Ripple Effects in Construction Supply Chains:

Risk Identification, Propagation, and Mitigation in SMEs

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ABSTRACT

This thesis examines the ripple effect within construction supply chains, with a particular focus on small and medium-sized enterprises (SMEs). Although the ripple effect has been widely investigated in supply chain contexts, research addressing its characteristics in the construction sector remains limited. To bridge this gap, this study identifies the key triggers of ripple effects in construction SMEs, evaluates their relative importance, and explores how ripple effects materialise and influence project performance in practice.

Using a multiple-method approach, the research combines thematic analysis, Analytical Hierarchy Process (AHP), and an in-depth case study. Four overarching categories of risk: Financial, safety, design, and contractual, were identified as the primary triggers of ripple effects in construction SMEs. The AHP results reveal substantial variation in risk perception across six SME sub-sectors, with safety and financial risks exerting the highest overall influence. A detailed case study of a renovation project further demonstrates how ripple effects evolve across project phases and propagate among stakeholders, affecting time, cost, and quality outcomes. Supported by Causal Loop Diagrams (CLDs), the study visualises the mechanisms through which ripple effects escalate or are contained and identifies the role of communication, design accuracy, and supervision in shaping their impacts.

The thesis makes three key contributions. First, it proposes a structured framework for examining ripple effects in construction SMEs and identifies 13 risk factors that drive ripple propagation. Second, it introduces a new SME sub-sector categorisation that enables targeted risk analysis and supports more effective management strategies. Third, the study enhances both theoretical and practical understanding of ripple dynamics in project-based supply chains. Overall, the research advances knowledge on ripple effects within the construction domain and provides actionable recommendations to strengthen SME supply chain.

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DEDICATION

This thesis is dedicated to my father, *Yong Chen*, and my mother, *Liping Zhang*, for their constant love and unwavering support.

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LIST OF PUBLICATIONS/CONFERENCES ARISING FROM THIS RESEARCH

1. Chen, S., Eyers, D., Gosling, J. and Huang, Y. 2025. Supply chain risks for SMEs in construction projects: A structured literature review and research agenda. The International Journal of Logistics Management (10.1108/IJLM-12-2023-0548)

2. Chen, S., Eyers, D., Gosling, J. and Huang, Y. 2023. Supply Chain Risks and their importance for SMEs in Construction Projects: A Structured Literature Review and Research Agenda. Presented at: 27th International Symposium on Logistics (ISL), Amsterdam, Netherlands, 9-12 July 2023.

3. Chen, S., Eyers, D., Gosling, J. and Huang, Y. 2024. Ripple Effects for SMEs in Construction Projects: A Structured Literature Review and Research Agenda. Presented at Twenty-third International Working Seminar on Production Economics (IWSPE), Innsbruck, Austria, 14-18 February 2024.

4. Chen, S., Eyers, D., Gosling, J. and Huang, Y. 2025. How does the ripple effect manifest in construction SMEs? Presented at 32nd International Annual Conference of the European Operations Management Association (EurOMA), Milan, Italy, 15-18 June 2025.

TABLE OF ABBREVIATIONS

Abbreviation	Description
AARC	Affinely adjustable robust counterpart
AHP	Analytic Hierarchy Process
BWM	Best-Worst Method
CR	Consistency ratio
DBN	Dynamic Bayesian network
DEMATEL	Decision making trial and evaluation laboratory
EDCT	Emerging digital communication technologies
F-DEMATEL	Fuzzy Decision-Making Trial and Evaluation Laboratory
FPSC	Fresh produce supply chains
GDP	Gross domestic product
MCDM	Multi-Criteria Decision-Making
MSMEs	Micro, Small, and Medium Enterprises
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
ODRS	Ohio Disease Reporting System
QFD	Quality function deployment
RO	Robust Optimization
SCR	Supply chain risk
SCRM	Supply chain risk management
SCV	Supply chain vulnerability
SDM	System dynamics modelling
SMEs	Small and medium-sized enterprises
SNA	Social network analysis
TOPSIS	Technique for Preference by Similarity to the Ideal Solution

Chapter 1 Introduction

1.1 Chapter overview

The purpose of this chapter is to introduce the thesis. It begins by outlining the background of the study, highlighting the dynamics of risk and the ripple effect within the supply chains of construction SMEs. The chapter also presents the motivation behind the research and defines five key research questions, each corresponding to an identified research gap. Finally, an overview of the thesis structure is provided to guide the reader through the subsequent chapters.

1.2 Research background

The construction industry, which encompasses the planning, design, and execution of building and infrastructure projects, despite its long-established history, continues to grapple with emerging risks and increasing demands for efficiency and resilience (Murtagh et al. 2020; Rane 2023). Owing to its complex, multi-tiered supply chains and the involvement of numerous stakeholders, construction projects are particularly vulnerable to unexpected disruptions arising from both internal and external sources (Smith et al. 2014). These disruptions, ranging from design flaws to fluctuating material prices, can significantly delay project timelines and inflate costs (Panova and Hilletofth 2018). Stakeholder complexity further compounds these challenges, often leading to unforeseen developments throughout the project lifecycle (Aloini et al. 2012; Koc and Gurgun 2021; Ghamarimajd et al. 2024). In addition, a range of factors, such as technological advancements, evolving regulatory frameworks, design modifications, and supply chain uncertainties, have been identified as major contributors to cost and time overruns in construction projects (Asiedu et al. 2017; Baghalzadeh Shishehgarkhaneh et al. 2025).

In response to these persistent risks, academic research on construction supply chain management has expanded significantly in recent years (Ekanayake et al. 2020; Nguyen

and Le 2022). However, the integration of theoretical models with practical strategies for effectively controlling supply chain risks (SCRs) in construction remains limited (Pomaza-Ponomarenko et al. 2023). This research gap underscores the need for more adaptable and comprehensive risk management approaches, particularly in an industry where project environments are inherently uncertain (Ho et al. 2015).

In the UK, SMEs account for approximately 99% of all businesses, representing around 5.67 million out of 5.7 million private sector enterprises across all sectors (Department for Business & Trade 2025). Within this complex landscape, construction SMEs account for a significant proportion of both the number of businesses and turnover (OECD 2023). These enterprises, ranging from small contractors to specialized service providers, are characterized by their size, owner involvement, and limited financial and managerial capabilities (Björnfot and Torjussen 2012). Depending on their specific functions, such as renovation or housebuilding, SMEs may encounter different levels and types of risk exposure within the supply chain (Acar et al. 2005; Joblot et al. 2019).

SMEs in the construction industry are the primary focus of this thesis. They have been chosen for several reasons: First, their limited financial resources and limit information source cause them to easily ignore the ripple effects (Algan et al. 2018). Second, their roles in the construction supply chain are complex and varied, so extensive construction supply chain management theories may not fit them (Pablo and London 2020). Third, current research on the ripple effect is developing rapidly, but there is a lack of corresponding literature support for construction industry (Duong et al. 2023).

Despite their significance role, construction SMEs face disproportionate risk burdens. Clients often transfer risks such as design flaws, cost inflations, and time overruns onto smaller contractors under design-and-build contracts (The Chartered Institute of Building 2024). This occurs because SMEs typically possess weaker bargaining power, limited financial reserves, and less contractual influence, making them more likely to accept unfavourable risk allocations to secure projects (Berry 2021). Often

compounded by limited financial capacity and underdeveloped information systems, SMEs frequently struggle to identify SCRs at an early stage, leaving them vulnerable to cascading disruptions that adversely affect project timelines and asset utilization (Kannabiran and Dharmalingam 2012). These vulnerabilities emphasize the critical need for more robust supply chain risk management (SCRM) frameworks that address the specific challenges faced by SMEs (Safari et al. 2024).

A notable example of the broader impact of SCR in construction is the cancellation of the second phase of HS2, a major high-speed railway project in the UK (HS2 2024). In 2023, UK Prime Minister Rishi Sunak announced the termination of the HS2 link from the West Midlands to Manchester due to escalating costs and extended timelines (Austin et al. 2023). This decision triggered a series of ripple effects across the construction supply chain, including contract terminations, workforce redundancies, and financial losses among subcontractors and material suppliers who had already invested in project-specific capacities (Anoyrkati et al. 2022). The cancellation also disrupted regional development plans and delayed related infrastructure investments in the North of England, demonstrating how risks can cascade beyond the primary contractor to affect multiple tiers of the supply chain (Winch 2025). Furthermore, the UK government is expected to invest £1.25 billion to cover the costs of cancellation (Banks 2023). This reallocation of budgetary funds may hinder the progress of other infrastructure or public service projects, causing further delays and recovery costs. The HS2 example illustrates how supply chain disruptions can extend beyond immediate project boundaries, highlighting the necessity for flexible and efficient SCRM that can adapt to uncertainties in both project processes and financing (Shishehgarkhaneh et al. 2024; Okika et al. 2025).

Traditional SCRM often focuses on localized risks within immediate supplier networks, overlooking how disruptions can propagate across multiple tiers of the supply chain (Scheibe and Blackhurst 2018). This phenomenon, known as the ‘ripple effect’, occurs

when a disruption in one part of the supply chain cascades through interconnected networks, affecting firms across different tiers or even industries (Ivanov et al. 2014c). In complex construction supply chains, where interdependencies are high and substitute suppliers are limited, ripple effects can amplify initial disruptions, exacerbating risks for SMEs that may have limited visibility beyond their direct suppliers (Ali et al. 2017b). Failing to recognize these ripple effects leads to an incomplete understanding of risk exposure and underestimates the true impact of disruptions (Li et al. 2021).

In practice, unmanaged ripple effects can escalate into severe consequences, including funding losses, project failures, and in extreme cases, the collapse of entire businesses through constrained management resources or bankruptcy (K.E.K et al. 2022). This vulnerability is particularly acute for construction SMEs, which often lack the resilience to withstand disruptions originating beyond their immediate control (Ferreira de Araújo Lima et al. 2020). By examining how disruptions propagate and identifying key factors that influence ripple effects, this research aims to bridge the gaps between theoretical insights and practical management strategies. This not only contributes to academic understanding but also provides valuable guidance for practitioners in managing ripple effects during the process of project development.

1.3 Research aim & objectives

The overall aim of this thesis is to investigate the theory and practice of the ripple effect in construction supply chains from the perspective of SMEs. It seeks to address a critical research gap identified in both the literature and industry practice: The limited theoretical understanding and the absence of practical frameworks that specifically capture how ripple effects manifest within construction SMEs. Although the ripple effect has been conceptually recognised in broader supply chain research, its application to the construction SMEs industry remains underexplored (Duong et al. 2023; Thi Binh et al. 2025). This is partly because the concept is relatively recent and continues to evolve, leading to ongoing develops over empirical research methods

(Ivanov et al. 2025). Moreover, the vast and varied nature of the construction SME landscape makes data collection and validation particularly challenging (Kissi et al. 2022). Nevertheless, focusing on SMEs offers a valuable opportunity to understand how risks propagate through multi-tier supply networks characterised by resource constraints, informal coordination, and contractual flaw.

Amid global cascading supply chain disruptions, interest in the ripple effect has grown (Ivanov 2021b). Much of the research has focused on the evolution of the ripple effect and advancing research methodologies. This includes state-of-the-art techniques, comprehensive reviews of the literature, and the growing convergence between disciplines (Birkie and Trucco 2020; Li et al. 2021; Mishra et al. 2021; Pavlov et al. 2022). For example, Li and Zobel (2020) examines the overall resilience of supply chain networks in the presence of ripple effects or risk propagation by developing a multi-dimensional quantitative framework. In contrast, a few studies have adopted an empirical method, focusing on regional analyses of the causes of ripple effects. A notable example is the study by Duong et al. (2023), which identified the propagation mechanisms of ripple effects and assessed the concurrent impact of risk on supply chain performance. However, the above studies neglected the perspective of SMEs. This omission is significant because SMEs often operate with limited information resources, weaker contractual leverage, and less formalised risk management systems (Rostami et al. 2015). Therefore, this study focuses on construction SMEs to conduct an in-depth analysis of the ripple effect.

The **First** objective of this study is to identify the risks that trigger ripple effects in the construction supply chain to better manage risk propagation and ensure the smooth implementation of projects. Due to the complexity of its activities and the large number of stakeholders involved, the construction industry is particularly vulnerable to ripple effects (Ye et al. 2025). Yet existing research on this topic remains limited and fragmented. Although several studies have explored ripple effects within construction

supply chains, they have predominantly focused on large firms, offering limited insight into the distinctive characteristics and vulnerabilities of SMEs. As a result, there is little about how ripple effects emerge, spread, and are managed in resource-constrained SME environments. The aim of this exploration is to identify current risks that lead to ripple effects through interviews with practitioners in the construction SME industry, particularly summarizing various construction supply chains.

The **Second** objective of this thesis is to rank the factors that trigger ripple effects in the construction supply chain. This involves analysing the risks that cause ripple effects across different type of the construction industry. This motivation stems from analysing the characteristics of SMEs base on their functions. These firms often struggle to cope with all the risks arising from the ripple effect due to their limited resources (Etemad 2020). Therefore, the author adopts an approach that aims to identify and prioritize the most significant risks and provide SMEs with the guidance they need to effectively manage the risks associated with the ripple effect.

The **Third** objective of this study is to understand how the ripple effect manifests in the operations of actual construction SMEs. This also highlights the current dearth of empirical studies on SMEs ripple effects, i.e., cases using real company data that allow for medium and long-term empirical observations of ripple effects across the industry sector (Dolgui and Ivanov 2021b). To further explore this situation, this thesis examines the supply chain ripple effect in construction SMEs by investigating how the ripple effect occurs and possible manage strategies through the examination of actual operations.

The **Fourth** objective of this study is to explore how the ripple effect can be mitigated within construction supply chains. This objective arises from the need to translate theoretical insights into practical strategies that strengthen supply chain performance. Existing studies suggest that mitigation approaches generally centre on enhancing robustness and resilience (El Baz and Ruel 2021). However, how these concepts apply

within the fragmented and resource-constrained context of construction SMEs remains unclear. Understanding these dimensions is essential for developing realistic and scalable strategies for managing ripple effects in practice.

Finally, the **Fifth** objective is to investigate how ripple effects manifest in real construction projects. This objective seeks to generate an empirical understanding of the causes, consequences, and progression of disruptions as they unfold in practice. By examining how practitioners perceive and respond to these events, the study aims to identify the gap between expected and actual outcomes and to derive propositions that explain the dynamics of ripple effects and their implications for project performance.

1.4 Research gaps and questions

While supply chain ripple effects have been identified in academia and across various industries (Marcucci et al. 2024), their manifestation within construction SMEs remains unexplored. Construction SMEs have distinctive characteristics, such as limited personnel, constrained capital, and reliance on single or narrow supply chains (Su et al. 2022), all of which may shape how ripple effects manifest. Existing theories often general supply chain risk events without accounting for these industry specific characterises (Srivastava and Rogers 2022). This has resulted in conceptual and empirical gaps in understanding the operational mechanisms of ripple effects within construction SMEs.

To address these deficiencies, the overarching aim of this thesis is to examine both the theory and practice of the ripple effect in construction supply chains from the perspective of SMEs. This aim is operationalised through five specific objectives, each corresponding to a key research gap identified in the literature. The alignment between the objectives and gaps ensures that each stage of the research systematically advances understanding of how ripple effects can be identified, measured, visualised, and mitigated within construction SME environments. As a result, the research Gap 1 and Question 1 are identified.

Gap 1: There is limited research on supply chain ripple effects in construction SMEs.

Research Question 1 (RQ1): What are the risks that cause ripple effects in the supply chains of construction SMEs?

While risk identification frameworks are established in the supply chain management literature (Ho et al. 2015), prioritising which risks have the greatest impact in triggering ripple effects remains underexplored, particularly within the context of construction SMEs. Theoretical models often neglect industry-specific risk interactions or the varying degrees of influence these risks have in propagating disturbances (Merz et al. 2013). There is a clear need to refine existing models to better categorise, weight, and rank these risks specifically for construction SMEs. From a practical standpoint, construction SMEs also lack concrete tools or methodologies that enable them to prioritise risks based on their likelihood of triggering ripple effects. Therefore, Gap 2 and Question 2 in this study focus on addressing this issue by ranking the risks that contribute most significantly to ripple effects.

Gap 2: Current research does not clarify which risk factors exert the greatest influence in triggering ripple effects across construction SME supply chains.

Research Question 2 (RQ2): What is the impact of risk factors on construction SMEs under ripple effects?

Conceptual models of the ripple effect have rarely been empirically validated within the context of construction SMEs, this is because limited data on the real companies and difficulty to access (Llaguno et al. 2022). These theories often rely on simulations, hypothetical scenarios, or data from large enterprises, failing to capture the real-world interactions characteristic of construction SMEs supply chains (Mishra et al. 2021). As a result, the robustness and applicability of these frameworks remain limited in this specific context due to the lack of empirical evidence. In the absence of concrete case studies that demonstrate the actual manifestations of ripple effects within construction

SMEs, these firms have limited opportunities to learn from real-world experiences. This gap restricts the development of industry-specific best practices. Therefore, Gap 3 and Question 3 focus on addressing this issue by investigating real-world cases of construction SMEs through in-depth study.

Gap 3: There is a lack of empirical studies demonstrating how ripple effects materialize in practice.

Research Question 3 (RQ3): How can ripple effects in the supply chains of construction SMEs be evaluated?

There is limited research on the specific applicability and effectiveness of SCR mitigation strategies for SMEs in the construction industry (Rostami et al. 2015; Pham et al. 2022b). Theoretical discussions often overlook the constraints faced by these firms, such as project-based sourcing and fragmented operations, and fail to adapt mitigation strategies to the unique structural and operational dynamics of the construction sector (Siamuzwe-Manase et al. 2024). In practice, resource limitations make it challenging for construction SMEs to adopt risk mitigation strategies that are both feasible and effective (Turgay and Aydin 2023). The absence of tailored approaches that account for cost, complexity, and the potential for risk reduction leaves SMEs less resilient to ripple effects. Therefore, Gap 4 and Question 4 focus on exploring appropriate ripple effect manage strategies specifically designed for construction SMEs.

Gap 4: Existing research offers limited empirical insight into the practical application of mitigation strategies for ripple effects within construction SMEs.

Research Question 4 (RQ4): What practical mitigation strategies do construction SMEs implement to minimize the impact of ripple effects?

Existing research on ripple effects offers limited visualisation models capable of simulating different scenarios and assessing the propagation of disruptions from the

perspective of the projects (Ghadge et al. 2022). Moreover, only few studies have explored the visualisation of ripple effects in real-world cases (Ojha et al. 2018; Kinra et al. 2020). From construction SMEs perspective, there is also a notable absence of quantitative data capturing the actual impacts of ripple effects, particularly in terms of financial costs, timelines, and quality. There is a lack of empirical evidence depicting actual ripple effects and their subsequent impacts within real-world construction projects. Gap 5 and Question 5 encompass both the absence of practical visualisation methods and the scarcity of assessments that measurable project outcomes.

Research Gap 5: There is a lack of empirical evidence on actual ripple effects in the real world and their impacts.

Research Question 5 (RQ5): How do ripple effects unfold in real construction projects, and what are their impacts on project performance?

