a lack of awareness has an influence on safety, which is consistent with Zhang et al. (2020). Similarly, "Complexity of 63 risk factors hinders analysis" (centrality: 0.907) implies analytical difficulties (Banerjee

Chattapadhyay et al., 2021). The network graph shows interconnected challenges, affecting coordination (Challenge 9) and assessment of low-risk factors (Challenge 5). The terms "poor" and "lack" (6 times each) denote resource limits, as in "Poor coordination increases complexity" (Li et al., 2021). "Delay" (6 instances) highlights inefficiencies, per Liu et al. (2023). These findings confirm stakeholder misalignment and poor communication as critical challenges, often seen as "poor" coordination and "complicated" collaboration in joint ventures (Challenges 9 and 46). Effective risk management involves overcoming systemic hurdles, particularly recognizing new hazards, managing complexity, and enhancing coordination.

5.3 Evaluation of Effective Mitigation Strategies

The analysis of the “mitigation_strategies.csv” dataset, with 82 mitigation strategy descriptions from 38 studies (2017–2025), addressed the question RQ3. Python-based text analysis, using LDA topic modeling, frequency analysis, and keyword extraction with NLTK, Scikit-learn, and RAKE, identified prevalent strategies. Visualizations such as bar charts and word clouds per subject offered information about their thematic distribution.

Four themes were found using LDA topic modeling and categorized accordingly. Topic 1, "Contingency Planning," used terminology like "cost," "analysis," "overrun," "factor," and "sensitivity," focused on financial risk methods (e.g., "Sensitivity analysis mitigates cost overrun risks" by Aarthipriya et al., 2020). Topic 2, "Risk Identification," featured "control," "factor," "implement," "identify," and "management," focusing on identifying risks (e.g., "Improved contract management mitigates business risks" by Saeed, 2018). Topic 3, "Other Mitigation Strategy," included "management," "aid," "project," "effective," and "factor," suggesting general strategies (e.g., "Identifying critical risk factors aids project management" by Jackson & Priya, 2024). Among the words used in Topic 4, "Systematic Frameworks," were "political," "management," "delay," "assessment," and "decision," suggesting organized methods (e.g., "ANP model quantifies risks for prioritization" by Erol et al., 2021).

Frequency analysis showed "management" as the most frequent term (17 instances), followed by "factor" (11 instances), "assessment," "identify," and "project" (8 instances each), and "accuracy," "reduces," "cost," "aid," and "strategy" (6 instances each). These words place a strong emphasis on risk detection and systematic management. For example, "Implementing Building Information Modeling (BIM) enhances planning accuracy" (Ramadhan & Waty, 2025) highlights technology’s role, while "Risk-integrated planning enhances project scheduling" (Osei-Kyei et al., 2022) focuses on project management. Figure 5 illustrates the top 10 frequent terms, confirming "management" and "factor" prominence. Appendix 4 has word clouds for each topic, including terminology such as "cost" in contingency planning.