In addressing these research questions, this thesis contributes to ripple effect theory by developing an empirically grounded systems thinking explanation of disruption propagation in construction SME supply chains. Although systems thinking has been applied to the study of ripple effects, its application in the context of construction SMEs remains limited, particularly in providing a transparent explanation of how disruptions propagate through interconnected risks and stakeholders (Ghamarimajd et al. 2024; Baghalzadeh Shishehgarkhaneh et al. 2025). This perspective connects stakeholder interdependencies and interactions among risks with their consequences for project cost, schedule, and quality. It further clarifies how the timing of disruptions and the availability of buffers shape these consequences, thereby extending understanding of ripple effects within the resource-constrained context of construction SMEs.

1.5 Thesis structure

In the literature review presented in Chapter 2, the author first explores key concepts related to SMEs in the construction industry, supply chain disruptions, and ripple

effects. In the second part, the author analyses the current state of research on these topics based on a structured literature review, providing readers with insights into prevailing research methodologies and highlighting the limited body of literature specifically on construction SMEs. It also provides a descriptive analysis detailing the years and methods in which the research was conducted. The review reveals significant gaps in academic research on the application of ripple effects in the construction industry. This chapter evidence gaps and aims of research in the Figure 1.1.

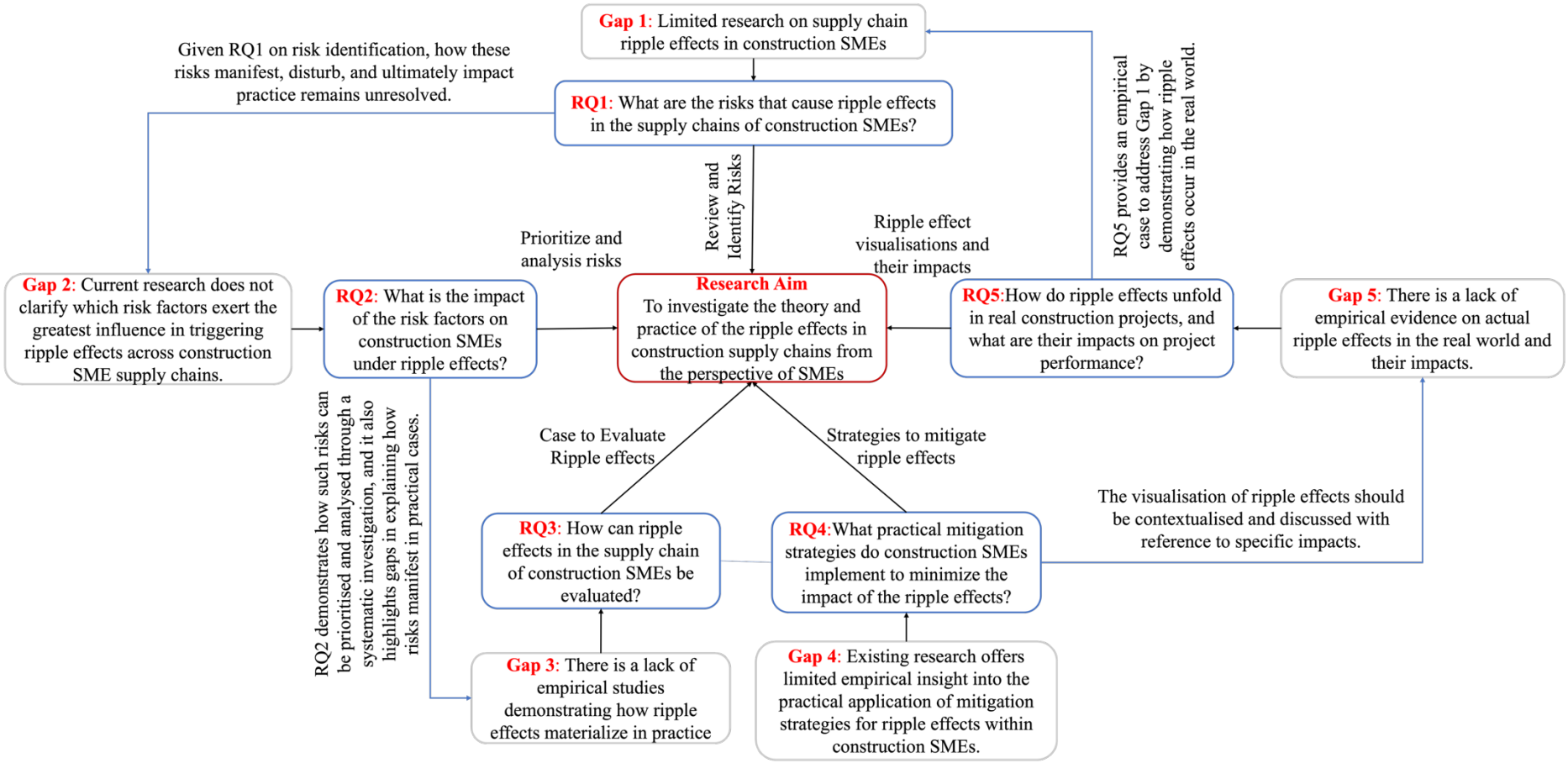


Figure 1.1: Thesis overview

Source: The author

Chapter 3 establishes the methodological framework of the thesis by outlining the philosophical stance, research paradigm, and the rationale for adopting a multiple-methods design. It integrates qualitative techniques, such as semi-structured interviews, questionnaires, and systems thinking, with the quantitative Analytic Hierarchy Process (AHP) to ensure methodological rigour and triangulation. This framework provides a coherent foundation for addressing the research questions and linking theory with empirical investigation.

Chapter 4, which aims to answer RQ 1, focuses on the identification of risk factors as the basis for following Chapters. The rational collection of real-world construction supply chain ripple effect risks is key to subsequent risk ranking and case study analyses. According to the structured literature review in Chapter 2, there are very few qualitative studies on construction supply chain ripple effects. Therefore, this chapter collects data from real-world construction firms through interviews to identify risk factors that trigger ripple effects in the construction SMEs.

Chapter 5 explores the impact of ripple effect factors. The chapter uses surveys to collect data from construction practitioners and ranks the risks using the AHP method. The chapter is divided into two parts. The first part identifies the importance of risk in different supply chains across construction industries through questionnaire with a wide range of construction practitioners. The second part analyses the ranking by AHP method for typical industry supply chain expert data. Chapter 5 answers RQ 2.

Chapter 6 addresses RQ3 by examining the ripple effects in construction SMEs through an in-depth case study. It explores events such as project delays and financial losses, traces the evolution of associated risk paths, and identifies the key factors that contribute to the generation of ripple effects. In addition, the chapter presents current practices for managing ripple effects in the construction supply chain to address RQ4. Drawing on stakeholder interviews, it adopts a systems thinking approach to visualise

how disruptions propagate across project stakeholders and integrates the influence of stakeholder performance on overall project outcomes for RQ 5.

Chapter 7 synthesises the literature review and the empirical findings from Chapters 4 and 6 to generate deeper insights into the chain effect within construction SME supply chains. Building on this synthesis, the chapter develops four propositions that conceptualise how chain effects emerge, propagate, and influence project performance in construction SMEs.

Chapter 8 concludes the thesis by summarising the research undertaken and addressing all the research questions. This is followed by a discussion of the conceptual and practical contributions of the study. The chapter then outlines the limitations of the research and proposes directions for future investigation. The overview thesis structure as shown in Figure 1.2.

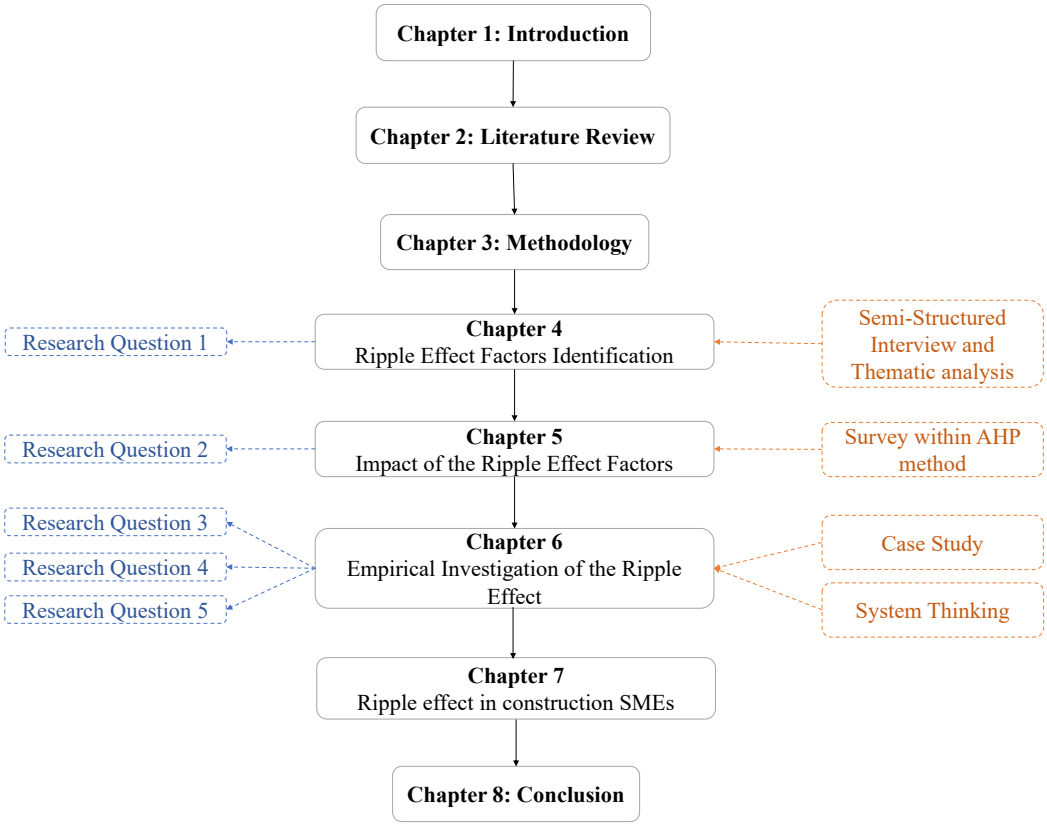


Figure 1.2: Thesis structure

Source: The author

1.6 Chapter summary

The chapter presented the background of the study, focusing particularly on the various challenges faced by construction SMEs, such as financial constraints and limited resources, as well as the consequences of ripple effects, including funding losses and project failure. In discussing the motivation for the study, the chapter outlines the overarching research aim to investigate the theory and practice of the ripple effect in construction supply chains from the perspective of SMEs. Furthermore, it introduces the specific research questions derived from the identified research gaps. Finally, the chapter concludes with a summary of the thesis structure, providing an overview of each chapter.

Chapter 2 Literature review

2.1 Chapter overview

The aim of this chapter is to provide the academic literature background that underpins this PhD, together with an overview of the current state of research on the ripple effect. Part one begins with a discussion of the conceptual theories relevant to the thesis, including the ripple effect, SCR, and the construction industry, with a particular focus on SMEs. This section is designed to help the reader understand the theoretical foundations of the topic. Part two presents a structured literature review (Sections 2.5–2.9), which offers a descriptive analysis of existing studies and examines the current state of the art on ripple effects. The review equips the reader with the background knowledge required to critically assess gaps in the literature on ripple effects in construction SMEs. It also establishes a foundation for more focused discussions in the subsequent chapters, providing comprehensive information and insights to guide the reader through the thesis.

Part one: Concept of Ripple Effect, SCR, and Construction SMEs

This literature review begins with the ripple effect (Section 2.2) as the central conceptual framework, given its pivotal role in explaining the cascading nature of supply chain disruptions. By foregrounding this concept, the review highlights the distinctive perspective offered by the ripple effect in understanding disruption propagation. Following this, mitigation strategies specific to ripple effects are examined to illustrate existing responses to such disruptions. The review then broadens its scope to SCRM frameworks (Section 2.3), which provide the theoretical foundation for understanding risk categories and management approaches. Finally, Section 2.4 focuses on construction supply chains and SMEs, situating these discussions within the specific context of this research and emphasising the vulnerabilities and challenges that SMEs face in managing ripple effects.

2.2 Ripple effect

The interaction and transmission of supply chain risks (SCRs) across interconnected actors form the basis of disruption propagation within a networked system (Scheibe and Blackhurst 2018). For example, when the ship Ever Given blocked the Suez Canal in 2021, delays and disruptions in the transport of goods propagated upstream and downstream in the supply chain, adversely affecting global supply chains (Wan et al. 2023; Li et al. 2025). This propagation within the supply chain network, caused by interactions between risks and leading to risk spreading at different levels, has been referred to by scholars as the 'ripple effect,' 'domino effect,' and 'snowball effect' (Świerczek 2014; Thi Binh et al. 2025). This section presents the definition and sources of the ripple effect, as well as potential mitigation strategies.

2.2.1 Definitions of ripple effect

The ripple effect in supply chains has garnered increasing attention from scholars as an emerging area of research (Ivanov et al. 2025). The study of ripple effects in supply chains remains at an emerging stage, with scholars increasingly exploring its theoretical foundations and practical implementation (Dolgui et al. 2018b; Ivanov et al. 2019a; Ivanov 2021b). Scholars focus on exploring its disruptive consequences, where the impact spreads from individual entities to various parts or even the entire supply chain (Li et al. 2021). The ripple effect can lead to diverse outcomes, affecting on-time delivery of goods, profit margins, market share, and company reputation (Ivanov 2017). In addition, from a theoretical perspective, understanding the mechanics of the ripple effect enables scholars to better anticipate and minimise SCRs and disruptions (Mishra et al. 2021; Pavlov et al. 2022). Ivanov et al. (2014c) were among the first scholars to provide a comprehensive representation of the ripple effect, arguing that:

> *Ripple effect describes the impacts of how supply chain disruptions to some variables are rippling through the rest of the supply chain and influencing its performance. (*pp. 2155*)*

Since 2014, scholars have increasingly examined the ripple effect, recognizing its link to supply chain structural dynamics (Ivanov 2018; Dolgui and Ivanov 2020; Ghadge et al. 2022). Another example is the evaluation of the methods adopted in ripple effect literature, where many researchers focus on applying mathematical modelling and simulation such quantitative method to interpret the mechanisms of the ripple effect and explore potential mitigation strategies (Llaguno et al. 2022). The ripple effect in supply chains can be characterised by several interrelated attributes that collectively describe how disruptions originate, propagate, and evolve across networked systems as summarised in Table 2.1.

Table 2.1:Ripple effect attribution and definition

Attribute	Definition / Description
Trigger or Initiating Event (Marcucci et al. 2022)	The initial disruption that activates the ripple effect, such as supply delays, demand surges, production stoppages, or regulatory changes.
Propagation Path (Li et al. 2021)	The route through which disruptions spread across the supply chain network
Amplification / Weaken Mechanism (Thi Binh et al. 2025)	The processes or factors that amplify or weaken disruption propagation, including buffering capacity, safety stocks, flexible contracts, and adaptive managerial responses.
Dynamic nature (Ghadge et al. 2022)	The dynamics of ripple effects, referring to how disruptions evolve over time and spread across multiple supply-chain levels or geographic regions.
Multi-dimensional Impact (Sokolov et al. 2016; Li and Zobel 2020)	The range of outcomes resulting from ripple propagation, affecting cost, schedule, quality, profit margins, market share, reputation, and overall structural resilience.

Source: The author

Despite growing academic interest in ripple effect research, a significant gap persists in understanding how the ripple effect behaves in the construction industry. To-date, only one study, by Duong et al. (2023) has explored the ripple effects of disruptions on performance within the construction supply chain. Their findings indicate that human

risk leads to operational risk, while natural risk results in both supply and operational risks within the construction industry context. Furthermore, they observed that the effects of human and natural risks on performance are exacerbated by operational risk. This study is valuable in specifies risk-to-risk propagation pathways and links these pathways to measurable performance impacts within a construction context. However, its scope is limited by its aggregate treatment of SMEs, the absence of multi-tier stakeholder dynamics, and restricted operationalisation of mitigation strategies. Considering the current state of academia regarding ripple effects in the construction supply chain, the author believes that empirical research in this area can help scholars identify possible risks and provide effective guidance to practitioners. Therefore, the author defines the ripple effect in the context of the construction supply chain:

> *In the construction supply chain, the ripple effect manifests as the propagation of an event or risk over time, culminating in significant impacts dimensions, including cost, schedule, quality, safety, sustainability, and organisational reputation. This effect may manifest through single or multiple channels, or via a complex interplay of factors, ultimately influencing projects in various ways.*

The ripple effect may occur through various channels, which refer to the mechanisms or pathways by which disruptions spread across stakeholders and project stages, such as material supply, information exchange, financial transactions, and contractual dependencies. The interaction among these channels often generates compound effects that extend beyond the initial disruption, influencing overall project performance and resilience.

2.2.2 Ripple effect mitigation strategies

When discussing mitigation strategies for the ripple effect, many scholars adopt a disruption-oriented perspective to minimise its impacts (Scheibe and Blackhurst 2018; Yang et al. 2021). Within this stream of research, two primary concepts: Robustness and resilience are commonly employed to mitigate ripple effects in supply chains.

Robustness refers to the capacity of a supply chain to withstand the adverse effects of disruptions while maintaining normal operations and minimizing the impact on performance (Ivanov and Sokolov 2013; Han and Shin 2016; Dolgui et al. 2020). Resilience focuses on the ability of a supply chain to recover and resume its normal operations after disruptions (Ivanov et al. 2014c; Dabhilkar et al. 2016; Ivanov 2018; Liu and Lee 2018). Notably, resilience can be categorized into two dimensions: active or passive, and internal or external (Dabhilkar et al. 2016). Table 2.2 demonstrates literature related to supply chain robustness and resilience, including the scope of the literature.

Numerous studies have demonstrated that the efficacy of resilience capabilities in mitigating ripple effect is contingent upon contextual factors such as supply chain complexity (Bode and Wagner 2015; Tokui et al. 2017). The academic debate on resilience locates around the role of supply chain complexity as a potential driver of ripple effects. Researchers such as Ivanov et al. (2014c) contend that supply chain complexity might provoke ripple effect. Conversely, other scholars like Birkie and Trucco (2020) have investigated the negative moderating impact of supply chain complexity on such ripple effect. This argument implies that higher supply chain complexity can often be more effective in mitigating the consequences of ripple effect.

Within the context of construction SMEs, robustness and resilience are conceptualised mechanisms for mitigating ripple effects (Ekanayake et al. 2022a). In this study, robustness refers to the capacity of a supply chain to absorb and withstand disruptions without major loss of function, relying on design stability, redundancy, and proactive control measures. Resilience, on the other hand, is understood as the capacity to recover, adapt, and restore performance once disruptions have propagated through the system. Thus, robustness helps prevent ripple effects from escalating, while resilience enables adaptation and learning in their aftermath.