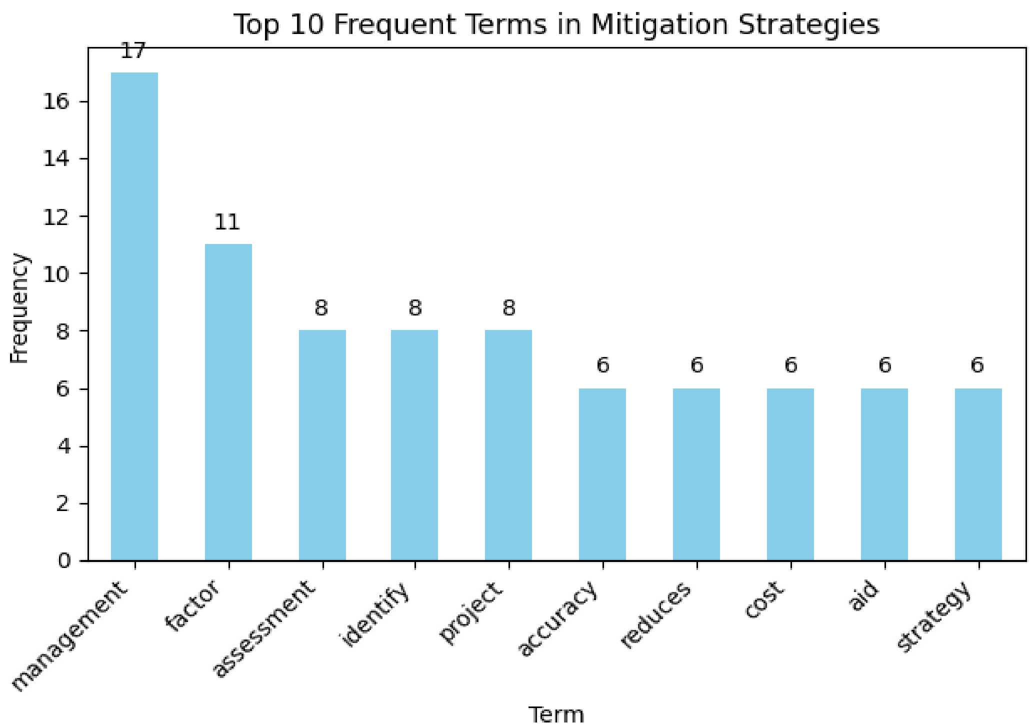

Figure 5. Top 10 frequent terms in mitigation strategies across 82 descriptions.

The prominence of "management" (18 instances) and "project" (9 instances) aligns with the focus on structured strategies, as effective mitigation requires robust project management (Jackson & Priya, 2024; Osei-Kyei et al., 2022). Risk identification procedures (Topic 4) are supported by "Factor" (11 times) and "identify" (9 instances), as in "Sensitivity analysis identifies key risk factors" (Aarthipriya et al., 2020). "Cost" (6 instances) in Topic 1 highlights contingency planning’s role in financial risks, per Aarthipriya et al. (2020) and Ramadhan and Waty (2025). "Systematic Frameworks" (Topic 2) with "model" underscores structured approaches (Erol et al., 2021). Although "technology adoption" wasn’t a labeled topic, "accuracy" (6 instances) and BIM references (Ramadhan & Waty, 2025) suggest its relevance. The title "Other Mitigation Strategy" in Topic 3 suggests that some strategies—like separating project management from operational strategies—need more precise classification.

These findings suggest that effective mitigation in large-scale projects requires contingency planning, rigorous frameworks, and risk identification. Contingency planning addresses financial risks, systematic frameworks control risks, and risk identification ensures targeted mitigation, addressing risks from Section 5.1. Technology adoption, inferred through "accuracy," supports its growing role (Ramadhan & Waty, 2025).

6 DISCUSSION

This discussion synthesizes findings from Sections 5.1, 5.2, and 5.3, analyzing the “risk_categories.csv,” “common_challenges.csv,” and “mitigation_strategies.csv” datasets. Thematic analysis (Braun & Clarke, 2006) was the qualitative approach which based on constructivism and interpretivism (Creswell, 2007) and investigated risk management on large construction project. The findings relate to the objectives: (1) identify key risk categories, (2) analyze risk management challenges, and (3) evaluate effective mitigation strategies, corresponding to the research questions in the introduction.

6.1 Primary Risk Categories: Implications and Insights

Section 5.1 revealed several risk categories, with "Other Risks" (29.0%) and Operational Risks (17.8%) being the most common, followed by Technical Risks (10.3%) and Financial Risks (9.3%). The keyword-based approach mapped risks, but the high "Other Risks" (e.g., "Lack of knowledge of new technology slows project efficiency" by Jackson & Priya, 2024) suggests keyword dictionary limitations, as noted in the methodology. This aligns with Nawaz et al. (2019), who emphasized controlling growing risks in regions such as Pakistan.

Delays cause operational risks (Ramadhan & Waty, 2025), which are indicative of a systemic issue (Saeed, 2018). Technical and financial risks are linked, as design changes result in cost overruns and technical failures (Adriantama et al., 2025). Environmental Risks (7.5%), like geological challenges (Adriantama et al., 2025), emphasize sustainability in megaprojects (Ahmad et al., 2025). Risk management must prioritize operational efficiency, sustainability, and integrated financial-technical strategies.

6.2 Common Challenges: Barriers to Effective Risk Management

Section 5.2 highlighted systemic hurdles, with the phrases "hinder" (25 occasions) and "complicate" (23 instances) appearing often in the frequency analysis. Network study of 76 issues using NetworkX revealed interconnection, with "Poor understanding of new risks hinders safety management" (centrality: 0.987; Zhang et al., 2020) being the most central. This aligns with the methodology's thematic focus (Braun & Clarke, 2006), showing how unawareness of emerging risks affects safety (Zhang et al., 2020).