Table 2.2: Literature on supply chain resilience and robustness

Main topic: Supply Chain Resilience **Scope:** Literature within this scope examines supply chain resilience, with several studies investigating the enablers and barriers specific to SMEs. Other articles propose methodologies for analysing resilience, such as the Digital Twins, and Bayesian Networks methods.		
Topic(s)	Reference (s)	Content(s)
Review on the resilience	Hohenstein et al. (2015); Kamalahmadi and Parast (2016); Hosseini and Ivanov (2020a); Tennakoon et al. (2023); Kumar and Singh (2025)	These literature review defined supply chain resilience and its key building elements, developing a framework of principles that support its understanding, while also identifying research trends and offering a comprehensive overview of the field.
Structural relationships Supply network disruption and resilience	Kim et al. (2015)	The study conceptualizes supply network disruption and resilience by examining the structural relationships among entities in the network. The research compares four fundamental supply network structures to help understand supply network disruption and resilience.
Resilience in SMEs	Ali et al. (2017b)	This study identifies key enablers and barriers of resilience in SMEs and proposes an optimal portfolio for balancing efficiency and flexibility. The level of resilience, as well as the nature of barriers and risks, varies considerably among SMEs depending on their size (small vs. medium) and their position within the supply chain.

The relationship between resilience and risk	Aven (2017)	Resilience management is not depending on risk considerations and assessments to be effective but could benefit from such considerations and assessments if properly conducted. Argues that resilience management should complement, rather than replace, risk assessment practices.
Supply chain network resilience in the presence of the ripple effect	Li and Zobel (2020)	Network type influences supply chain network resilience more in the short term due to ripple effects, while enhancing node risk capacity improves resilience more effectively than adjusting network structure. Highlights the short-term dominance of network type and the longer-term importance of node risk capacity.
Construction supply chain resilience	Chen et al. (2024)	In construction supply chains, backup sourcing and backordering primarily address supply-side risks, while inventory holding mitigates financial uncertainties caused by fluctuating demand.
Main topic: Supply Chain Robustness		
Scope: The literature in this scope explores how supply chain robustness can be managed through the design of supply chain networks. Some studies have focused on specific supply chains, such as humanitarian relief supply chains or critical incident supply chains. Common approaches to investigate the robustness of supply chains include modelling and Bayesian Networks methods.		
Topic(s)	Reference (s)	Content(s)

Robust value-creating supply chain networks	Klibi et al. (2010)	Distinguishes between robustness and resilience in network design, arguing that robustness supports long-term stability.
Mechanism for structural robustness of supply chain	Han and Shin (2016)	The paper develops a mechanism to evaluate structural robustness under disruption propagation, linking topology to robustness performance.
Robust dynamic schedule coordination control	Ivanov et al. (2016a)	Examines coordination robustness under capacity and supply disruptions using attainable sets analysis.
Improve robustness of a dairy supply chain	Liu et al. (2019)	Demonstrates that mitigating external institutional risks, such as corruption, can enhance overall supply chain robustness.
Robust dynamic Bayesian network optimisation	Liu et al. (2021)	Introduces a robust dynamic Bayesian Network (DBN) for disruption risk assessment, comparing algorithmic and solver-based solutions.
The interrelationships of supply chains robustness, complexity and efficiency	Monostori (2021)	Proposes an integrated framework linking robustness, complexity, and efficiency, enabling holistic evaluation of supply chain performance.
literature review on robustness	Durach et al. (2015); Monostori (2018); Saisridhar et al. (2024)	Provides a comprehensive review of robustness capabilities and propagation characteristics across diverse disruption types.

Source: The author

2.2.2.1 Supply chain resilience

Following the COVID-19 pandemic, resilience has become a striking theme in supply chain research, as evidenced by a 62.04% increase in academic publications on the topic (Castillo 2023). From a supply chain management perspective, multiple enablers for building supply chain resilience include flexibility, redundancy, visibility, and agility (Hohenstein et al. 2015; Kamalahmadi and Parast 2016; Ali et al. 2017b). Current scholarly studies on supply chain resilience concentred on several key areas. Firstly, scholars are exploring strategies to improve supply chain resilience in the period following the COVID-19 pandemic (Banerjee et al. 2022; Munir et al. 2022; Gupta and Kumar Singh 2023). Secondly, researchers have employed empirical studies to examine the obstacles faced by companies in enhancing their resilience (Pal et al. 2014; Ali et al. 2017b; Ashiru et al. 2022; Banerjee et al. 2022; Gupta and Kumar Singh 2023). Thirdly, the academic community is conducting extensive literature reviews on supply chain resilience, aiming to explore whether resilience is just another supply chain concept or if it constitutes its own theory (Castillo 2023). Table 2.3 presents the supply chain resilience dimensions base on the literature.

In terms of methodological approaches to supply chain resilience, scholars have explored supply chain resilience through empirical research and the application of emerging technologies. Ashiru et al. (2022) explored how emerging digital communication technologies (EDCT) impacted the resilience of SMEs during the COVID-19 pandemic. Their study found that the adaptation of EDCT to SMEs' resilience originated from four resilience drivers: facilitating connections and linkages with employees, customers, and suppliers. On the other hand, Banerjee et al. (2022) explored the barriers to building supply chain resilience in Indian Micro, Small, and Medium Enterprises (MSMEs) after COVID-19 and assessed these barriers. Furthermore, Gupta and Kumar Singh (2023) extracted significant barriers affecting the resilience issues of MSMEs from a literature review and subsequently determined the

importance ratings of these barriers to developing resilience in MSMEs using the Best-Worst Method (BWM).

Table 2.3: Supply chain resilience dimensions

Factors	Explanation
Supplier proximity	The proximity of firms to suppliers has traditionally been regarded as a crucial factor in supply chain design, offering advantages such as faster transaction turnaround and cost savings associated with location-based efficiencies (Reichhart and Holweg 2008).
Supplier relationships	Strong linkages between supply chain partners foster long-term relationships, trust, and collaboration, which in turn enhance supply chain resilience (Dyer et al. 2018).
Previous experiences in disruptions	Firms that effectively leverage knowledge and lessons learned from past supply chain disruptions are better positioned to strengthen their resilience and mitigate future risks (Riley et al. 2020).
Digital capability	Digital technologies play a critical role in enabling agile and timely decision-making, as well as facilitating interventions to manage disruptions (Faruquee et al. 2021).
Redundancy and Flexibility	Enterprises must maintain redundancy, such as high safety stocks and additional production capacity, alongside flexibility, including alternative supplier sourcing and diverse transport terminals and delivery modes, to enhance their resilience against disruptions. (Ali et al. 2017a; Dolgui et al. 2018b)
Financial Strength	Enterprises should ensure cash flow stability and financial resilience to absorb supply chain shocks (Katsaliaki et al. 2022).
Associate with robustness	Relationships between supplier proximity and supply chain robustness with supply chain resilience (Nakandala et al. 2025)
Resilience through digitalisation and visibility	Highlights digital supply chain twins, data sharing, and network visibility as enablers of real-time resilience (Sunmola et al. 2023).

Source: The author

The current literature on supply chain resilience in the construction industry focuses on modelling the impact of supply chain vulnerability (SCV) and exploring the factors that contribute to vulnerability in the construction supply chain. For instance, Ekanayake et al. (2021b) simulated the dynamic impact of SCV on construction supply chains through social network analysis (SNA) and system dynamics modelling (SDM). The study demonstrated that limited visibility amplifies disruption propagation across the network, whereas higher transparency enables faster detection and coordination. These findings directly relate to the ripple effect, as they highlight how information flow and network connectivity determine the extent to which disruptions escalate or are contained within construction supply chains. In exploring vulnerability factors in construction supply chains, Zainal Abidin and Ingirige (2018) explores the level of resilience needed to handle disruptions in construction projects by assessing the critical vulnerabilities and capabilities of the supply chain. To summarise, research related to supply chain resilience for the construction industry is currently increasing (Ekanayake et al. 2021a; Tennakoon et al. 2023; Tennakoon et al. 2024). Due to the complexity of process and stakeholders in the construction industry, which corresponds to the complexity of the supply chain, scholars need to optimise existing simulation research methods to apply to the construction supply chain.

2.2.2.2 Supply chain robustness

Robustness focuses on maintaining operational stability during disruptions and can be achieved in practice through several mechanisms such as structural diversity, flexible response, and maintaining active redundancy (Azadegan et al. 2013). Structurally, robustness needs to be achieved at both inter-organizational and intra-organizational levels (Durach et al. 2015). Each level is interdependent, and the level of robustness achieved by an individual node usually affects the robustness of the network. An increase in flexible response can be achieved by increasing inventory, capacity, or implementing alternative transport methods and standby facilities (Mishra et al. 2021).

Maintaining active redundancy may involve material inventories or capacity buffers (Dolgui et al. 2018b). However, this approach may clash with the lean principles of the organisation, so the dynamic balance between achieving robustness and leanness in the management of the organisation is a topic that scholars have been investigating (Carvalho et al. 2011; Martínez-Jurado and Moyano-Fuentes 2014; Ahmed and Huma 2018). Table 2.4 summarises the supply chain dimensions draw on the literature.

In the methodological discussion of supply chain robustness, scholars often combine the study of supply chain resilience to jointly examine their similarities and differences (Mackay et al. 2020; Negri et al. 2021). The specific approach is to explore their antecedents through Robust-Optimization (RO) models and empirical studies (Brandon-Jones et al. 2014). Simchi-Levi et al. (2018) examines a RO model that provides parsimonious expressions for the optimal inventory solution and investigates the effectiveness of varying degrees of flexibility. Perera et al. (2017) suggest that supply chain visibility enhances both resilience and robustness, while four dimensions of complexity: scale, geographic distribution, delivery, and differentiation, exert distinct conditional effects on the relationship between supply chain visibility and these two capabilities. Empirical research from literature on supply chain robustness is developed (PN 2021; Ruel and El Baz 2023). For instance, Lin and Zhang (2020) considers the incentives of a construction supply chain containing a contractor and multiple subcontractors from both economic and environmental perspectives.

Table 2.4: Supply chain robustness dimensions

Factors	Explain
Supply chain visibility	Efforts to improve supply chain visibility through the sharing of risk-related information can enhance the ability to anticipate, identify, and respond to disruptions, thereby increasing overall SCR aversion (Lavastre et al. 2012).
Network complexity	Network complexity refers to the degree of connectivity and interdependence among entities within a supply chain network (Blackhurst et al. 2011). A highly complex supply chain often involves numerous suppliers, partners, and

	logistics channels, which can increase the difficulty of synchronising operations and coordinating activities (Meepetchdee and Shah 2007).
Uncertainty	Uncertainty typically emerges when relevant environmental information is incomplete, ambiguous, or entirely absent (Klibi and Martel 2012).
Risk management orientation	Risk management at each node of the supply chain is essential for preventing chain failures (Wieland and Wallenburg 2012).
Node criticality	While every node in the network contributes to value creation, some nodes are more critical than others due to their influence on the overall functioning of the supply chain.
Intra-organizational relationship magnitude	The level of interaction and information exchange between different entities within an organisation is central to achieving internal robustness (Durach et al. 2015).
Measurement Perspective	Performance variance minimisation during disruptions (Saisridhar et al. 2024).

Source: The author

Current research on supply chain robustness in the construction sector primarily examines how network design and optimisation among project stakeholders influence disruption (Malik et al. 2022). For example, Lin et al. (2020) investigated the incentives and coordination of a construction supply chain consisting of owners, general contractors, subcontractors, and suppliers based on sustainability goals in an uncertain environment. Hsu et al. (2019) conceived a mathematical model for designing and optimizing the risk-averse logistic configurations of a modular construction project under operational uncertainty. However, these studies often overlook the distinctive challenges faced by construction SMEs, whose limited resources and informal coordination mechanisms constrain their ability to embed robustness into supply chain design. This thesis provides a methodology for analysing construction projects from a supply chain perspective, considering both economic and environmental performance and uncertainty. Methodologically, research on supply chain robustness in the construction industry has predominantly relied on simulation-based modelling to analyse how network structures and stakeholder interactions respond to disruption

scenarios (Zhong et al. 2016; Ekanayake et al. 2021b; Zhang et al. 2023). This is due to the difficulty in obtaining real data, which is often considered confidential by companies. This limitation is significant because simulation models, while valuable for theoretical exploration, rarely capture the behavioural and organisational dimensions of robustness that influence ripple effect in practice (Ivanov et al. 2025). Accordingly, this thesis aims to provide a more detailed understanding of how robustness manifests within the supply chains of construction SMEs, where structural diversity, flexibility, and redundancy are inherently constrained by financial and resource limitations.

2.3 Supply chain risk

While the ripple effect provides a valuable lens for understanding how disruptions propagate across multiple tiers of a supply chain, it is fundamentally rooted in the broader landscape of supply chain risks (SCRs) (Scheibe and Blackhurst 2018). In this thesis, the ripple effect is conceptualised as the progressive amplification of risks within the interconnected networks of construction SMEs, whereby a disruption in one actor or phase can trigger cascading consequences across subsequent project stages and stakeholders (Llaguno et al. 2022; Ivanov et al. 2025). To fully understand how ripple effects emerge and escalate, it is essential to first explore the underlying sources of SCRs, their diverse categories, and the strategies employed to mitigate them. Therefore, this section broadens the scope from the specific phenomenon of ripple effects to the foundational concepts of SCR, offering an overview of risk types and mitigation approaches that form the basis for effective supply chain ripple effect management.

2.3.1 Definitions of SCR

Many researchers are currently working on developing a definition of SCR across various domains (Heckmann et al. 2015). However, due to the diverse backgrounds and interests of these researchers, an integrated definition has not been established. A common understanding of risk in this context is centre on probability and impact (March and Shapira 1987; Zsidisin 2003a; Wagner and Bode 2006). One limitation of

this perspective is the exclusion of unknown risks, which stem from uncertainties that cannot be analysed or comprehended (Klibi et al. 2010). A prime example of such a risk is the COVID-19 pandemic, before its emergence, researchers lacked the ability to assess the likelihood of an outbreak or estimate its potential impact. To address this gap, Table 2.5 summarises the main definitions of SCR found in the literature, highlighting how scholars have progressively broadened the concept. By mapping this definitional evolution, the table situates the present study within a more inclusive understanding of risk and their potential to trigger ripple effects within construction supply chains.

Based on the definitions provided, common features of SCRs include their association with uncertainty and adverse impacts on supply chain objectives such as cost, time, quality, and performance (Tang 2006; Klibi et al. 2010). However, distinctions arise in the scope and focus of these definitions. Some emphasize probability and consequences, framing risk as a measurable likelihood of disruptive events, while others focus on vulnerability and exposure, considering the structural weaknesses within the supply chain network that amplify risk effects (Zsidisin 2003b; Ho et al. 2015). Additionally, certain definitions explicitly reference stakeholder-specific impacts, such as financial losses or reputational damage, while others adopt a system-level perspective, addressing the broader interdependencies and ripple effects across the supply chain (Ivanov 2018). Collectively, these definitions converge on the idea that SCRs are multifaceted and dynamic but differ in their emphasis on quantitative versus qualitative dimensions, as well as the domain of their focus: individual company compare entire supply network.

Table 2.5: Definitions of SCR

Authors	Research Methodology	Definitions of SCR
Jüttner et al (2003)	Literature review	Any risks for the information, material, and product flows from original supplier to the delivery of the final product for the end user. (p. 200)
Zsidisin (2003b)	Case study	The probability of an incident associated with inbound supply from individual supplier failures or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety. (p. 222)
Wagner and Bode (2006)	Survey	Consider risk as the negative deviation from the expected value of a certain performance measure, resulting in negative consequences for the focal firm. (p. 303)
Rao and Goldsby (2009)	Literature review	Risk is defined using the relationship between the range of possible negative outcomes (severity or impact) and the distribution of the corresponding probabilities for each outcome. (p. 100)
Ellis et al. (2010)	Literature review; interview	Unforeseen events that interfere with ‘‘the normal flow of goods and[/or] materials within a supply chain. (p. 35)
Klibi et al. (2010)	Modelling	Distinction between uncertainty and risk. suggest characterizing decision-making situations based on the quality of the information available: decisions are made under certainty when perfect information is available and under uncertainty when one has only partial (or imperfect) information. (p. 289)
Heckmann et al. (2015)	Literature review	SCR is the potential loss for a supply chain in terms of its target values of efficiency and effectiveness evoked by uncertain developments of supply chain characteristics whose changes were caused by the occurrence of triggering-events. (p. 130)

Ho et al. (2015)	Literature review	The likelihood and impact of unexpected macro and/or micro level events or conditions that adversely influence any part of a supply chain leading to operational, tactical, or strategic level failures or irregularities. (p. 5035)
Ivanov (2018)	Literature review	Uncertainty is the general property of a system environment that exists independent of us for any system of a sensible complexity degree. Risk arises from uncertainty. Risks can be identified, analysed, controlled, and regulated. (p. 294)

Source: The author

By defining SCR, this thesis further explores its application within the construction sector. While construction shares common characteristics with general SCR, such as uncertainty, disruption, and vulnerability to external shocks, it also reflects the unique conditions of the construction environment (Shojaei and Haeri 2019). In principle, risk can encompass both negative (threat) and positive (opportunity) outcomes across all project-based contexts (Rose 2013; Xia et al. 2018). However, in construction supply chains, these outcomes are amplified by the project-specific nature of activities, temporary organisational structures, and inter-firm dependencies (Chen et al. 2021). Consequently, opportunities (e.g., design optimisation, process innovation) and threats (e.g., delays, cost overruns) are closely interacted, often result disruptions propagation (Gurgun et al. 2024). The construction supply chain typically includes multiple temporary stakeholders, such as contractors, subcontractors, and suppliers, all operating under tight project schedules and budgets (Benton and McHenry 2010). This increases the likelihood of schedule delays, cost overruns, labour shortages, and quality issues (Larsen et al. 2016). Additionally, specific risks such as design errors and contractual issues, further add to the complexity, distinguishing construction from other industries. Therefore, managing risk in the construction supply chain requires tailored approaches that synthesise definitions from various scholars, focusing on different areas of construction SCR, such as supplier segmentation or differentiating between internal and external risks within the supply chain (Gosling et al. 2013). The definition of construction SCR provided in this thesis is as follows:

> *Construction SCR is defined as the potential loss/opportunities to the efficiency of the supply chain or the project itself, arising from inherent properties present in the project and events occurring during production activities.*

The definition of construction SCR in this study is shaped by two key considerations. First, given the recognised complexity and diversity of construction supply chains, the definition aims to capture a broad range of risk factors, including those inherent in both project-specific conditions and production activities. Second, this definition explicitly

positions construction projects as integral components of a wider supply chain network, thereby shifting the analytical focus from isolated project operations to the interconnected flows of materials, information, and responsibilities among stakeholders. This perspective enables a more comprehensive examination of risk sources and transmission pathways across organisational boundaries rather than within individual firms or work packages. By integrating these two aspects, the study provides a solid foundation for the analysis of ripple effects specific to the construction supply chain context.

2.3.2 Categories of SCR

Building on the above definition of construction SCR from the perspective of supply chain efficiency and performance, scholars have categorised SCR in various ways depending on the focus and purpose of their research (Kilubi 2016). Scholars have identified various types of SCRs through their definitions of SCR (Tang 2006; Rangel et al. 2015; Ganesh and Kalpana 2022), and this research summarizes these classifications based on the existing literature, as presented in Table 2.6. The studies included in this table were selected through a focused review of influential and frequently cited works on. The Table 2.6 also considered research that bridges general SCR theory with construction-oriented contexts, ensuring relevance to the unique characteristics of the construction supply chain. The current trend of risk differentiation is oriented towards specific research directions. For example, when exploring the relationship between overall SCR and individual SCR, supply chains are categorized into two types based on the source of risk: Endogenous and exogenous risks. Endogenous risks arise from interactions between member firms within the supply chain, while exogenous risks arise from interactions between the supply chain and its external environment (Chapman et al. 2002).

Table 2.6: Types of SCR

Identified SCR	Chapman et al. (2002)	Sodhi and Chopra (2004)	Kleindorfer and Saad (2005)	Tang (2006)	Manuj and Mentzer (2008)	Rao and Goldsby	Hiles (2010)	Clemons and Slotnick (2016)	MacKenzie and Apte (2017)	Quang and Hara (2018)	Hosseini et al. (2019)	Linkov and Kott (2019)	Ivanov and Dolgui (2019)	Birkie and Trucco (2020)	Li et al. (2021)	Agrawal and Jain (2022)	Ghadge et al. (2022)	Duong et al. (2023)
Demand risks					√					√								√
Disruptions risks				√				√	√		√		√	√	√	√		
Environmental risks						√												
Financial risks							√			√								
Industry risks						√												
Information risks										√		√					√	
Contactual risks		√			√													
Material flow-related risks												√					√	
Natural risks			√															√
Operational risks			√	√	√		√			√					√			√
Design risks						√												
Safety risks					√										√			√
Supply risks					√					√								√

Source: The author

Tang (2006) categorizes SCR according to severity, distinguishing between operational risks, such as fluctuating demand and extended supply lead times, and disruption risks, including natural disasters, pandemics, and human-induced events. Supply chain disruption risk is the risk of unforeseen man-made events or natural disasters interrupting the supply chain, causing it to deviate from normal operations for a period and fail to meet the minimum requirements for business activities (Ivanov 2021a). Operational risks are usually considered high-frequency, low-impact events, whereas disruption risks have a high impact despite a low probability of occurrence (Dolgui and Ivanov 2020). Owing to inherent uncertainty, disruption risk is partly unpredictable and difficult to analyse, thereby placing substantial demands on firms' robustness and resilience (Ho et al. 2015; Ivanov et al. 2017; Dolgui et al. 2018b).

With the advancement of science and technology, the categorization of SCR has become more complex, incorporating new risk factors such as cyber-attacks and financial crises (Ghadge et al. 2019; Linkov and Kott 2019; Sawik 2022). One of the objectives of categorizing SCR is to rank them to determine the order in which they should be mitigated. Given that risks arise from uncertainty and their probability of occurrence is uncertain, companies need to prioritize the impact of SCR to address the most critical ones within their management capabilities (Abdel-Basset et al. 2019).

Risk categorization within the supply chain is particularly important for SMEs, which often operate with a single source of income and a simple management structure (Al Mawli et al. 2021). Many construction SMEs rely heavily on outsourcing, increasing the complexity of their supply chains while reducing their visibility and traceability (Björnfot and Torjussen 2012). By categorizing risks, construction SMEs can more clearly identify the specific risks associated with each outsourced process and better understand how these risks propagate through the supply chain. This enables companies to quickly pinpoint which segments pose the most impact risks and implement targeted mitigation measures (Karmaker et al. 2023). Without such categorization, the

associated increases in costs and labour requirements can exacerbate risks, further impacting construction SMEs. Therefore, effective risk categorization allows SMEs to assess potential impacts in advance and develop preventive strategies, reducing the likelihood and severity of unexpected events disrupting their operations (Erdiaw-Kwasie et al. 2023).

2.3.3 SCR management strategies

SCR management strategies refer to the systematic actions and processes undertaken by companies to identify, assess, and respond to risks in order to reduce their likelihood and potential adverse impact (Jüttner et al. 2003; Hallikas et al. 2004; Wagner and Bode 2006). Within this broader framework, risk mitigation constitutes one component of risk management, it focuses specifically on reducing the probability or severity of adverse events once risks have been identified (Sreedevi and Saranga 2017). In contrast, risk management encompasses the entire lifecycle of dealing with risks, including identification, assessment, mitigation, monitoring, and continuous learning (Shishehgarkhaneh et al. 2024). To date, scholars have proposed a wide range of SCR management strategies. For instance, Norrman and Jansson (2004) argue that mitigation strategies should differentiate between routine operational accidents and catastrophic uncertainties, based on the probability and severity of the risk outcomes. Mullai et al. (2009) categorize risk mitigation into four types: avoidance, reduction, transfer, and acceptance.

Table 2.7 summarises the literature on supply, demand, operational, and macro risk mitigation strategies, demonstrating the breadth of scholarly approaches to mitigating disruptions. The classification reveals several key themes and patterns that inform the theoretical and practical understanding of SCRM. These papers were essential for this thesis because they collectively offer several relevant insights. First, they establish a foundational understanding of risk management practices across supply, demand, operational, and macro-level disruptions, highlighting the diverse mechanisms, such as

collaboration, risk-sharing contracts, optimisation, and information integration used to prevent or mitigate supply chain risks. Second, they reveal recurring themes that are transferable to the construction context, such as the importance of proactive risk identification, supplier relationship management, information sharing, and resilience-building.

There are also significant differences in mitigating SCRs depending on the type of risk. For example, reducing supply risks often relies on optimisation models that balance cost and reliability in sourcing decisions (Kim et al. 2012; Fang et al. 2013). In contrast, operational risk mitigation typically emphasises collaborative strategies, integrating suppliers, customers, and internal teams to manage process variations and disruptions (Chen et al. 2013). Demand risk mitigation approaches include robust optimisation techniques and contractual mechanisms to manage uncertainty in customer requirements (Prakash et al. 2020). For geopolitical risks or labour disputes, mitigation strategies focus on information sharing, network analysis, and risk-sharing contracts (Daghar et al. 2021). These varying approaches highlight the need for tailored risk mitigation strategies that align with the specific characteristics of different risk types.

Another effective way to differentiate SCRM strategies (Wakolbinger and Cruz 2011; Kilubi 2016), is by distinguishing between proactive and reactive measures. Proactive measures are implemented before a disruption occurs, whereas reactive measures are applied after the disturbance has materialised (Ivanov et al. 2016b). However, as Knemeyer et al. (2009) suggest, having pre-arranged plans and actions significantly improves the speed and effectiveness of post-disruption responses. In the context of ripple effect mitigation, proactive SCRM becomes particularly critical, as it involves pre-actions designed to limit the propagation and amplification of disruptions throughout the supply chain (Shahsavari et al. 2025). Therefore, while reactive strategies help contain damage after disruptions occur, proactive approaches are

essential for mitigating ripple effects and ensuring that risks are addressed before they cascade through the network.

In the construction industry, supply chain mitigation research at the application stage, with a focus on real-world experiences. For example, Sodhi and Chopra (2004) suggest that the key to effective risk mitigation strategies lies in balancing costs and benefits. Other researchers emphasize substantive actions such as information sharing (Lee and Wolfe 2003; Tang 2006) and collaborative partner approaches (Harland et al. 2003). Pham et al. (2022a) further argues that since risks are often interrelated, mitigating one risk can either reduce or exacerbate the impact of other risks. In practice, many managers rely heavily on personal experience rather than leveraging available analytical tools, and the adaptation of manufacturing best practices to the construction and service sectors remains underutilised (Shojaei and Haeri 2019).

Table 2.7: Literature related to the risk management

Authors	Theme	Contents
Chen et al. (2016)	Supply risk mitigation	The article examines how to mitigate supply risk enlightened by discussing the concept of risk in association of three closely related concepts which are uncertainty, variability and trust.
Grötsch et al. (2013)		This paper examines the prerequisites for facilitating the proactive implementation of SCRM from the perspective of Contingency Theory. It finds that past experiences of supplier bankruptcy have a moderating effect on proactivity but not a direct effect.
Ruiz-Torres and Mahmoodi (2007)		This paper employs a decision tree approach to determine the optimal number of suppliers in the presence of supplier failure risk. The results indicate that when suppliers are highly reliable, single sourcing is the least-cost approach under all experimental conditions. However, as supplier reliability decreases, additional suppliers may be necessary to achieve the lowest cost.
Tapiero (2007)		This paper aims to provide a strategic collaborative approach to risk and quality control in a cooperative supply chain by employing a Neyman–Pearson quantile risk framework for statistical risk control.
Chen et al. (2013)	Operational risk mitigation	This study employs supply chain collaboration as a risk mitigation strategy. The study links three types of risks: supply risk, demand risk, and process risk with three types of collaboration, supplier collaboration, customer collaboration, and internal collaboration—as mechanisms to mitigate these risks.
Shojaei and Haeri (2019)		This study demonstrates the applicability and effectiveness of the proposed methodology through a real case study, proposing an integrated construction project SCRM approach

		using rootedness theory, fuzzy cognitive mapping, and grey relational analysis. The proposed methodology develops and evaluates various risk mitigation strategies.
Aqlan and Lam (2015)		This study proposes an approach based on Bow-Tie analysis and optimization techniques to quantify and mitigate SCR. The proposed approach considers risk interconnections and identifies the optimal combination of mitigation strategies within budget constraints.
Prakash et al. (2020)	Demand risk mitigation	A generic closed-loop supply chain network based on mixed integer programming formulation is proposed with direct shipping to the customer from manufacturing plants as well as shipping through distribution centres under supply risks, transportation risk and uncertain demand using a RO approach.
Ben-Tal et al. (2011)		This paper presents a methodology for generating robust logistics plans to mitigate demand uncertainty in humanitarian relief supply chains. Simulation experiments demonstrate that the affinely adjustable robust counterpart (AARC) solution provides superior results compared to deterministic and sampling-based stochastic planning solutions. The paper also provides general insights into RO and transport that may have broader applicability in humanitarian relief supply chains.
Chen and Yano (2010)		This study examines how structure of manufacturers weather-related discounts to enhance their expected profits. The results indicate that weather-related discounts can take various forms. This flexibility allows suppliers to design Pareto-improving contracts and limit both their risk of offering the contract and the retailer's risk of accepting it.
Chen et al. (2006)		The article proposes a risk-sharing contract wherein the retailer partially compensates the manufacturer for losses due to overproduction in the first stage, and the manufacturer partially compensates the retailer for losses due to excess inventory in the second stage. Such a contract not only maximizes supply chain profit but also improves the profit of each supply chain member by adjusting the contract parameters.

Guo et al. (2006)		This paper aims to address the issue of motivating supply chain partners to share information from an information system design perspective. The results indicate that such information can be used to enable accurate demand forecast sharing and improve channel coordination in supply chain systems.
Thomas and Helgeson (2021)	Macro risk mitigation	This paper examines how manufacturers and other firms are affected by disruptions in the supply of low-substitutable goods at both the industry and economy-wide levels. The results suggest that the compounding effects of hazards in the supply chain may outweigh local hazards. This misalignment can lead to misaligned incentives.
Mithun Ali et al. (2021)		This study examines the factors and drivers of disruptions in the ready-made garments industry in Bangladesh. This study not only expands the scope of literature on supply chain disruption risk assessment but also offers insights that can be applied in any environment or industry to reduce the impact of disruptions and enhance the resilience of the entire supply chain. As such, these enhancements enable managers to develop robust and computationally efficient mitigation strategies.
Wakolbinger and Cruz (2011)		This paper develops a framework to capture the impact of information management and risk-sharing contracts in supply chain networks. In particular, the paper analyses the impact of strategic information acquisition and sharing on the risk and cost of supply chain disruptions and assesses the performance of risk-sharing contracts in supply chains.
Gopalakrishna-Remani et al. (2018)		The purpose of this study was to assess the timeliness of data reporting to the Ohio Disease Reporting System (ODRS). Results indicate that a centralized approach using an electronic disease reporting system transmits information faster than traditional reporting channels (decentralized approach). To better understand the information supply chain system for managing rare infectious diseases, delays in the decentralized approach were isolated across stakeholder levels and different types of rare infectious diseases.

Todo et al. (2015)	This paper uses firm-level data to examine how supply chain networks influenced firms' recovery after the Great East Japan Earthquake. The results indicate that networks with firms outside the affected region facilitated an earlier resumption of production, while networks within the region supported medium-term sales recovery. Positive impacts of supply chain networks typically outweigh negative impacts.

Source: The author

2.4 Construction and construction SMEs

As a key enabler of infrastructure and industrial development, the construction industry underpins economic activity and employment generation at both national and global scales (Oti-Sarpong et al. 2022). It is characterized by its significant environmental and resource impact, while also contributing to economic development and fulfilling essential human needs (Bao et al. 2020; Baghalzadeh Shishehgarkhaneh et al. 2024). Despite its central role, the industry remains highly fragmented and project-based, involving numerous SMEs that operate under tight financial, temporal, and contractual constraints (Dauda et al. 2024). These conditions make construction supply chains particularly susceptible to disruption propagation and performance variability (Duong et al. 2025). Accordingly, this thesis argues that understanding specific concepts and data is necessary to identify the ripple effects faced by construction SMEs. In this section, the author first introduces the characteristics of the construction industry and its current risks from a SCRM perspective, followed by a discussion of the definition of construction SMEs, emphasizing their key role in the industry. By exploring these aspects, this section aims to provide the reader with a detailed understanding of SMEs in the construction industry, the risks they face, their roles in the supply chain, and the lack of academic exploration regarding the ripple effect on SMEs.

2.4.1 Introduce to construction industry

The construction industry represents a pivotal sector within global economies, serving as the backbone for infrastructure development and urbanisation (Moavenzadeh 2022). It encompasses a broad range of activities, including the planning, design, construction, maintenance, and eventual decommissioning of physical structures, ranging from residential and commercial buildings to industrial facilities (Iacovidou and Purnell 2016). In this study, based on the typical project process, the construction project is divided into four key stages: design, beginning, process, and closeout. These stages provide a lens for capturing how risks emerge, interact, and evolve throughout the project lifecycle.

The construction supply chain also involves a diverse array of stakeholders, such as clients, main contractors, suppliers, supervisors, and regulatory bodies, each playing distinct roles and holding different interests (Sacks et al. 2018; Kuitert et al. 2019). The construction industry integrates multi-disciplinary knowledge, drawing from civil engineering, architecture, environmental sciences, project management, and operates within a highly dynamic, project-based environment (Ikudayisi et al. 2023).

The construction industry is often regarded as a high-risk business (Mavroulidis et al. 2022). It involves numerous stakeholders, extended production times, open production systems, and requires significant interaction between internal and external environments (Taroun 2014). The construction industry makes a substantial contribution to both the global economy and society by generating employment, supporting infrastructure development, and stimulating growth across related sectors such as manufacturing and services (Durdyev et al. 2018; Hussain et al. 2021). Since the 1990s, the application of supply chain management in the construction sector has been extensively documented (Nguyen and Le 2022). Love et al.(2004) present a definition of supply chain management for projects in the construction industry as follows:

> *The network of facilities and activities that provide customer and economic value to the functions of design development, contract management, service and material procurement, materials manufacture and delivery, and facilities management (p.44).*

Implementing supply chain management in the construction industry can be a valuable tool for controlling business processes coherently and systematically (Kim and Nguyen 2022). By engaging stakeholders and facilitating better information and knowledge sharing, this system approach can lead to improved quality, time savings, and increased profitability (Bankvall et al. 2010). Table 2.8 illustrates the key participants, such as contractors, suppliers, and subcontractors, and their respective positions within the construction process.

Table 2.8: Construction supply chain stakeholders and their roles

Stakeholder	Role	Examples	Key Interests
Clients/Owners	Commission and finance construction projects.	Private developers, government agencies, individual homeowners	Cost, quality, timely delivery, functionality, regulatory compliance
Main Contractors	Manage overall project delivery and coordination of subcontractors.	General contractors, construction firms	Profitability, efficiency, reputation, risk minimization
Subcontractors	Perform specialized tasks within the construction process.	Electrical, plumbing, heating, ventilation, air conditioning, and roofing	Scope clarity, timely payment, safety, performance standards
Suppliers and Manufacturers	Provide materials, equipment, and prefabricated components.	Cement suppliers, steel manufacturers, equipment providers	Demand consistency, long-term partnerships, quality assurance
Designers (Architects and Engineers)	Develop project designs and technical specifications.	Architectural firms, structural engineers	Design integrity, compliance, innovation, client satisfaction
Consultants	Offer specialized services like project management, cost control, legal advisory.	Project Management Consultants, Quantity Surveyors	Accuracy, risk mitigation, ensuring project success
Regulatory Bodies	Enforce legal, environmental, and safety standards.	Building control authorities, environmental agencies	Compliance assurance, public safety, environmental protection
Financial Institutions	Provide funding and financial products for construction projects.	Banks, investment funds, insurance companies	Risk mitigation, return on investment, project viability
Industry Associations and Trade Unions	Represent industry participants and workers' interests.	Construction Industry Federation, labour unions	Policy influence, fair labour conditions, industry development

Source: The author, adapted from Xue et al. (2007); Balasubramanian (2020); Koc and Gurgun (2021)

In a rapidly evolving business landscape marked by significant uncertainty and complexity, it is crucial for companies to effectively integrate their supply chains to enhance responsiveness and efficiency (Jaboob et al. 2024). Specifically, the integration process involves devising strategies to tackle SCR to minimize adverse consequences from both internal and external disruptions (Nguyen and Le 2022). Consequently, a company's ability to identify, analyse, and manage risks plays a vital role in its overall risk management capabilities.

SCRM is a crucial aspect of a supply chain management system. As described by Kamalahmadi and Parast Kamalahmadi and Parast (2016), SCRM involves identifying potential risk sources and adopting suitable strategies to decrease SCV through a coordinated approach among supply chain members. The primary goal of SCRM is to protect organizations from adverse events and the consequent negative consequences (Fan and Stevenson 2018a). While SCRM has attracted attention in recent years, additional research is necessary to fully comprehend its influence on the supply chain (Zsidisin 2003b; Sodhi and Chopra 2004; Kleindorfer and Saad 2005; Rao and Goldsby 2009; Altay and Ramirez 2010; Ivanov et al. 2014c).

SCR in construction can manifest in various ways, such as supply delays, poor product quality, and reduced demand (Stecke and Kumar 2009). Supply delays are one of the most widespread forms of SCR in the construction sector, primarily due to poor communication, lack of coordination and conflict between stakeholders (Durdyev and Hosseini 2020). Poor product quality can arise from supplier non-compliance with specification or lack of standardized quality controls (Thunberg et al. 2017). Factors such as economic downturns, political instability, regulatory changes, or consumer preference shifts can reduce the demand for construction services, particularly impacting SMEs within the supply chain (Kaur et al. 2023). Scholars have conducted systematic research on construction SCR, primarily focusing on the identification and assessment phases within the four steps of supply chain management: identification,

assessment, mitigation, and monitoring (Aloini et al. 2012). Regarding research methodology, most studies examining supply chain risks and ripple effects within construction projects adopt mixed-method designs that combine qualitative and quantitative approaches, including semi-structured interviews, case studies, system simulations, and mathematical modelling (Pham et al. 2022b).