Terms like "poor" and "lack" (6 instances each) indicate resource constraints, as in "Poor coordination increases complexity" (Li et al., 2021), confirming stakeholder misalignment and poor communication. Figure 4 depicts a network graph that connects difficulties related to safety, coordination, and the assessment of low-risk elements. Effective risk management requires addressing coordination and risk awareness barriers.

6.3 Risk Mitigation Strategies: Effectiveness and Applicability

Section 5.3 identified mitigation strategies via topic modeling and frequency analysis. Contingency Planning (Topic 1), Risk Identification (Topic 2), and Systematic Frameworks (Topic 4) appeared, with "management" (17 instances) and "factor" (11 instances) being the most common. Contingency planning, focusing on "cost" (e.g., "Sensitivity analysis mitigates cost overrun risks" by Aarthipriya et al., 2020), addresses Financial Risks (Ramadhan & Waty, 2025). Risk identification, focusing on "management" and "identify" (e.g., "Improved contract management mitigates business risks" by Saeed, 2018), targets Contractual and Operational Risks. Systematic frameworks that include "decision" (e.g., "ANP model quantifies risks" by Erol et al., 2021) address complexity issues (Banerjee Chattapadhyay et al., 2021).

The LDA approach proved effective, although Topic 3's label "Other Mitigation Strategy" indicates that finer themes are required. Technology adoption, as shown by "accuracy" (6 occurrences) and BIM (Ramadhan & Waty, 2025), reinforces its significance in creative projects (Adriantama et al., 2025).

6.4 Interconnections Between Risks, Challenges, and Mitigation Strategies

The findings show interconnections, reflecting the methodology's multi-source approach. Operational Risks like delays (Ramadhan & Waty, 2025) are worsened by challenges such as poor coordination (Li et al., 2021). Risk identification and systematic frameworks mitigate these by identifying key factors (Aarthipriya et al., 2020) and providing structured control (Erol et al., 2021). Financial Risks link to complexity challenges (Banerjee Chattapadhyay et al., 2021), which contingency planning addresses through cost management (Aarthipriya et al., 2020).

While technology adoption (i.e., BIM), reduces Operational and Technical Risks through improved planning as well as reducing design errors (Ramadhan & Waty, 2025), challenges of 'Poor understanding of new risks' (Zhang et al., 2020) can pose barriers to adoption. They minimize environmental risks through systematic frameworks that involve sustainability (Ahmad et al., 2025).

6.5 Broader Implications for Risk Management

Effective risk management in large scale construction projects suggests that a holistic approach is needed from 38 sources. The operational and financial risks, and other issues like lack of coordination, emphasize the need for efficient and financial solution like contingency planning, identification of risk and methodical framework. Given, technology adoption, here, BIM, resolves operational, technical and environmental risks and therefore promotes sustainability. The constructed viewpoint emphasizes that the stakeholders need to be more involved in coordinating and increasing awareness of risks in order for practitioners to achieve mitigation methods proper implementation.

7 CONCLUSION

This chapter summarizes the interpretation of the key findings from the study on risk management in large scale construction projects relative to the research goal and question as presented in Chapter 1. This section also discusses the practical and theoretical implications of these findings as well as making recommendations to future research filling out the gaps stated towards Chapter 5 and staying with the construction risk management enterprise.

7.1 Summary of Key Findings

The study achieved its three objectives and were addressed through the analysis of three datasets—risk_categories.csv (107 risk descriptions), common_challenges.csv (76 challenge descriptions), and mitigation_strategies.csv (82 mitigation strategy descriptions)—compiled from 38 empirical sources spanning 2017–2025.

Identification of Key Risk Categories: According to the report, "Other Risks" (29.0%) and Operational Risks (17.8%) dominate the risk landscape, followed by Technical Risks (10.3%) and Financial Risks (9.3%). "Other Risks" included emerging or context-specific risks, such as technological adoption challenges (Jackson & Priya, 2024), while Operational Risks were driven by delays (Ramadhan & Waty, 2025). Environmental risks (7.5%) emphasized the necessity of sustainability (Ahmad et al., 2025), while the interconnection of Technical and Financial Risks underlined the need for integrated risk management systems (Adriantama et al., 2025).