For construction SMEs, there are several barriers to implementing SCRM (Kim and Nguyen 2022). First, the recognition of risk transfer varies between SMEs and large enterprises (Falkner and Hiebl 2015; Rostami et al. 2015). For instance, in large construction enterprises, the risk associated with contract transfer is more frequently borne by downstream contractors. SMEs, whose main role is often as contractors, are more passive bearers of risk rather than active transferors (Kamal and Flanagan 2014b). Second, the assessment of risk relies more on the subjective judgment of the owner than on professional risk assessment tools (Adzivor et al. 2023). Third, due to financial and capacity constraints, SMEs concentrate their resources on the most impact risks rather than a comprehensive risks management system (Thun et al. 2011). Finally, in the risk monitoring stage, SMEs seldom employ risk register due to a lack of human resources, opting instead to respond to risks as they arise (Crovini et al. 2021).

2.4.2 SMEs in construction industry

Construction SMEs are vital to economic and social stability, and defining and assisting SMEs is a common goal in different countries (OECD 2023). The definitions of SMEs in the construction industry can vary significantly among the United States, United Kingdom, and China. This variation stems from the different policies and support measures implemented by each country. For instance, the US does not have specific regulations exclusively targeting SMEs. Instead, the US adopts the North American Industry Classification System (NAICS) to define and guide small businesses across various industries, enabling numerous small businesses to apply for government contracts and funding as long as they fulfil the necessary specifications (Bureau 2022).

As an illustration, Table 2.9 presents the definitions of construction SMEs across different countries.

Table 2.9: Comparison of SMEs in different countries

Country	Scale	Definition
USA	For construction small business, usually have less $45 million dollar earnings.	Defined by ownership structure, number of employees, earnings, and industry.
EU	Staff <250, and less than or equal to €50m in annual turnover or a balance sheet total of less than or equal to €43m.	Defined by Staff number, Turnover or Balance sheet total
UK	Staff <250, and less than or equal to £44m in annual turnover or a balance sheet total of less than or equal to £38m.	Defined by Staff number, Turnover or Balance sheet total
China	SMEs businesses: <300 employees or < £111 million revenue	Defined by revenue, number of employees, or total assets.

Source: (Muller et al. 2015; National Bureau of Statistics of China 2017; EuropeanCommission 2020; US Census Bureau 2022; Government Commercial Function 2024)

The definition of SME varies from country to country due to differences in policies and socioeconomic environments. However, there is a global consensus that SMEs tend to have less developed financial and technological capabilities compared to larger enterprises (Yang et al. 2020b; Caballero-Morales 2021). Although many SMEs attempt to offset falling revenues by incurring additional debt, construction SMEs, due to their limited capacity for executing projects, struggle to repay their debts within the stipulated deadlines (OECD 2023).

In term of the characteristics of SMEs, the sources of capital often coming from banks or private relatives are well recognized (Kamal and Flanagan 2014b). This tendency makes them focus more on getting money rather than investing in new technologies (Roba and Milos 2023). Additionally, having a single source of information access makes it more challenging for SMEs to access first-hand information, market trends,

and industry best practices (Varis and Littunen 2010). Indrawati (2020) argues that SMEs may lack the technical knowledge and expertise required to adopt new technologies and processes, which can limit their ability to innovate and compete in the marketplace. Another notable characteristic of SMEs is that they are often managed by a single owner or a small team (Roba and Milos 2023). This can lead to a lack of diverse perspectives and expertise in decision-making, resulting in less comprehensive management capabilities and strategies compared to larger organizations.

Despite these challenges, SMEs can leverage their adaptability and agility to remain competitive and capitalize on new opportunities. Comparing the characteristics of large enterprises and SMEs helps better understand the challenges that SMEs face. SMEs have been acknowledged in the literature as the drivers of the economy, possessing a unique role in innovation (Kamal and Flanagan 2014b). This is partly attributed to their ability to rapidly adapt to change and their receptiveness to emerging technologies. Main characteristics of construction SMEs compared to large construction enterprises are shown in the Table 2.10.

SMEs typically have flat, flexible organizational structures that enable quick decision-making, while large companies operate with hierarchical systems that ensure standardization but slower responses (Stoica et al. 2004). SMEs often focus on local markets with limited product lines, whereas large firms maintain diversified portfolios and broader geographical reach, including national or international markets (Cieślik et al. 2012). Ownership structures also vary, with SMEs being privately or family-owned, offering agility but limited financial resources, while large companies are usually publicly listed, benefiting from greater capital strength (Chu 2009). Within the supply chain, SMEs occupy downstream positions as subcontractors with weaker bargaining power, while large companies dominate upstream roles, controlling project bidding and supply coordination (Wattanapruttipaisan 2002).

Table 2.10: Characteristics of construction SMEs compared to large construction enterprises

	Construction SMEs	Large Construction Enterprises
Organizational Structure	Generally simpler, fewer hierarchies	Typically, more complex, with clear hierarchies
Product Line	May be limited, focusing on certain types of projects	Diversified, covering a variety of projects
Geographical Presence	Typically operate within a local or regional scope	Operate across multiple regions, nationwide or even globally
Ownership	Likely to be private, family-owned, or partnership-based	Possibly publicly listed, with diversified equity structures
Position in the Supply Chain	Likely to be a smaller link in the supply chain	Likely to be a major or key link in the supply chain
Operational Flexibility	High, due to smaller size and less bureaucracy.	Lower, due to larger size and more complex decision-making processes.
Risk Management	May have less formal risk management strategies.	Likely to have formalized risk management strategies in place.
Information resources	Single, often from other company	Multiple, from government or their own sources

Source: adapted from (Kheni et al. 2008; Bak et al. 2023)

Operationally, SMEs are more adaptable due to their scale but lack the systematic efficiencies of large enterprises (Sullivan-Taylor and Branicki 2011). In risk management, SMEs rely on reactive, experience-based approaches, whereas large firms implement comprehensive, proactive frameworks supported by dedicated teams (Henschel 2008). Additionally, SMEs have limited access to information technologies and data management systems, depending more on personal networks, while large companies leverage advanced IT infrastructure for data-driven decision-making and efficient information flow (Brandy 2023).

In addition to the classification of characteristics of the construction SMEs, this thesis categorises them based on the specific types of construction SMEs are presents in the Table 2.11. This approach helps scholars understand the corresponding ripple effects associated with different construction SMEs based on their respective responsibilities.

Table 2.11: Construction SME types

Type of Company	Description
Design company	Provides building design solutions, including architectural, interior, and landscape design, focusing on combining aesthetics with functionality (Bo and Chan 2008).
Engineering company	Specializes in engineering design, construction, and technical support for projects, covering structural and civil engineering.
Construction management company	Offers project management services, including planning, budget control, supervision, and scheduling to ensure timely and on-budget completion.
General contractor	Manages and coordinates the entire construction project, hiring specialized subcontractors to execute specific tasks (Yang et al. 2020a).
Material supplier	Supplies various materials needed for construction and renovation, including basic construction materials (e.g., steel, cement) and finishing materials (e.g., flooring, tiles).
Equipment lessor	Provides rental services for various construction equipment needed for projects, such as excavators, cranes, and scaffolding, helping companies reduce equipment procurement costs (Lopes et al. 2015).
Renovation company	Responsible for interior or exterior renovation projects, such as residential or commercial space interior design and renovation, including wall treatments, flooring installation, etc (Rajala et al. 2022).

Source: The author adapted from Kamal and Flanagan (2014a); Liu et al. (2022)

Part one establishes the conceptual foundation of this thesis by integrating three interrelated themes: the ripple effect, SCR, and the construction SME context. It begins by defining the ripple effect as the dynamic propagation of disruptions through interconnected supply chain nodes, highlighting its multi-dimensional attributes and triggers. The discussion then situates the ripple effect within broader SCR theory, reviewing how risks are categorised, managed, and mitigated through robustness and resilience strategies. Finally, the part one contextualises these concepts within the construction industry, characterised by its fragmented structure and heavy reliance on

SMEs. It argues that such structural features heighten vulnerability to disruption propagation while constraining the resources available for mitigation. Accordingly, understanding the ripple effect in construction SMEs requires linking theoretical models of SCR with empirical realities of project interdependence, stakeholder coordination, and resource availability, laying the groundwork for the empirical investigations in subsequent chapters.

Part two: A structured review of literature in the context of supply chain ripple effect

The main objective of this section is to provide a structured literature review on supply chain disruptions and ripple effects in the context of SMEs within the construction industry. Specifically, it seeks to answer the question: How have scholars conceptualised, analysed, and addressed supply chain disruptions and ripple effects in construction SMEs, and what gaps remain in current understanding? By systematically reviewing recent studies, this section aims to identify the key research trends, methodological approaches, and unresolved challenges that inform the empirical direction of this thesis. Importantly, this section provides the necessary literature base to address the RQ1. This section is structured as follows: Section 2.5 outlines the structured literature review process and defines the selected keywords. Section 2.6 presents the descriptive analysis gained from the review. Section 2.7 demonstrates the current research tools in the literature addressing ripple related risk, including mathematical modelling, simulation, and empirical studies. Section 2.8 demonstrates the sources of risk for supply chain disruptions and the ripple effect. Finally, Section 2.9 summarizes Chapter 2.

2.5 Structured literature review

Given the complicated diversity of concepts and the manifold nature of ripple effect inherent in the research objectives, the structured literature review has been proposed

as an effective way to cohesively integrate and summarise disparate sources of information. Structured literature reviews synthesise research findings from multiple databases and adopt a systematic and transparent approach to keyword selection and review procedures, in contrast to conventional narrative literature reviews (Touboulic and Walker 2015). This method assists researchers in achieving a higher degree of reproducibility and transparency in their literature reviews, and effectively reduces the scope for author bias (Tranfield et al. 2003). It is worth noting that this structured literature review has been widely adopted in supply chain studies (Touboulic and Walker 2015). The ensuing subsections elaborate on the processes involved in identifying relevant articles and selecting articles as shown in Figure 2.1.

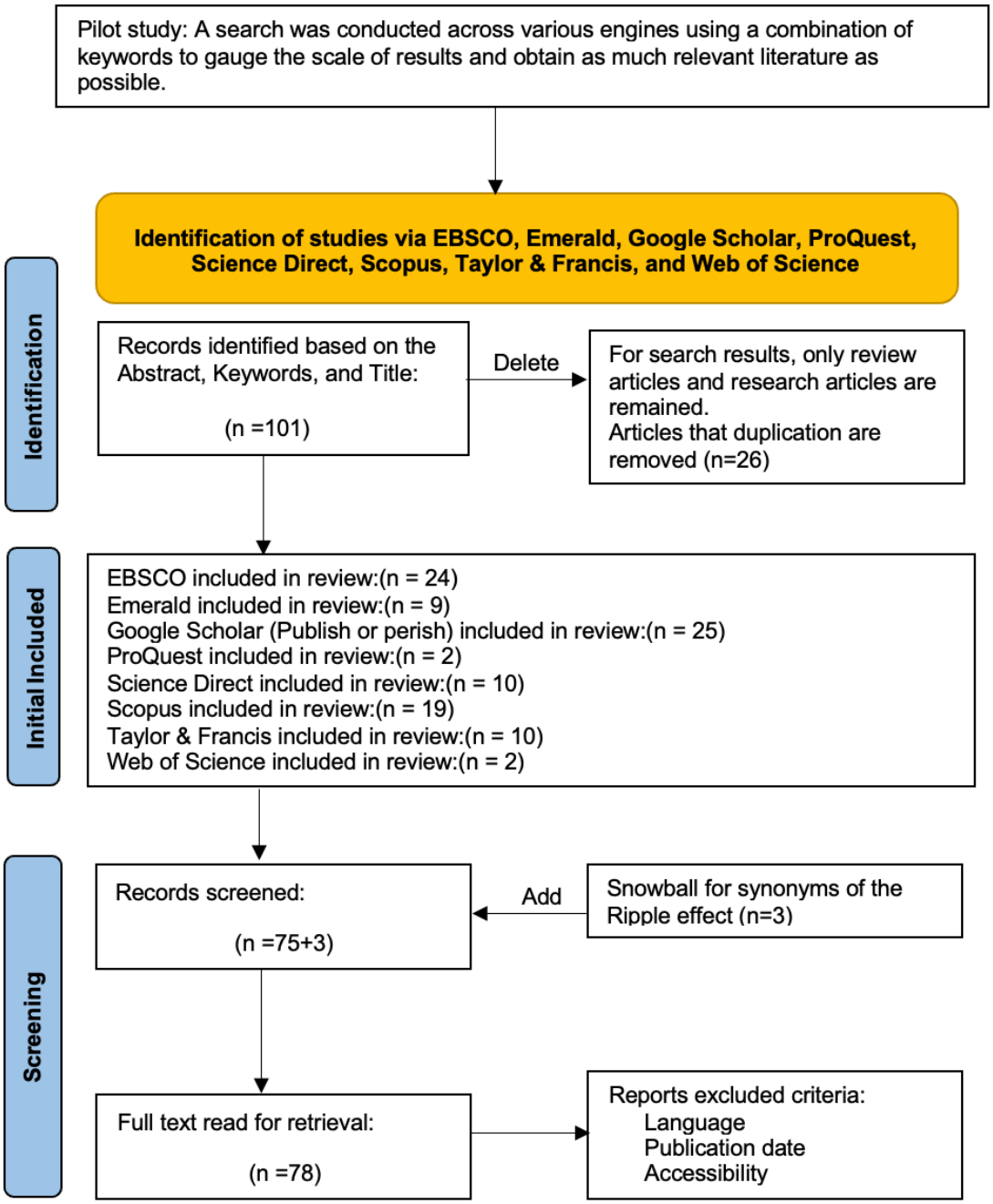


Figure 2.1: Structured literature review process

Source: The author

To ensure a comprehensive understanding of the scope and diversity of available literature, a pilot study was conducted prior to the full literature review. The pilot study helped identify the most relevant literature review methodology and select appropriate keywords for the research (Saldanha et al. 2013). The pilot study literature search was

conducted using four major academic databases: Google Scholar, Scopus, ScienceDirect, and Emerald Insight.These databases were selected based on their comprehensive coverage of peer-reviewed literature in the fields of supply chain management and construction, as well as their frequent use in similar literature reviews (Ho et al. 2015; Friday et al. 2018; Shishehgarkhaneh et al. 2024).

The primary challenge encountered during the pilot study was the breadth and diversity of the available literature, which varied considerably in both quality and accessibility. Above features make it researchers challenging to conduct a complete and meaningful review. The searching results spanned several disciplines and included numerous unrelated articles, demonstrating the need for a systematic approach in selecting high-quality and relevant articles for the full review. Therefore, the databases presented in Figure 2.1 were used to ensure the quality and integrity of the literature screening process. It is worth noting that, to maintain quality and consistency, only peer-reviewed articles available in English were included in this literature review. Additionally, the terms ‘risk propagation’ and ‘snowball effect’ were included as related or synonymous expressions of the ripple effect to ensure comprehensive coverage of the literature. To ensure the inclusion of all articles, the snowballing method were utilized during the literature review process, articles like Lai et al. (2023) were incorporated into the database.

To ensure a comprehensive literature search, this study employs a variety of keyword combinations, thereby maximizing the potential for revealing relevant resources. The chosen keywords Construction AND SMEs AND supply chain AND ripple effect are conducted during the sourcing process. In the end of review process, all identified records were compiled into Excel spreadsheets for further descriptive statistics. All articles were assigned unique numbers to ensure their uniqueness. The other items include authors, title of the article, year of publication, publisher, topic of the article, type of article, methodology, research objectives, questions, results, and keywords.

2.6 Descriptive analysis

This section presents descriptive analysis for the 78 collected articles, the purpose of which is to document the evolution of the research topic and shed light on current research interest in the field. It is worth mentioning that all the figures presented in this section are cumulative, a format that is widely used in the literature (Farooque et al. 2019). Figure 2.2 illustrates the trend in articles focused on ripple effects under disruption risk, with a gradual increase in relevant research from 2013 to 2025 August.

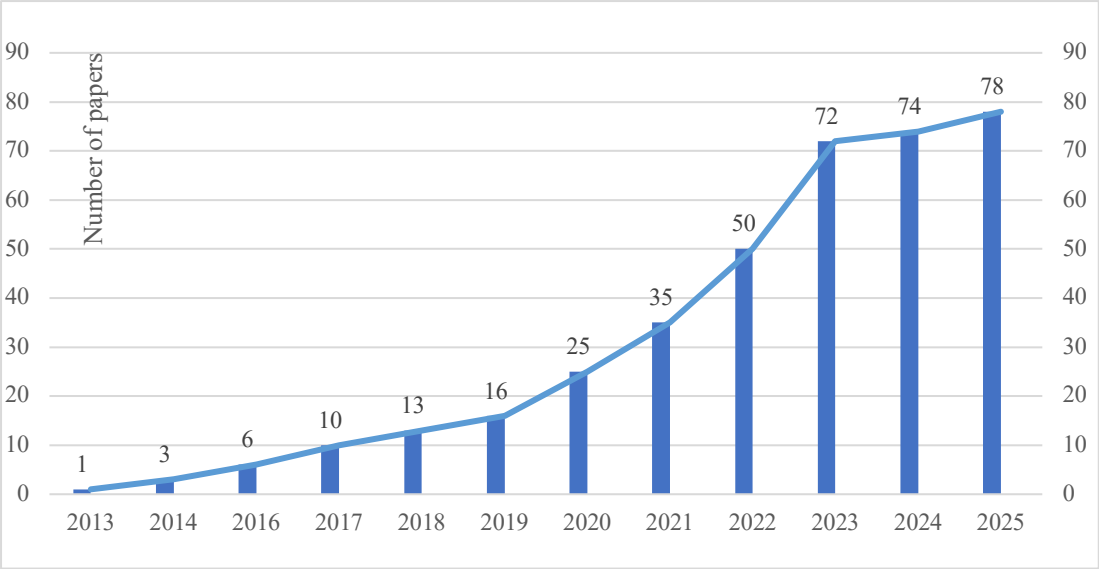


Figure 2.2: Year of publication

Source: The author

Supplemented by the results presented in Figure 2.3, it becomes clear that academic research on the ripple effects of disruption is predominantly quantitative. Intriguingly, since 2020, the proportion of both studies has increasing rapidly. This may be attributable to the abrupt outbreak of COVID-19, leading to increased supply chain disruptions (Ivanov 2020).