Insights into Common Challenges: Systemic barriers to risk management were identified, with "hinder" (25 instances) and "complicate" (23 instances) as the most frequent terms. It was found that "Poor understanding of new risks hinders safety management" (Zhang et al., 2020) has substantial information one about the roles of the poor understanding of developing risks on measures of safety and operational performance. Challenges like poor coordination and complexity (Li et al., 2021) confirmed the research question’s focus on stakeholder misalignment and poor communication, emphasizing the need for improved coordination and risk awareness.

Evaluation of Effective Mitigation Strategies:

The analysis confirmed that both contingency planning and risk identification and methodical frameworks function as essential strategic plans especially when considering the most frequent use of "management" and "factor". Aarthipriya et al. (2020) addresses financial risks planning, Saeed (2018) addresses risk identification for delays, and Erol et al. (2021) addresses the using systematic frameworks to tackle complexity. Terms including technology adoption like “accuracy” (Ramadhan & Waty, 2025) inferred technology adoption, and it is consistent with the research question’s focus on its adoption.

Integrated Discussion: During the discussion panel various risks and challenges and their corresponding mitigation methods were linked with one another. Poor coordination made operational risks (such delays) worse, while complexity was associated with financial risks. These risks were both reduced by systematic frameworks, risk identification, and contingency planning. Technology adoption, particularly BIM, addressed Operational, Technical, and Environmental Risks, though implementation challenges, such as limited understanding, persisted. The lessons learnt in these insights’ stresses on the importance of a holistic risk management that balances out operational efficiency, cost control and sustainability while running with risks and challenges.

7.2 Addressing Research Goals

The research questions were successfully answered and the contribution of the study was everything one could think about dynamic risk management in large construction projects:

Research Question 1: “Which risk categories are most important for major building projects?” The study identified Operational and Financial Risks as dominant, with Environmental Risks highlighting sustainability concerns. An important frequency (29.0%) showed that the “Other Risks” were developing risks and more fully understood risk profile in building projects.

Research Question 2: “What obstacles exist for efficient risk management?” The findings confirmed stakeholder misalignment and poor communication as critical challenges, manifesting as poor coordination and complexity, with a lack of risk awareness exacerbating safety and operational issues.

Research Question 3: “Which risk reduction techniques, according to the literature, are the most successful?” Contingency planning, risk identification, methodical frameworks, and technology adoption (e.g., BIM) were highlighted as useful solutions for mitigating financial, operational, and technical risks and encouraging sustainability.

7.3 Implications for Risk Management

These findings create essential implications which affect both theory and practical application of construction risk management. The study demonstrates theoretically that adaptable risk classification systems must exist to detect new risks because 29.0% of the respondents identified "Other Risks". Research should focus on constructing integrated models which address risks and challenges as complete systems since risk management faces these characteristics in practice. In real terms, the focus on backup planning spotting risks, and organized methods gives useful ways to handle money and work risks. At the same time, BIM's part in making planning more exact and eco-friendlier opens a door to update building methods (Ramadhan & Waty 2025; Ahmad et al. 2025). To overcome implementation barriers, practitioners must top their list of things to do as improving stakeholder coordination and awareness of risks, and also applying mitigation strategies to real projects.

7.4 Final Remarks

The vital aspects of large-scale construction risk management were identified, the systemic challenges were revealed and effective mitigation strategy was evaluated in this study. A key finding is that there are operational and financial risks, widespread issues of poor coordination and complexity, and the effectiveness of interventions, i.e. contingency planning, risk identification, structured approaches, and technological adoption, namely building information modeling. The research provides useful risk management practice improvement insights even though it faces constraints from literature-based data analysis and the absence of stakeholder input and its wide geographical range.

By addressing stakeholder misalignment, enhancing risk awareness, and leveraging technology for sustainable outcomes, practitioners can enhance the resilience of large-scale construction projects. Future research, as outlined in Section 7.6, should focus on incorporating real-time data, region-specific analyses, and advanced analytical techniques to address these limitations, ensuring that risk management strategies are both theoretically robust and practically applicable.

7.5 Limitations

This study, while comprehensive, is subject to several limitations that impacted the findings and their applicability, as anticipated in Section 1.5 and further revealed through the analysis in Chapters 5 and 6.