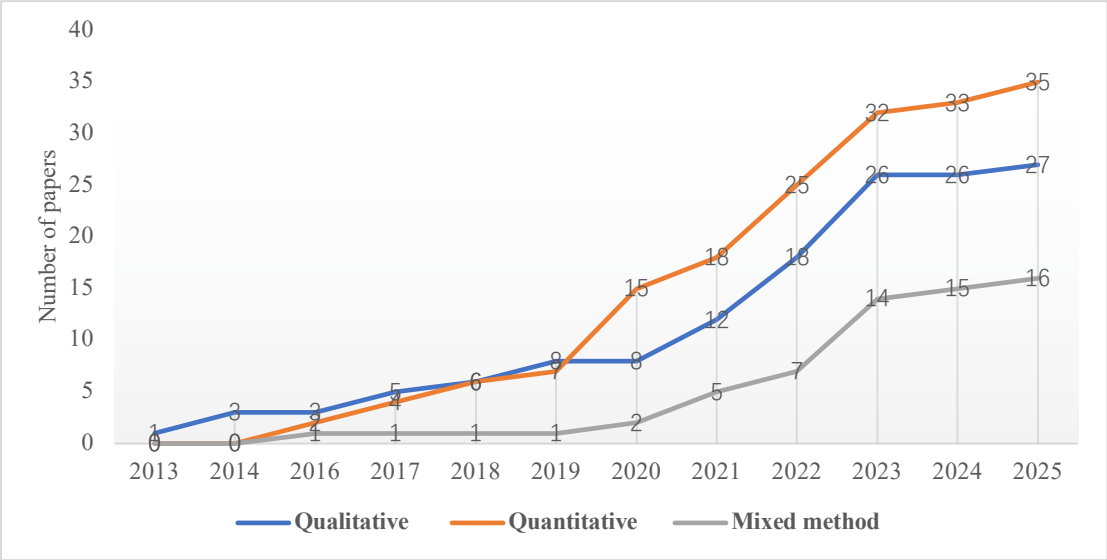


Figure 2.3: Research types for selected articles

Source: The author

The increasing convergence of conceptual and empirical research methods is evident, as illustrated in Figure 2.4. While conceptual research on supply chain ripple effects has shown signs of decline, empirical research in this area is steadily gaining momentum. Moreover, there is a growing trend towards integrating empirical and conceptual approaches in order to bridge theoretical insights with practical data analysis. Figure 2.5 presents the research method adopted in the selected articles, where other represents papers that applied multiple methods. For instance, the study by Castillo (2023) combines a literature review with bibliometric analysis to identify the past, present, and future lines of research in the supply chain resilience literature.

From both Figure 2.4 and Figure 2.5, literature reviews remain the predominant research type and methodology. Nevertheless, scholars are not limited to this approach. Following the prevalence of literature reviews in methodology, quantitative research methods such as modelling and simulation are listed below, with these methods currently having a significant presence in the field of ripple effect research. However, qualitative like interview research are not overlooked (Pal et al. 2014; Baghersad and Zobel 2021; El Baz and Ruel 2021; Chand et al. 2022; Timotius et al. 2022; Dickens et

al. 2023; Duong et al. 2023). Commonly adopted qualitative methods encompass semi-structured interviews and survey (Ashiru et al. 2022; Timotius et al. 2022).

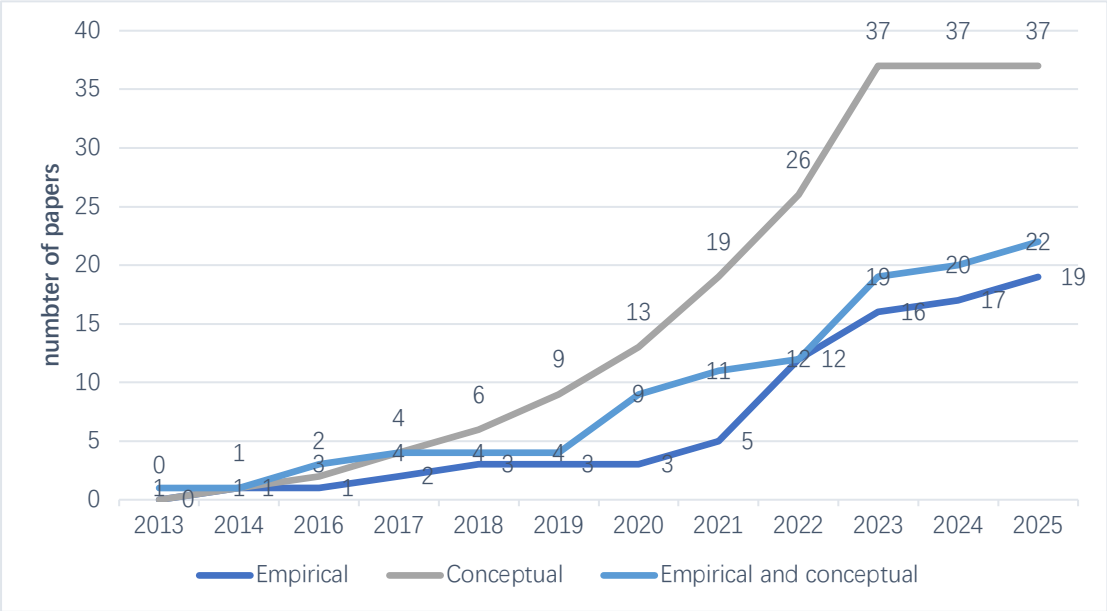


Figure 2.4: Research approach for selected articles

Source: The author

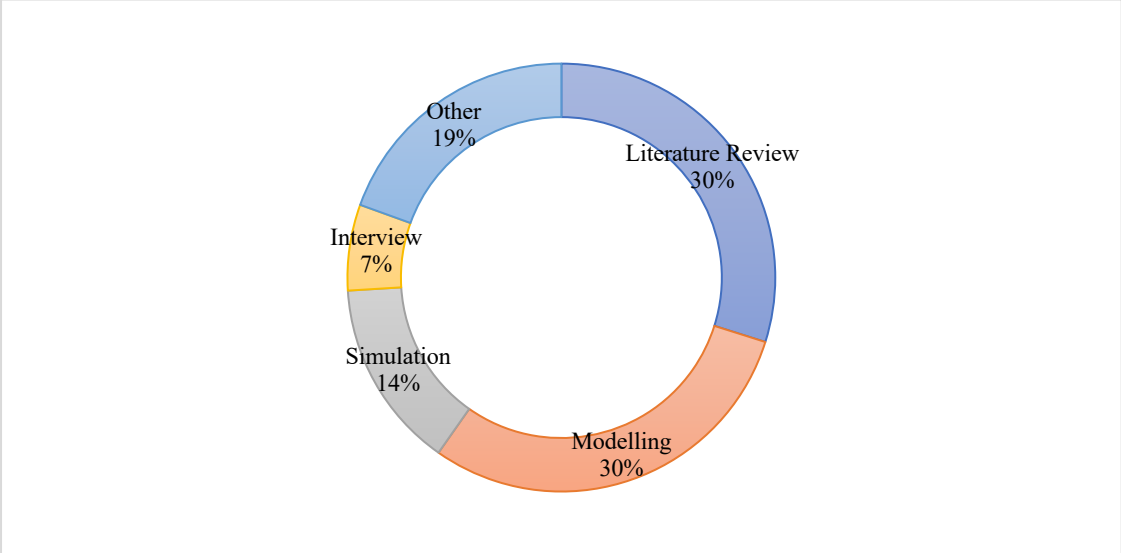


Figure 2.5: Research method for selected articles

Source: The author

2.7 Review of research tools for the ripple effect

A review of 78 papers reveals that scholars have explored the ripple effects under disruption risk using various research methods and tools. These include mathematical modelling, simulation, and empirical studies. This section compiles the most popular research tools and methods to facilitate an understanding of the prevailing tools and possible trends in the field of research (Burgess et al. 2006).

2.7.1 Mathematical modelling

Mathematical modelling provides a powerful tool for academics to understand the causes and consequences of supply chain disruptions, enabling the exploration of potential solutions at relatively low cost. The utility of mathematical modelling remains unparalleled in addressing the ripple effect of supply chain disruptions. Its role includes balancing the probability of disruption and optimising efficiency of the supply chain (Dolgui et al. 2018b). It is worth noting that although mathematical modelling has a long history in the construction supply chain sector, only a few relevant studies have explored ripple effects, and these are often based on partial or incomplete data (Jung et al. 2018; Dolgui and Ivanov 2021a; Ye et al. 2025).

In terms of supply chain optimisation. MacKenzie and Apte (2017) utilized mathematical modelling to investigate the factors contributing to the vulnerability of fresh produce supply chains (FPSC) to disruptions. This research quantified the benefits of various disruption management strategies. Similarly, Hosseini et al. (2019) used probabilistic graphical modelling to address supplier selection issues, demonstrating how such models can be used to calculate the probability of different disruption scenarios. Notably, their model captured the dependencies between disruptive events and their impact on supplier performance, effectively illustrating the ripple effect.

In a study focused on balancing supply chain disruption risk, Baghersad and Zobel (2021) highlighted the extended effects (both short-term and long-term) on supply

chain disruptions. By introducing and analysing a novel resilience-based approach, their research illuminated the concept of robustness in this context. Chand et al. (2022) examined the impact of supply chain complexity drivers on supply chain performance by mathematically modelling the causal effects, both direct and mediated, of the supply chain performance. However, the effectiveness of applying these studies to construction supply chains remains uncertain (Vidalakis et al. 2013; Abdolazimi et al. 2024). Disruptions in construction supply chains are complex and dynamic, requiring the identification of actual influencing factors before mathematical modelling can be meaningfully applied (Abotaleb and El-adaway 2018).

2.7.2 Simulation

The simulation approach has secured a significant place in the literature studying the ripple effect due to its ability to incorporate factors such as the duration of disruption, the modelling of the disruption event, and the recovery time (Dolgui et al. 2018b). Currently, three main approaches dominate the simulation of the ripple effect: System dynamics, Agent-based simulation, and Discrete event simulation.

System dynamics is one approach to simulate supply chain ripple effects. Brusset et al. (2023) proposed an optimal control model for supply chain reconfiguration and ripple effect analysis in conjunction with an epidemic dynamics model. The model can help reconfigure the supply chain and mitigate the ripple effect that occurs due to a decrease in production because of worker infections. Since the ripple effect reflects the dynamic behaviour of risk propagation, system dynamics can be a valuable tool for understanding the evolution of risks and for controlling or mitigating their impact (Ghadge et al. 2022). In the context of construction supply chains, some studies such as MacAskill et al. (2021), which models the demographic dynamics of affordable housing rental demand and supply in Southeast Queensland have employed system dynamics. However, the study relies on individual or collective stakeholder perceptions of reality rather than empirical evidence, which limits its practical applicability.

Agent-based simulation has been used to model supply chain disruptions and their impact on performance. Li et al. (2021) investigated the propagation of disruptions by modelling simple interaction rules of firms in a supply chain network. They developed an agent-based computational model to describe the behaviour of supply chain disruption propagation. Proselkov et al. (2024) developed an agent-based simulation model of a supply network to examine the structural conditions that render it susceptible to the propagation of financial pressures and the resulting financial ripple effects. Interestingly, despite the maturity of agent-based simulations in the construction field, relatively few scholars have applied them to the study of ripple effects (Marzouk and Daour 2018; Mishra et al. 2021). However, in specific contexts such as housebuilding, agent-based simulations can offer valuable insights into the interactions between human actors and technological systems throughout the design and construction phases (Stieler et al. 2022). These simulations are particularly useful for understanding the mechanisms of cascading impacts associated with ripple effects.

Considering severe supply chain disruptions, discrete event simulation can be employed to explore ripple effects within the construction supply chain. Lishner and Shtub (2023) utilised this approach, simulating a construction project life-cycle model based on a real case study of the automotive supply chain. This study analysed 1363 different projects and 68,150 randomly generated simulated scenarios to measure the impact of project disruptions on labour productivity. Similarly, Larsson et al. (2016) used discrete event simulation to simulate the construction of a structural steel bridge, evaluating potential schedules and optimising project duration by accounting for constraints in both on-site construction and off-site fabrication. This approach is particularly suitable for the construction supply chain, which involves diverse project types, high complexity, and numerous stakeholders (Manuj et al. 2009). However, a notable limitation of discrete event simulation is the significant manual effort required to customise models for each supply chain link, often resulting in extended implementation timelines (Agalianos et al. 2020).

2.7.3 Empirical research

Current empirical research on supply chain ripple effects primarily relies on a combination of quantitative methods and case studies (Pal et al. 2014; El Baz and Ruel 2021; Banerjee et al. 2022; Chand et al. 2022; Duong et al. 2023; Sakai and Yao 2023). For example, Baghersad and Zobel (2021) analysed the operational performance and stock market reactions of more than 300 companies that experienced supply chain disruptions between 2005 and 2014. They employed a novel quantitative indicator to empirically assess the impact of these disruptions on corporate performance. Additionally, Dickens et al. (2023) developed a theoretical model of resilience based on theory. They tested the application of the model through a survey study and structural equation modelling with 298 supply chain professionals from 15 industries in the US.

In addition to case studies, empirical studies addressing the ripple effect include interviews and Multi-Criteria Decision-Making (MCDM). The MCDM approach is a methodology that can describe, evaluate, and rank evaluation objects by simultaneously considering multiple criteria and processing evaluation information given by decision-makers (Mabrouk 2021). For example, Hsu et al. (2022) proposes an integrated quality function deployment (QFD)-MCDM model to identify key Industry 4.0 enablers to strengthen supply chain resilience metrics and mitigate ripple effect risk factors, providing an effective approach for firms to develop resilient supply chains capable of responding quickly to change and uncertainty. They integrate MCDM into the model identification process to provide decision support for supply chain management.

Although most current research on supply chain disruption risk primarily relies on quantitative methods base on descriptive analysis, interest in empirical research is growing for two key reasons. First, while simulations and mathematical models have provided valuable insights into the causes of ripple effects, these sources can vary significantly across industries (Ivanov et al. 2019a). In the context of the construction

supply chain, it is therefore essential to empirically validate the sources of ripple effect specific to SMEs. Second, as ripple effect theory continues to develop, mitigation strategies, particularly those centred on robustness and resilience, require further empirical investigation to evaluate their practical effectiveness in real world settings (Llaguno et al. 2022).

2.8 Supply chain disruption and ripple effect

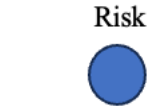
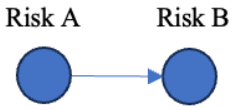
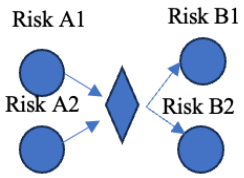
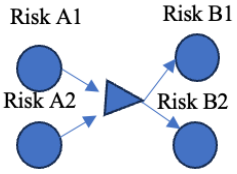
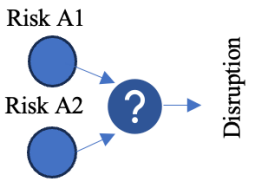
Disruption risk, as a category of SCR, represents a situation where the probability of occurrence is low relative to operational risks, yet the impact is severe and can cause significant disruption (Kleindorfer and Saad 2005). There has been a significant increase in academic exploration of supply chain disruption (Sudan et al. 2023). This trend is reflected in various aspects. For example, researchers have delved into the causes and categorisation of disruption risk (Tang 2006; Ivanov et al. 2017). Based on a temporal perspective, disruption risk can be categorised into two groups: preventive robustness measures implemented prior to a disruption, such as maintaining safety stock, redundant output capacity, or input flexibility (Gao et al. 2019; Snoeck et al. 2019) and resilience-based contingent recovery strategies after a disruption, including re-routing, inventory management, product substitution, dynamic pricing, and outsourcing (Gupta et al. 2021).

The study by Piprani et al. (2020), based on a review of existing literature, identified and prioritised resilience factors at different stages of supply chain disruptions in the Pakistani textile industry. By mapping these factors to disruption phases, preparedness, response, and recovery, they provide an operational framework for applying resilience concepts in practice. Many scholars have continued to focus on systematic reviews of supply chain disruptions, aiming to summarise the applied methodologies in the literature through content analysis and ultimately outline the research progress in the field (Xu et al. 2020; Shekarian and Mellat Parast 2021).

The relationship between supply chain disruptions and the ripple effect is well-established, as the latter represents the dynamic extension of disruptions across interconnected supply chain networks (Ghadge et al. 2022). In the event of localized disruption risk, the risk may shift from the level where the disruption occurs, extend to a portion of the network, or even envelop the entire network. Indeed, numerous real-life examples, such as the Thailand floods in 2011, the Japan earthquake in 2012, and the global supply chain disruption caused by the COVID-19 pandemic in 2020, underscore the importance of understanding and managing ripple effect under the supply chain disruptions (Ivanov 2020), demonstrates how it may propagate under different risk relationships.

Independence, dependence, parallel, and series describe the structural relationships between risks within a system, focusing on how the occurrence of one risk influences another. As summarised in Table 2.12 independence indicates no interaction between risks, dependence refers to one risk triggering another, while parallel and series relationships represent more complex multi-risk propagation patterns. The ripple effect, however, extends beyond these direct risk-to-risk relationships. It captures the cascading impact of an initial disruption across multiple processes, stakeholders, and supply chain tiers, often increasing in scale as it spreads. The ripple effect emphasises the dynamic and cross-organisational propagation of disruptions within and across supply chains, highlighting how a single event can evolve into broader performance and operational consequences.

Table 2.12: SCR relationship path

Risk relationship	Definition	Visualization
Independence	Independence in risk refers to characteristics like probability, start time, duration, and loss, which remain unaffected by other risks in the system, indicating that this risk does not influence or is influenced by other risks.	
Dependence	Dependence in risk signifies that the occurrence of risk B is contingent on the occurrence of risk A.	
Parallel	In a parallel situation, the collective occurrence of multiple risks (A1, A2, ..., An) likely leads to the manifestation of associated risks (B1, B2, ..., Bm), representing interdependent influences in each scenario.	
Series	In a series relationship, a set of risks (A1, A2, ..., An) must occur together for the manifestation of associated risks (B1, B2, ..., Bm); for example, both bad weather and substructure construction are needed for the risk of project overrun time to potentially occur.	
Ripple effect	Ripple effect visualised through various forms, such as dependence, parallel, or series, often originating from within a system and impacting the operations of firms across their supply chains or spanning multiple supply chains.	

Source: The author, adapted from Ren (1994)

The ripple effect is characterised by its inherent uncertainty, which allows it to emerge at stage of supply chain disruption (Ivanov and Dolgui 2021). Furthermore, the ripple effect often results in changes to supply chain structures, distinct from the bullwhip effect, which affects the supply chain at the operational level by mismatching demand and supply without inducing structural changes in supply chain design (Dolgui et al. 2018b; Ivanov et al. 2019b). Other important characters of ripple effect are the dynamic nature; it can quickly propagate to other parts of the supply chain (Sokolov et al. 2016). The rate of this propagation depends on the initial impact of the disruption and the robustness of the supply chain itself.

The ripple effect is influenced by numerous factors spanning multiple dimensions of supply chain operations. Empirical and simulation-based studies have shown that direct causes often include supplier failures, fluctuating demand, production delays, and transportation disruptions (Ivanov 2017). Meanwhile, disruptions might also be attributed to lean business strategies adopted by supply chain companies, such as low inventory levels and single sourcing (Dolgui et al. 2018b). Regarding environmental factors, the increasing complexity of the supply chain environment, as well as changes in policy and technological innovation, may contribute to the risk of disruption and subsequently the ripple effect as summarized in Table 2.13 on the drivers of the ripple effect.