First, as indicated in Section 1.5, the study's capacity to capture actual implementation issues was restricted by its dependence on existing literature (38 sources) and a lack of real-time data or case studies. For example, while technology adoption (e.g., BIM) was highlighted as a crucial mitigation technique, hurdles like as training costs or opposition to adoption were not investigated, thereby overestimating its practicality in real-world scenarios.

Second, Section 1.5 mentioned that stakeholder feedback was lacking, and hence limited the usefulness of the study's findings. Although stakeholder misalignment and its effects on risk management were considered, further insight would have been enriched had project managers or contractors been directly included as a source of findings to these challenges (e.g. poor coordination).

Third, Section 1.5 notes the magnitude of geography that was the study's focus, thereby restricting its local applicability to special regional types of projects. Political Risks, reported as 6.5% in Section 5.1, like the example "Political unpredictability delays international construction projects" by Ullah et al. (2024), can differ a lot depending on the political environment. These include areas like conflict zones or stable regions, though this research did not examine such distinctions.

Fourth, the keyword-based categorization approach resulted in a high proportion of "Other Risks" (29.0%), confirming the limitation noted in Section 1.5 that emerging risks like technological disruptions or geopolitical tensions may not be fully addressed. This suggests that the predefined keyword dictionary was not comprehensive enough to capture nuanced or evolving risks, such as those related to cybersecurity or global supply chain disruptions.

Fifth, the topic modeling in Section 5.3 labeled Topic 3 as "Other Mitigation Strategy," indicating a need for more granular themes to fully capture the diversity of mitigation strategies, a limitation that emerged during the analysis and aligns with the methodological constraints noted in Section 1.5.

Finally, the qualitative approach and focus on large-scale projects, as anticipated in Section 1.5, limit the generalizability of the findings to smaller projects or those with different stakeholder dynamics. For instance, simpler approaches could be more practical for smaller projects with less resources, making the emphasis on methodical frameworks less useful. These drawbacks show that researching risk management in building projects requires a more comprehensive and useful methodology.

7.6 Recommendations for Future Works

The following suggestions are put up for further study in order to build on the present findings and overcome the limitations mentioned in Section 7.5:

Incorporate Real-Time Data and Stakeholder Feedback: Future studies should include primary data through case studies, surveys, or interviews with stakeholders (e.g., project managers, contractors) to validate literature-based findings and capture practical implementation challenges. Exploring impediments to BIM adoption, such as training costs or opposition, might offer practitioners with practical insights while also addressing the lack of stakeholder feedback mentioned in Section 1.5.

Region-Specific Analysis: To overcome the geographical limitation, future research could focus on specific regions with unique conditions, such as conflict zones or emerging economies, to assess how Political Risks and other categories vary across contexts. This would enhance the applicability of findings to diverse project environments, as suggested in Section 1.5.

Advanced Risk Categorization: The significant amount of "Other Risks" (29.0%) suggests that better natural language processing (NLP) approaches, such as BERT, are required to increase risk identification accuracy and catch developing threats such as technology disruptions or geopolitical conflicts, as indicated in Section 1.5. Expanding the keyword dictionary to include terms related to cybersecurity, climate change, or global supply chain disruptions could further enhance categorization.

Improved Topic Modeling: The topic modeling technique has to be improved by making themes more specific, especially when it comes to mitigation tactics. For instance, distinguishing between project management and operational strategies within the "Other Mitigation Strategy" topic could provide more specific recommendations for practitioners, addressing the methodological limitation of thematic granularity.

Cost-Benefit Analysis of Technology Adoption: The implementation of technology adoption through cost-benefit analysis (fuzzy logic and BIM) would demonstrate how these methods improve project results while decreasing operational risks. According to the generalizability limitation outlined in Section 1.5, this would provide practitioners with useful information, particularly for resource-constrained endeavors.

Longitudinal Studies for Smaller Projects: Longitudinal studies that look at how well mitigation techniques—like risk identification, contingency planning, and systematic frameworks—work over the long term in smaller projects may improve the findings' generalizability. This would solve the drawback of concentrating on big projects (Section 1.5) and shed light on how flexible these tactics are in various project situations.

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APPENDICES

Appendix 1. Summary of Literature Sources Based on Results

Table 4. Summary of literature sources based on results, organized chronologically by publication year (2017–2025) and alphabetically by first author's last name within each year

Source	Risk Categories Identified	Challenges Highlighted	Mitigation Strategies Proposed
Ahmed (2017)	Technical (uncertainty in innovation), Other (technological risks)	Dispersed innovation, difficulty identifying success factors	Risk mitigation planning, step-by-step methods for AV projects
Chang et al. (2018)	Political (disruptions from political risks)	Understanding political risks, negotiating favorable terms	Correct decision-making, full preparations, shaping a favorable environment
Rachid et al. (2018)	Operational (delays from slow change orders), Contractual (unrealistic contract duration)	Ineffective planning, slow variation orders	Identifying delay causes, assessing stakeholder views to improve management
Saeed (2018)	Operational (time and cost overruns), Other (poor business performance)	Inaccurate estimation, changes during construction	Adequate planning, improved contract management to reduce overruns
Bahamid et al. (2019)	Operational (time delays), Financial (cost overruns), Other (quality risks)	Complexity of identifying 111 risk factors, limited resources	Classifying critical risks, using literature reviews for better management
Nawaz et al. (2019)	Other (unmanaged risks), Contractual (financial risks from competition)	Lack of core risk management system, poor reputation for risk handling	Implementing risk management, survey-based analysis to improve success rates

Source	**Risk Categories Identified**	**Challenges Highlighted**	**Mitigation Strategies Proposed**
Sharma & Gupta (2019)	Operational (unavailability of funds, poor site management), Technical (design errors)	Complexity of large projects, changes in laws	Questionnaire surveys, classifying risks for early assessment
Aarthipriya et al. (2020)	Operational (time delays), Financial (cost variance), Other (unquantified risks)	Analyzing diverse risks, managing cost/time overruns	Monte Carlo simulation, sensitivity analysis, cost mitigation measures
Shaktawat et al. (2020)	Financial (economic risks), Environmental (geological uncertainties), Other (sustainability risks)	Long gestation periods, insufficient cost margins	Sensitivity analysis, risk analysis in cost estimation to reduce overruns
Zhang et al. (2020)	Safety (accident rates, technological risks)	Poor understanding of new risks, stakeholder coordination challenges	Identifying critical factors, surveys with professionals to improve safety
Banerjee Chattapadhyay *et al.* (2021)	Financial (cost risks), Operational (time delays), Other (quality risks)	Complexity of 63 risk factors, identifying sub-risk components	GA–K-means clustering, SMOTE to enhance risk prediction accuracy
Erol et al. (2021)	Other (complexity, uncertainty, unrealistic assessments)	Lack of structured risk synthesis, ineffective strategies	ANP model, Delphi study for risk quantification and assessment reliability
Li et al. (2021)	Financial (cost overruns, land acquisition), Environmental (sustainability impacts), Other (social risks)	Poor coordination, limited information sharing	Fuzzy set theory, extending sustainability with coordination for better strategies

Source	**Risk Categories Identified**	**Challenges Highlighted**	**Mitigation Strategies Proposed**
Santarsiero et al. (2021)	Technical (bridge failures), Other (aging infrastructure, degradation)	Data gaps, conservative guidelines limiting bridge operations	Prioritizing bridges for assessments, using public image repositories for data
Khairullah et al. (2022)	Contractual (contract-related, subcontractor issues), Technical (design risks)	Absence of risk management, lack of control over systems	Identifying risk causes, analyzing root causes to improve EPC project management
Nguyen et al. (2022)	Financial (economic risks), Operational (pandemic delays), Contractual (competence risks)	Joint venture organizational and legal risks	Ranking risk factors, understanding latent risks for better contractor selection
Osei-Kyei et al. (2022)	Operational (cost and schedule risks), Other (Industry 5.0 uncertainties, stakeholder issues)	Complexity of risk models, limited knowledge-based systems	Risk-integrated planning, effective knowledge-based systems
Shibani et al. (2022)	Financial (currency fluctuation), Operational (solvency delays), Other (inflation risks)	Severe economic crisis, barriers to effective risk management	Implementing risk management, classifying risks for targeted financial control
Canesi & Gallo (2023)	Financial (cost overruns), Other (economic risks from infrastructure decline)	Complexity of infrastructure projects, uncertainties in cost estimation	ANAC risk assessment tool, risk matrix to mitigate cost increases
Coskun et al. (2023)	Environmental (sustainability risks), Other (economic, social risks)	Cross-impacts of risks, unique nature of megaprojects	RAMSCOM for sustainability integration, visualizing interrelated risks