Table 2.13: Construction supply chain ripple effect drivers

Themes	Drivers	Authors
Supply risk	Supplier opportunism	Scheibe and Blackhurst (2019)
	Unstable quality of inputs	Ivanov et al. (2019b)
	Price fluctuations	Ivanov et al. (2019b)
	Inflexibility of suppliers	Ivanov et al. (2019b)
	Supplier bankruptcy	Hua et al. (2011); Yang et al. (2015)
	Logistics reliability	Sullivan et al. (2011)
Operational risk	Design changes	Papadopoulos et al. (2016)
	Low quality of equipment and materials	Zou et al. (2007)
	Safety issues	Wang et al. (2022)
	Poor planning and scheduling	Thunberg et al. (2017)
	Technological change	Eshraqi and Eshraqi (2019)
	Design errors	Han et al. (2013)
	Failure to perform an obligation	Haidar (2011)
	Dissatisfaction with work	Amade et al. (2016)
	Accident	Chen et al. (2023)
	Inflexible materials	Hsu et al. (2019)
	Labour disputes/strikes	Ekanayake et al. (2022b)
	Lack of experience or training	Kim and Nguyen (2022)
Demand risk	Demand variability	Chen et al. (2024)
	Deficient customer relationship management	Costa et al. (2019)
	Customer bankruptcy	Houston et al. (2016)
	Customer dependency	Amade et al. (2017)

	High competition in the market	Johnsen and Lacoste (2016)
	Customer fragmentation	Luo et al. (2023)
Human-made risk	Environment issues	Jiang et al. (2023)
	Miscommunication for material size and features	Kwofie et al. (2015)
	Social and cultural grievances	Govindan et al. (2021)
	Contractual ambiguity	Koc and Gurgun (2022)
	Ineffectiveness of supervision mechanisms	Wu et al. (2014)
	Failure to carry out a second check	Love et al. (2011)
	Advance funds for the project	Zou et al. (2007)
	Delay in wage payment	Peters et al. (2019)
	External legal issues	Stamatiou et al. (2019)
	War and terrorism	Ekanayake et al. (2022b)
	Transfer unavoidable risks to other stakeholders	Burke and Demirag (2017)
	Political instability	Abas et al. (2022)
Natural risk/Force majeure	Epidemics	Karamoozian and Wu (2022)
	Natural catastrophes	Sandanayake et al. (2018)
	Tsunami	Ogawa et al. (2019)
	Heavy raining	Hsu et al. (2018)
	Fire	Ekanayake et al. (2022b)
	Cold/Hot weather	Ekanayake et al. (2022b)

Source: The author, adapted from Duong et al. (2023)

The existing literature reveals a research gap concerning the drivers of the ripple effect, as there is no systematic classification of these drivers. Gaining an understanding of the mechanisms that generate ripple effects and the specific domain interactions involved is crucial. A striking example is the 2011 Tohoku earthquake in Japan, which triggered a massive tsunami and led to severe damage at the Fukushima Daiichi nuclear power plant (Norio et al. 2011). This single natural event cascaded through multiple domains: physical infrastructure, energy systems, and industrial production. The resulting electrical and cooling failures caused widespread nuclear shutdowns, which in turn disrupted global automotive and electronics supply chains that depended on Japanese suppliers (Lu et al. 2025). This case illustrates how a localised disruption can evolve into a multi-tier, multi-industry ripple effect through the interaction of physical, technological, and economic systems.

Scholars have made notable contributions in exploring the forward and backward diffusion of ripple effects and in analysing various disruption scenarios (Dolgui et al. 2018b). Forward diffusion refers to the downstream propagation of a disruption, moving from suppliers to manufacturers, distributors, and ultimately customers. In contrast, backward diffusion describes the upstream transmission of disruption effects, whereby disturbances originating from customers or downstream actors propagate back toward suppliers (Bugert and Lasch 2023). For instance, Li et al. (2021) provided a comprehensive depiction of the disruption propagation mechanism. By simulating disruption propagation, they distinguished between forward and backward propagation and their respective influencing factors. Their findings show that these two directions of propagation affect node vulnerability and network health in distinct ways. This is because forward propagation typically amplifies the impact of supply-side disruptions. In contrast, backward propagation transmits demand shocks or cancellations upstream, reducing order volumes and destabilising supplier operations. Consequently, investment strategies to minimise propagation in both directions may substantially differ in practice. In the other hand, Pavlov et al. (2022) investigated disruption

scenarios, ripple effect propagation, and recovery paths in supply chains, grounded on the basis of structural genomes. Through the case study, they illustrated how Nissan was able to effectively recover from the severe supply chain disruption caused by the 2011 earthquake and tsunami in Japan. The key to this successful recovery was Nissan's ability to anticipate different disruption scenarios and promptly implement reconfiguration paths (Schmidt and Simchi-Levi 2013). This example provides important insights for current research, illustrating that understanding the antecedents and consequences of ripple effects is essential for developing effective mitigation strategies and for preventing their emergence in the first place. Moreover, ripple effects arising from different types of disruptions, such as operational, environmental, or behavioural, cannot be addressed uniformly, as each type follows distinct propagation paths and affects supply chain nodes in different ways.

In the literature review on ripple effects, scholars studying ripple effect have primarily focused on estimating the impacts generated by ripple effects, along with the current methodologies and possible mitigation strategies (Ivanov et al. 2019b; Hosseini and Ivanov 2020b; Ghadge et al. 2022). Scholars like Birkie and Trucco (2020) have categorised the methods of estimating the ripple effects into two types: one measures the distance from the point of the initial strike to the point where the consequences are evaluated (Kim et al. 2015), and the other measures the time required to recover from the consequences of the disruption that occurs at a point in the supply chain (Ivanov 2017). Another reason to research the drivers of ripple effects is to measure the extent and magnitude of these ripples. The extent and magnitude depend on both the degree of redundancy (e.g., inventory or capacity buffers) and the effectiveness of recovery measures (Ivanov 2021a). By understanding the extent and magnitude of ripple effects, efforts can be made to mitigate their consequences.

Despite the growing academic interest in empirical research, there remains a gap concerning the ripple effect in the construction industry. Only few study, such as Duong et al. (2023) has explored the ripple effects of disruptions on performance within the

construction supply chain. They found that human risk leads to operational risk, while natural risk leads to both supply and operational risks in the context of construction industry. Furthermore, the effects of human and natural risks on performance are amplified through operational risk. Future research needs to concentrate more on the influencing factors and research methodologies of the ripple effects within the construction supply chain, as well as potential mitigation strategies. Table 2.14 presents the link between risk management, traditional SCRM, and ripple effect.

Project risks as the initial sources of disruption, SCRM as the coordination mechanism across organizational boundaries (Denicol et al. 2020; Stefano et al. 2023), and ripple effects as the systemic manifestation of how these risks propagate and amplify within construction SME supply chains. In the construction industry, supply chains are inherently organised and operated through projects (Singh et al. 2024). Each project functions as a temporary supply chain, bringing together multiple stakeholders such as clients, designers, contractors, suppliers, and supervisors to deliver a specific outcome. As a result, project activities represent the primary context in which supply chain risks emerge, interact, and propagate. Disruptions such as design errors, payment delays, safety incidents, or contractual conflicts often originate within specific project stages but subsequently spread across organisational boundaries, affecting multiple supply chain levels.

Table 2.14: Comparison between risk management, traditional SCRM, and ripple effect

	Risk management (Project management)	Traditional SCR management	Supply chain ripple effect
Definition	Risk management, in the project context, is the art and science of identifying, analysing and responding to risk factors throughout the life of a project and in the best interests of its objectives (Pym 1987).	The management of SCR through coordination or collaboration among the supply chain partners to ensure profitability and continuity (Tang 2006).	Impacts of how supply chain disruptions to some variables are rippling through the rest of the supply chain and influencing its performance (Ivanov et al. 2014b).
Management Objectives	Protect organizational assets, reputation, and stakeholders through risk mitigation strategies (Merna and Al-Thani 2008).	Aims to reduce the likelihood and impact of risks, emphasizing risk prevention and resilience (Ghadge et al. 2012).	Aims to understand the mechanisms of risks interactions and adopt to reduce ripples (Liu et al. 2023).
Focus	Through following process to manage risks: risk identification, impact analysis, response planning, the response system, and the application of the resulting data (Chapman 2003).	Focuses on identifying, assessing, and mitigating risks such as supply shortage, price fluctuation, or natural disasters (Ho et al. 2015).	Describes the impact of a disruption on supply chain performance and disruption-based scope of changes in the

			supply chain structures and parameters (Ivanov et al. 2014b).
Scope & Complexity	Addresses project risks, often associate with management strategy and quality, communication production perspective (Atkinson et al. 2006).	Addresses static risks, often with a single-point perspective record on risk register (Singhal et al. 2011).	Addresses dynamic, systemic risks, emphasizing risk interaction and propagation.
Risk classification	Risk recognition: known risk, unknown risk, known-unknown risk, unknown-unknown risk. Project scope: Internal risk external risk (Ramasesh and Browning 2014).	Operational risks and disruption risks base on risk level of certain events (Tang 2006).. Internal and external risks (Wu et al. 2006).	Low-/high-impact disruption risk (Roh et al. 2022).
Methods	Qualitative methods: Expert interviews, surveys, and scenario analysis. Quantitative methods: Risk modelling (e.g., probability-impact matrices), Monte Carlo simulations, and optimization algorithms (Del Cano and de la Cruz 2002).	Uses qualitative methods: case study, survey, action research and grounded theory or quantitative tools: mathematical, simulation, programming and mixed method to assess likelihood and impact of risks (Fan and Stevenson 2018b).	Utilizes complex network analysis, SDM, and computer simulation to study risk propagation (Dolgui et al. 2018b).

Mitigation Strategies	Avoidance: Eliminating specific risks by changing plans or processes. Reduction: Implementing measures to decrease the likelihood or impact of risks (e.g., inventory buffers, dual sourcing). Transfer: Shifting the risk to third parties (e.g., through insurance or outsourcing). Acceptance: Acknowledging risks and preparing contingency plans (Raz and Michael 2001).	Depend on risk severity and likelihood of risk mitigation include acceptance, avoidance, transfer and sharing (Fan and Stevenson 2018b).	Focus on two aspects of supply chain resilience and robustness. Reduce the impact of ripple effects by improving both aspects in the supply chain (Ivanov et al. 2014b).
Research & Application Context	First applied in the National Aeronautics and Space Administration (NASA)'s systems engineering handbook, then been develop in the project management (Stamatelatos et al. 2011).	Originates from project risk management theories, widely applied in manufacturing and logistics (Chu et al. 2020).	Applied in studying globalized supply chain networks, particularly for disruptions (Ye et al. 2025).

Source: The author

In summary, this chapter has reviewed the evolution of SCR, ripple effect research, and construction SMEs, highlighting the contributions of disruption, robustness, resilience, and SCRM to the understanding of ripple effect. However, the literature remains fragmented, with few studies integrating these perspectives into a unified framework, particularly within the context of construction SMEs. To address this, Figure 2.6 synthesises the key theoretical domains that collectively inform conceptual approach of the study. It illustrates how supply chain disruptions trigger ripple effects, while robustness and resilience act as system capabilities that moderate or absorb these impacts. SCRM strategies, in turn, provide actionable mechanisms for mitigating and preventing such propagation. Together, these interrelated domains form the conceptual foundation for analysing ripple effect mechanisms in construction SMEs, thereby linking the theoretical insights from prior research to the empirical investigation presented in the following chapters.

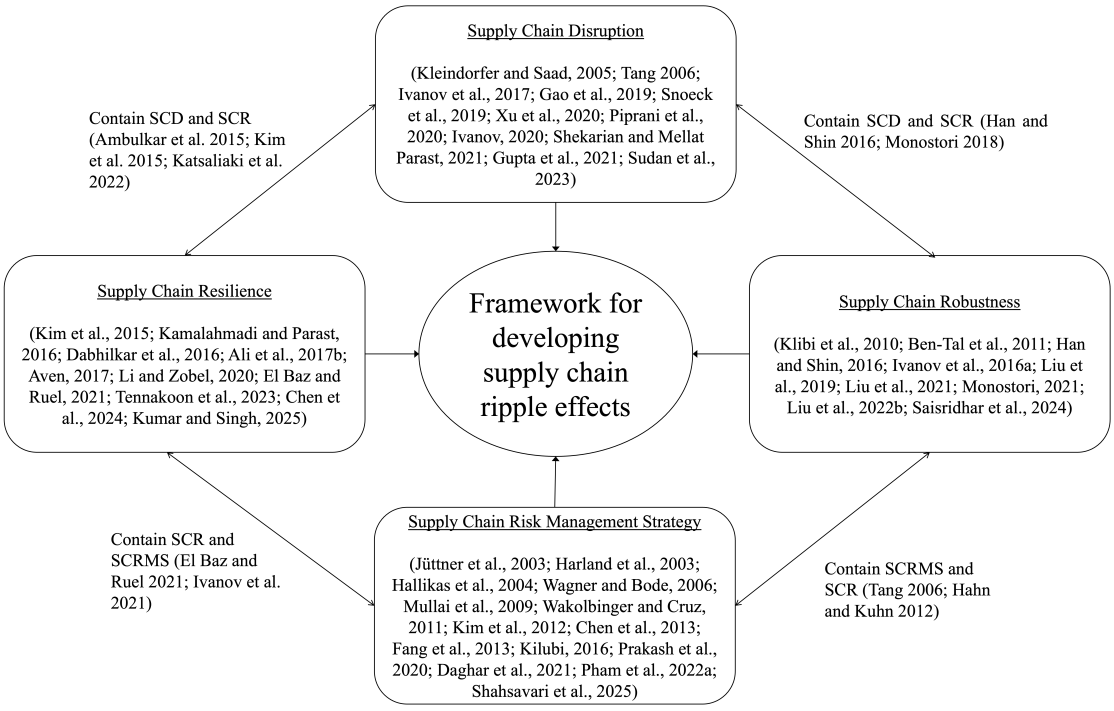


Figure 2.6: Key authors in the literature streams

Source: The author

Importantly, this synthesis is underpinned by a systems thinking perspective, which conceptualises construction SME supply chains as interconnected systems composed of interdependent stakeholders, processes, and feedback loops. From this perspective, ripple effects are not isolated outcomes of individual risks, but emergent phenomena arising from interactions within the system and across different project stages. By integrating systems thinking with supply chain disruption, robustness, resilience, and SCRM, this conceptual framework enables a holistic understanding of how ripple effects develop, propagate, and influence project performance in construction SMEs. This integrated view provides a critical theoretical foundation for the empirical investigations presented in the subsequent chapters.

2.9 Chapter summary

This chapter begins by reviewing key concepts related to the ripple effect and SCR in the construction industry, including their definitions and associated management strategies, followed by a discussion of the definition and classification of SMEs. Building on this foundation, the chapter employs a structured literature review to summarise the current state of research on supply chain ripple effects in construction SMEs. This includes a descriptive analysis of publication years, research types, methodologies, and tools used. Additionally, the literature review examines existing studies on supply chain disruptions and the ripple effect. From a methodological perspective, the review highlights those quantitative approaches, particularly simulations and modelling are commonly used to study ripple effects under supply chain disruption scenarios, while empirical research remains relatively limited. Overall, the research identifies a significant gap in the academic literature. This relates to Gap 1: Current studies on the causes and transmission pathways of supply chain ripple effects within SMEs in the construction industry remain extremely limited. By addressing this gap, this study aims to extend ripple effect theory to the construction sector, providing a theoretical foundation for understanding how risks arise and propagate among construction SMEs.

Chapter 3 Research methodology

3.1 Chapter overview

Research methodology lies at the core of this thesis, articulating the philosophical assumptions, epistemological stance, and methodological choices that underpin the research. This chapter provides a comprehensive examination of the research design and methodological framework adopted in this study. Section 3.2 outlines the research paradigm, including the philosophical stance and its implications for theory development and methodological choice. Section 3.3 describes the research strategies employed and provides justification for their selection. Section 3.4 details the implementation of the interview methodology, including participant selection and data collection procedures. Section 3.5 discusses the survey design and explains the specific procedures applied in the AHP methodology. Section 3.6 presents the case study design and elaborates on the principles of systems thinking that guide the analytical framework. Section 3.7 highlights the ethical considerations underpinning the research. Finally, Section 3.8 concludes the chapter.

3.2 Research paradigms

Researchers often operate under a set of assumptions, whether they are consciously aware of them or not (Burrell and Morgan 2019). Saunders et al. (2009) classify these assumptions into three categories: Ontological assumptions, epistemological assumptions, and axiological assumptions. Ontological assumptions relate to the nature of reality being studied, epistemological assumptions concern the nature of knowledge, and axiological assumptions address the ethical issues where values positively influence the research process (Kivunja and Kuyini 2017). These assumptions play a critical role in shaping how researchers approach their research questions, select their methodologies, and interpret their findings (Crotty 1998). Understanding the views of the author on these fundamental research concepts provides the reader with a clearer

comprehension of the research perspective and methodology. A research paradigm encapsulates foundational beliefs, primarily encompassing ontology, epistemology, and axiology. The following section will provide detailed information on the research paradigm.

In the field of business management, scholars have made significant efforts to structure and categorize research paradigms (Acedo and Casillas 2005; Burgess et al. 2006; Patel 2017). Notably, the research onion framework proposed by Saunders et al. (2009) has gained widespread acceptance and application in management and business research. The use of the research onion framework in this thesis offers several benefits. First, it allows the author to clearly articulate the philosophical position within a recognized structure, ensuring clarity and coherence in the research framework. Second, it enables readers to better understand the content by relating the stated position to their own views. Two opposing views, subjectivism and objectivism, dominate the discourse surrounding research paradigm assumptions. As Saunders et al. (2009) notes:

> *Objectivism incorporates the assumptions of the natural sciences, arguing that the social reality that we research is external to us and others (referred to as social actors) … Subjectivism incorporates assumptions of the arts and humanities, asserting that social reality is made from the perceptions and consequent actions of social actors (people) (Saunders et al. 2009, p. 128).*

From ontological, epistemological, and axiological standpoints, subjectivism, and objectivism each carry distinct attributes. These characteristics often reflect the inclinations and viewpoints of scholars toward understanding the world and are manifested in their academic endeavours. Ontologically, objectivism posits a singular, external reality, while subjectivism contends that reality is shapable and formed by societal practices and interpretations (Bryman 2016). Epistemologically, objectivism asserts that knowledge can be acquired using methods from the natural sciences, whereas subjectivism advocates for drawing insights from the arts and humanities, suggesting that knowledge is interpretative and contextual (Bell et al. 2022). In terms

of axiology, objectivism maintains that researchers should remain detached, refraining from infusing their work with personal beliefs (Burrell and Morgan 2017). Conversely, subjectivists argue that scholars should instil their work with their values, though within certain bounds (Willis 2007).

Objectivism and subjectivism have markedly different attitudes towards science. In the field of business management, academia has developed various philosophical positions to accommodate these differing perspectives. The distinctions among research paradigms arise from their unique combinations of ontology, epistemology, and methodology (May 2011). Table 3.1 summarised the five dominant paradigms and their attributes in business management disciplines.