Source	Risk Categories Identified	Challenges Highlighted	Mitigation Strategies Proposed
Khodeir (2023)	Operational (unfair risk distribution, overlapping phases), Other (execution risks)	Incorrect contract terms, strain from faster delivery demands	Clarifying risks, careful scope assessment to manage uncertainties
Liu et al. (2023)	Safety (security incidents), Technical (complexity of tunnel risks)	Delays in risk management, lack of real-time risk adaptation	Comprehensive risk awareness, real-time adaptation, shortening delays
Xiang et al. (2023)	Political (government conflicts), Technical (technology complexity), Other (natural environment)	Lack of technical experience, inadequate coordination mechanisms	Integrated risk assessment, interest coordination, flexible environmental strategies
Yousri et al. (2023)	Contractual (funding issues), Supply Chain (material price fluctuations), Other (economic shifts)	Unrealistic duration estimates, currency valuation challenges	Identifying high-risk factors, redefining risks based on current conditions
Zhao (2023)	Political (geopolitical risks), Technical (human factors), Other (unspecified categories)	Integration challenges with CRM, limited use of advanced techniques	Advanced risk analysis, ICT-driven CRM for monitoring and communication
Al-Mhdawi et al. (2024)	Environmental (PPE non-compliance), Technical (equipment failure), Political (economic instability)	Complexity of assessing 41 risk factors, stakeholder miscommunication	Fuzzy-based FMEA, targeting significant risks like PPE non-compliance
Gao et al. (2024)	Other (historical risk carryovers)	Time-consuming risk data collection, expensive manual extraction	NLP-based MCRI model, multi-sentence context-aware approach for risk extraction

Source	Risk Categories Identified	Challenges Highlighted	Mitigation Strategies Proposed
Jackson & Priya (2024)	Operational (resource planning issues), Other (conflicts, technological adoption)	Difficulty in timely conflict resolution, limited focus on risk identification	Mandatory conflict resolution boards, identifying critical risk factors
Shishehgarkhaneh et al. (2024)	Supply Chain (micro-level risks, logistics delays), Other (macro-level economic shifts)	Complexity of risk allocation, reliance on traditional methods	AI techniques for risk identification, risk recovery strategies for resilience
Tang et al. (2024)	Safety (complexity, environmental uncertainties)	Shortcomings in safety risk management, underutilization of data	Text mining with Jieba package, TF-IDF for safety risk identification
Ullah et al. (2024)	Political (policy shifts, unpredictability), Other (expropriation)	Volatility in political environments, disruptions from civil disturbance	Systematic risk identification, thorough political environment examination
Adriantama et al. (2025)	Operational (diversion channel delays), Environmental (geological issues), Technical (design revisions)	Poor scheduling, over-processing from inefficient workflows	Lean construction, FMEA, Pareto principle to target high-impact risks and waste
Ahmad et al. (2025)	Environmental (bridge lifecycle risks), Other (sustainability risks)	Complexity of integrating BIM with LCSA, supervision phase challenges	Integrating BIM with LCSA, Pareto principle, ISO 9001:2015 guidelines
Amin et al. (2025)	Supply Chain (delayed delivery, material prices), Other (skilled labor shortages)	Poor logistics coordination, insufficient collaboration with agencies	Real-time monitoring, stakeholder collaboration, improved logistics coordination
Chen et al. (2025)	Supply Chain (financial constraints, material delays), Environmental (sustainability risks)	Lack of risk frameworks, operational inefficiencies in SMEs	Systematic risk assessment frameworks, categorizing risks for SMEs

Source	Risk Categories Identified	Challenges Highlighted	Mitigation Strategies Proposed
Hatefi et al. (2025)	Operational (import restrictions, climatic conditions), Other (inflation volatility)	High work volume, dynamic project nature, limited data on low-risk factors	Fuzzy Shannon entropy, Fuzzy EDAS for risk prioritization and resource allocation
Ramadhan & Waty (2025)	Technical (design changes), Operational (planning errors)	Insufficient documentation, inaccurate cost estimation, poor coordination	BIM for planning accuracy, strengthening design reviews, structured change protocols

Note. Contributions are summarized based on the study's results.

Appendix 2. Word Clouds by Risk Categories

Figure 6. Contractual risks word clouds

Figure 7. Environmental risks word clouds

Figure 8. Financial risks word clouds

Figure 9. Operational risks word clouds

Figure 10. Other risks word clouds

Figure 11. Political risks word clouds

Figure 12. Safety risks word clouds

Figure 13. Supply chain risks word clouds

Figure 14. Technical risks word clouds

Appendix 3. Word Clouds by Common Challenges

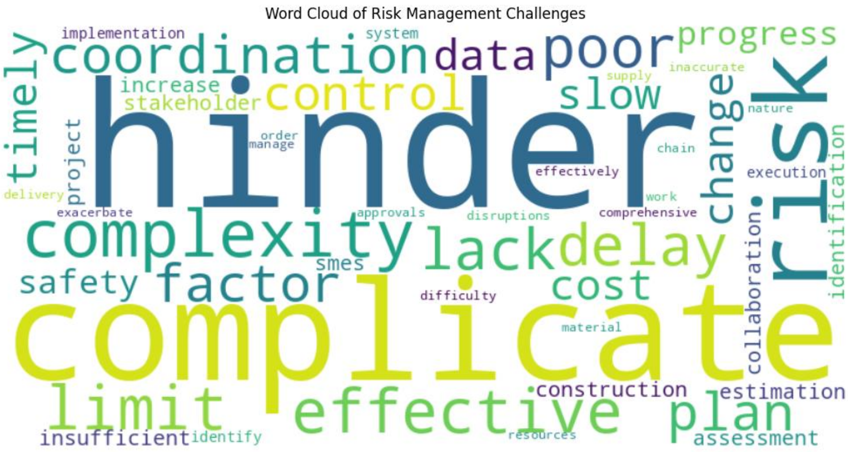

Figure 15. Management challenges word clouds

Appendix 4. Word Clouds by Mitigation Strategies

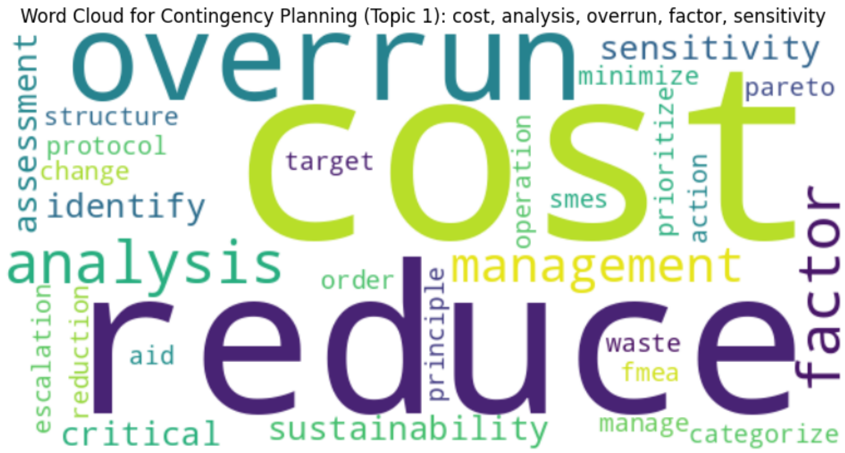

Figure 16. Contingency planning word clouds

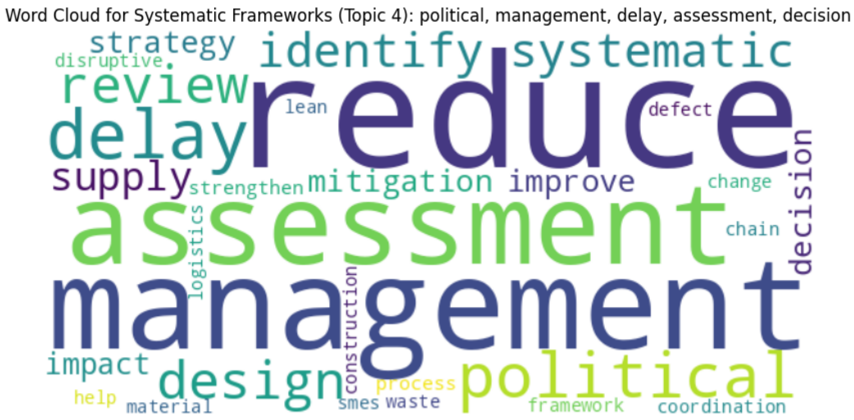

Figure 17. Systematic frameworks word clouds

Figure 18. Other mitigation strategy word clouds

Figure 19. Risk identification word clouds