Table 3.1: Comparison of five research philosophical positions

Positivism	Critical realism	Interpretivism	Postmodernism	Pragmatism
Real, external, independent	Stratified/ layered	Complex, rich	Nominal, complex, rich	Complex, rich, external
Scientific method Observable and measurable facts	Relativism	Theories and concepts	Decided by domiant ideplogies	Practical meaning of knowledge in specific contexts
Value-free research	Valuelade n research	Value-bound research	Vaule-constituted	Value-driven research
Deductive, highly structured	Retroducti ve, in-depth	Inductive	Deconstructive	Following research problem and research qeustion

Source: The author, adapted from Saunders et al. (2009)

3.2.1 Philosophical stance

This research resides within the domain of supply chain management. After evaluating the philosophical positions outlined in Table 3.1 and considering both the dominant approaches in this field and the perspective of the researcher on the nature of reality and knowledge, this thesis adopts a critical realism stance. Critical realism posits that reality exists independently and can provide insight into the ripple effects experienced by SMEs in the construction industry. This stance recognises that knowledge of underlying mechanisms and causal structures is best accessed through the diverse experiences and perspectives of participants, rather than relying solely on the interpretation of the researcher (Fletcher 2017). The subsequent section demonstrates the rationale behind selecting critical realism as the guiding research philosophy.

Although philosophical stance is not as predominant in the supply chain domain, scholars still emphasize their importance, many researchers have outlined their philosophical stances (Burgess et al. 2006; Adamides et al. 2012). Notably, Gosling et al. (2013) employed a critical realist approach to explore layers of uncertainty by identifying and categorizing significant sources of project uncertainty. Darby et al. (2019) illustrated how positivism informs various research methodologies, further detailing how positivists might implement this in supply chain management. Kumar and Sharma (2021) incorporated postmodern chaos theory in their analysis to understand disruptions in inter-firm oil and gas supply chains.

Critical realism was chosen for this thesis for several reasons. Firstly, critical realism allows for investigation through qualitative and multi-faceted research approaches. Given that the purpose of this research is to identify, categorise, and present case studies of ripple effects in the construction supply chain, it is essential to align the research design with real-world conditions by employing a diverse methodological approach. Secondly, the impartiality of critical realism ensures that qualitative methods, such as interviews and surveys, present the attitudes of respondents from multiple perspectives. Finally, the framework of critical realism aligns with the inherent characteristics present

in the ripple effect. From a critical realist perspective, SCR is ontologically conceptualized as consisting of interconnected objects that are structures, or parts of structures, with underlying causal forces and responsibilities that are activated and mobilised under specific conditions (Adamides et al. 2012).

In the context of supply chains, critical realism does not confine itself to a single theory but seeks to identify or develop a theory capable of describing generative mechanisms (Eriksson and Engström 2021). From an ontological perspective, the author believe that the social phenomena studied in science represent a separate reality containing inherent generative mechanisms. Epistemologically, the author assert that knowledge should be historical and subject to causal interpretation. In terms of axiology, the author acknowledges biases stemming from worldviews and backgrounds and aim to work towards reducing them. After evaluating various philosophical perspectives, critical realism was ultimately chosen as the guiding philosophy for this doctoral thesis.

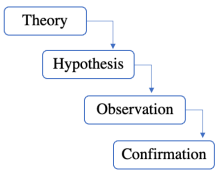
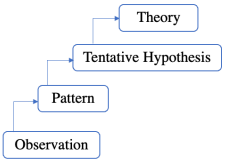
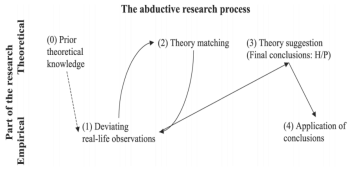
3.2.2 Approach to theory development

According to the research onion framework by Saunders et al. (2009), the next step is the selection of approaches to theory development, providing readers with an entry point for studying a phenomenon or theory. Empirically based research can be hampered by limited access to data and insufficient knowledge of the basics of observation or hypothesis formulation (Pandey and Pandey 2021). To compensate for these practical limitations, scholars have developed three different methods of reasoning (Kovács and Spens 2005). Table 3.2 summarised these reasoning methods based on their distinct features.

Inductive reasoning is interpretative, moving from specific observations to broader generalisations, and drawing general principles from particular instances (Bell et al. 2022). In induction, a logical gap exists between the conclusion and its observed premises, and the conclusion is “evaluated” based on these observations (Ketokivi and Mantere 2010). Researchers employing induction typically gather data to explore phenomena and create theories. Although conclusions derived from existing

phenomena in inductive reasoning are considered valuable, they are not always reliable and require further verification (May 2011).

Table 3.2: Comparison of deduction, induction, and abduction

	Deduction	Induction	Abduction
Logic	If premises are true, the conclusion must also be true	Known premises are used to generate untested conclusions	Known premises are used to generate testable conclusions
Generalizability	From the general to the specific	From the specific to the general	From the interactions between the specific and the general
Use of data	Data collection is used to evaluate propositions or hypotheses related to an existing theory	Data collection is used to explore a phenomenon, identify themes and patterns, and create a conceptual framework	Data collection is used to explore a phenomenon, identify themes and patterns, and create a conceptual framework
Theory	Theory falsification or verification	Theory generation and building	Theory generation or modification; incorporating existing theory where appropriate, to build new theory or modify existing theory
			

Source: The author, adapted from Saunders et al. (2009); Aliyu et al. (2015)

Deductive reasoning logically infers a conclusion from established premises, holding true when all premises are accurate (Ketokivi and Mantere 2010). Deduction involves theorising, followed by testing through specific propositions, making it popular in the natural sciences. Deductive reasoning typically starts with a known phenomenon or situation and then elucidates the inherent implications of the coexistence of two circumstances (Blaikie 2010).

The abductive approach blends deductive and inductive methods (Suddaby 2006). Abduction commences with the observation of an anomalous fact, followed by constructing a likely explanation for its existence (Maanen et al. 2007). When undertaking abduction, researchers must determine the study sequence based on their research focus (Saunders et al. 2009). Those favouring abduction often employ qualitative data and diverse data collection techniques to capture multiple perspectives of the subject, leveraging a combination of qualitative and quantitative methods to understand and numerically represent the causes behind phenomena. Given the complex and unpredictable nature of ripple effects, many scholars have employed various analytical approaches to identify their underlying determinants (Dolgui et al. 2018a). Table 3.3 outlines the example for methodologies adopted in existing supply chain research.

This study provides insights into the complex interactions between structural and operational dynamics in supply chains. As discussed in Chapter 1, the ripple effect in construction SMEs emerges not from isolated incidents but from interconnected relationships among project participants, resources, and processes. To capture these interdependencies, this study adopts systems thinking as its theoretical framework. A system thinking is defined as a whole comprising two or more interdependent parts, where each part can influence the performance or attributes of the whole (Ackoff 1994; Wilden et al. 2022). Systems thinking enables the supply chain to be viewed as an integrated whole, where disruptions in one part can trigger cascading effects across others. In the context of ripple effects across the supply chain, resilience and robustness serve as key mitigation strategies to manage SCRs (Tang 2006; Hahn and Kuhn 2012; El Baz and Ruel 2021; Ivanov et al. 2021). Supply chain disruptions are a primary cause of ripple effects, and their impact is influenced by the level of resilience and robustness within the supply chain (Ambulkar et al. 2015; Kim et al. 2015; Han and Shin 2016; Monostori 2018; Katsaliaki et al. 2022). This thesis aligns with the core concept of abductive reasoning and endeavours to achieve its research objectives through this approach, the rationale for which is explained below.

Table 3.3: Methodology adopted in ripple effect research

Author(s)	Focus Area	Method Adopted	Type of development
Ivanov et al. (2014a); Hosseini et al. (2020)	Conceptualisation and modelling of ripple effects	SDM; Simulation	Deductive
Scheibe and Blackhurst (2018)	Supply network complexity and ripple amplification	Case study	Inductive
Dolgui et al. (2020)	Differentiation of ripple vs. bullwhip effects	Simulation-based study	Deductive
Xu et al. (2020)	Systematic review of disruption propagation literature	Literature review; Content analysis	Inductive
Golan et al. (2020)	Resilience under COVID-19 disruptions	Literature review	Inductive
Hosseini and Ivanov (2022)	Quantify the resilience of the original equipment manufacturer	Bayesian networks; multi-stage modelling	Deductive
Li et al. (2021)	Supply chain network	Agent-based computational model	Deductive
(Eriksson 2014); Eriksson and Engström (2021)	Understanding moral responsibility in the supply chain	Case study	Abductive
Proselkov et al. (2024)	Cascading impacts of financial disruptions	Agent-based modelling	Deductive
Ye et al. (2025)	Assessing the resilience of the prefabricated construction supply chain	Modelling	Deductive

Source: The author

One of the reasons for adopting abductive reasoning in this thesis is the complexity and uncertainty of ripple effects in construction supply chains. As discussed in the literature review in Chapter 2, current theories on ripple effects in construction supply chains are not well developed. Abductive reasoning is particularly applicable when observations from empirical studies do not align with these existing theories (Dubois and Gadde 2002). Another reason for adopting abductive reasoning is the incomplete nature of the

construction SMEs. Therefore, a robust reasoning approach is needed to derive the most probable conclusions through reasonable speculation and interpretation. In addition, a variety of research methods such as interviews and surveys have been used in studies assessing the ripple effects of construction supply chains. Abductive reasoning can effectively integrate information from these different sources to form a coherent explanation (Żelechowska et al. 2020).

3.2.3 Methodological choice

After describing the theoretical development of this thesis, this section focuses on demonstrating the methodological choices of this study. Scholars hold different views on research methodology based on their own rationale (Bell et al. 2022). To summarise, there are three approaches to consider: qualitative research, quantitative research, and mixed methods research. This section will briefly describe these methods and present the rationale for adopting a multiple methods approach as shown in the Figure 1.2.

Qualitative research predominantly employs textual and visual data, closely aligned with philosophical interpretations, as the phenomena under study necessitate philosophical interpretation for meaningful understanding (Denzin and Lincoln 2011). Qualitative research encompasses a wide range of strategies, including interviews, case studies, and focus groups. Despite the shared epistemological roots across these strategies, each has a unique focus and scope (Bansal and Corley 2011). While methodological diversity is inherent in qualitative research, maintaining methodological rigour and ensuring substantial theoretical contributions remain essential (Ravitch and Carl 2019).

Quantitative research leans more towards numerical representation, examining phenomena through experimentation, surveys, and statistical analyses (Saunders et al. 2009). Some quantitative research designs use only one data collection method, termed single-method quantitative research, while others use multiple quantitative data collection methods, known as multi-method quantitative research (Guetterman et al. 2015). The current academic advocacy for the use of multiple methods, particularly in

business management research, is based on the belief that a single method may have inherent flaws and that employing multiple methods enriches the interpretation of the data. (Bryman 2006).

Mixed methods combine quantitative and qualitative research, and scholars value their adaptability in terms of data collection and analytical capacity (Sale et al. 2002). The choice between qualitative or quantitative analysis depends on the nature of the study (Winter 2000). For instance, richly theoretical studies might leverage quantitative methods to frame theoretical propositions, while observations are often better understood using qualitative analyses to forge new theories. In mixed-methods research, there is an integration of both qualitative and quantitative methods in diverse configurations (Creswell et al. 2011). Researchers often align findings from both qualitative and quantitative data collection techniques. Some employ qualitative techniques followed by quantitative ones to build upon preliminary findings, termed an exploratory research design (Mason et al. 2010). The inverse, where quantitative techniques first followed by qualitative ones, is known as an explanatory research design (Harwell 2011).

In conducting this research, a multi-method research approach was adopted. Given the gap in understanding the factors that influence the ripple effect in the construction SMEs supply chain, the author used a qualitative approach interview to identify the contributing factors. Subsequently, through survey within AHP analysis, the identified risk factors were statistically and comparatively assessed. Finally, the thesis presents a case study to validate the impacts of ripple effects and further adopts systems thinking tools to visualise their propagation. It is worth noting that some scholars in supply chain research have also used multi-method in their studies. For instance, Luthra et al. (2022) employed multiple methods including Aggregate Hierarchical Clustering, Fuzzy Decision-Making Trial, and Evaluation Laboratory (F-DEMATEL) to examine how cross-sectoral cooperation influences circular supply chain management. Their study illustrates how the integration of complementary methods enhances analytical depth

and improves the robustness of findings. This integration not only allows for a comprehensive understanding of the factors contributing to ripple effects but also facilitates the validation and visualisation of their impacts in real-world construction SME contexts.

3.3 Selection of research strategies

The research methodology outlined in Section 3.2.3 indicates the adoption of a multi-method approach in this study, combining both qualitative and quantitative strategies. This approach enables comprehensive exploration of the limited existing literature on construction supply chains while drawing robust conclusions using diverse methods. The qualitative component comprises three methods: Interviews, survey, and case studies with system thinking tool, while the quantitative component utilises the AHP method. Detailed explanations and justifications for each of these strategies are presented in sections 3.4 to 3.6. Table 3.4 offers an overview of all methods employed. The ethical considerations for all methods are presented in Section 3.7 and Appendix A. Semi-structured interviews were first conducted to explore the causes of ripple effects in construction supply chains (RQ1). The data were analysed thematically to identify the underlying drivers of disruption, and the findings were synthesised into a integrated construction SCR map illustrating how ripple effect drivers emerge within construction SMEs.

To address RQ2, a survey was administered to gather expert evaluations of the relative importance of risk factors. The collected data were analysed using the AHP to reveal ranking disparities across the construction industry, followed by a sensitivity analysis to test the robustness of the results. For RQs 3, 4, and 5, a single case study approach was adopted to validate how ripple effects unfold and how they are mitigated in practice. Interviews with project participants provided in-depth insights into the mitigation strategies applied. Systems thinking tools were adopted to visualise ripple effects and explain in detail the mechanisms underlying their propagation and impacts.

Table 3.4: Summarised strategies adopted in the thesis

Allocated Chapter	Chapter 4: Ripple effect factor identification	Chapter 5: Impact of the ripple effect factors	Chapter 6: Case study of the ripple effect
Method	Semi-structured Interview (Section3.4) and Thematic analysis (Section 3.4.1)	Survey-AHP method (Section 3.5)	Case Study (Section 3.6)
Description	Chapter 4 identifies the sources of the ripple effect through interviews with construction industry practitioners and experts. Then thematic analysis to adopted to coding the text to generate themes.	Chapter 5 begins with the distribution of a survey designed to understand rankings of the factors influencing the ripple effect. Subsequently, the AHP method was used to identify the most important ripple effect factors in construction SMEs.	Chapter 6 involves a case study in which real companies were selected to illustrate possible mitigating measures to be taken when ripple effect influences are present in construction SMEs.
Purpose	Gather sources of the ripple effect	Priorities ripple effect factors.	Examine real-world scenarios in construction SMEs and show the ripples
Input	Literature review ripple effect factors and designed questions	Opinion on importance of ripple effect factors in construction SMEs.	Real case, data, documents, and perceived ripple effects from interview and documents
Output	Selected list of sources of the ripple effect	Importance of the factors of the ripple effect	Key events, manage strategies and visualise of ripple effect
Rationale	Interviews explore the deep-rooted causes of the ripple effect from perspective of industry practitioners, aligned with a	Surveys broaden the empirical base, while AHP enables structured prioritisation of ripple effect factors, and	Provides real-world validation of previously identified risk factors and explores how key events propagate within actual construction projects, along with mitigation strategies.

	critical realism stance. Thematic analysis allows for the identification of ripple effect factors and causal mechanisms in context.	provided different types of SMEs' perspective.	
Benefit	Allows for in-depth exploration of complex, context-specific issues. Participants can share their own insights. Thematic analysis supports theory building and captures both expected and emergent factors related to ripple effects.	Translates expert judgments into a quantitative framework, aiding strategic decision-making. Enables comparison and prioritisation of risk factors to inform targeted mitigation and resource allocation.	Develop an in-depth understanding of ripple effects in supply chains, examine disruption propagation under different scenarios, and formulate mitigation strategies. Enable the visualisation of ripple impacts on project performance, including schedule delays, quality deterioration, and cost escalation associated with materials, labour, and equipment.
Limitation	Participant responses may be influenced by individual experience and recall limitations.	AHP depends on consistent and rational judgments from participants; subjective bias may influence pairwise comparisons. Surveys may have low response rates or misinterpretation of items.	Findings may not be transferable across different construction settings.
Addressed Ripple Effect Aspect	Identification of sources, triggers, and propagation causes of the ripple effect within construction SMEs supply chains.	Prioritisation of ripple effect drivers based on their perceived importance in construction SMEs.	Event propagation patterns and mitigation strategies include how ripple effects manifest in practice and how SMEs manage or recover from disruption.

Source: The author

3.4 Interview

Interviews are designed to understand the world from a subjective perspective, enabling participants to talk about their experiences and articulate their lived reality (Brinkmann and Kvale 2015). In this study, interviews were used as a tool to explore the ripple effects in the construction supply chain. The structured literature review of construction SMEs conducted in Chapter 2 revealed that there are no existing risk factors in this review that specifically address the ripple effect faced by construction SMEs. Therefore, there is a need to identify ripple effect factors by consulting professionals and experts in construction SMEs. This approach facilitates an understanding of the risks in the construction industry that can lead to ripple effects and assesses the consistency of these risks across different construction supply chains.

The type of interview reflects the research approach. Primarily, there are three forms of interviews based on structure: Structured, semi-structured, and unstructured interviews (Qu and Dumay 2011). This research adopted the semi-structured interview format. This style combines the benefits of structure, ensuring that the interviewer remains focused on key questions to successfully cover important topics, with the flexibility to adapt the sequence of questioning (Legard et al. 2003). Moreover, a semi-structured approach not only serves the interviewer but also offers interviewees an opportunity to express concerns, provide insights, or deliberate in a structured manner (Bell et al. 2022).

Another consideration when employing interviews is the decision regarding recording and transcription. Recording offers the advantage of capturing implications in the expression of the interviewee and provides a comprehensive record for subsequent analysis (Bolderston 2012). However, a potential drawback is that it might make the interviewee uncomfortable or reserved. To mitigate this, the strategy employed for this study involves sending the primary discussion questions to the interviewee in advance, with an assurance that the conversation will revolve around these focal points.

Figure 3.1 depicts the core framework used for the semi-structured interviews. Prior to the formal interviews, a pilot study was conducted to validate the appropriateness of the interview questions and to effectively manage the time and contributions of the interviewers (Majid et al. 2017). Before the interview, the author emphasised that the interviews were audio-recorded and that interviewees could opt out at any time. The content of the interview data is kept confidential and stored in a secure location. The interview questions are shown in the Appendix B.

The interview questions were developed based on insights derived from the structured literature review presented in Chapter 2, particularly studies on supply chain risk, disruption, and ripple effect mechanisms. The review revealed that, although ripple effects have been widely discussed in general supply chains, there is no systematic identification of risk factors within the context of construction SMEs, which directly relates to RQ1. In addition, the interview design was informed by the existing framework proposed by Duong et al. (2023). Rather than testing predefined assumptions, the interview questions adopted an open-ended approach to capture practitioners' experiences of disruptions, their perceived causes, and how these events propagated across project stakeholders. This exploratory design enabled the identification of potential factors that may trigger ripple effects within construction SME supply chains.

The interviews were conducted with a purposive sample of construction SMEs based in China, selected according to their project experience, organisational size, and involvement in multi-tier supply chain activities. Initial participants were identified through established industry and professional networks to ensure representation from firms with substantial operational visibility and experience within the sector. The sample was subsequently expanded using a snowball sampling approach, whereby initial interviewees recommended additional participants with relevant experience in supply chain management and risk handling. This approach facilitated preliminary

screening of targets, enhancing the quality of the interviews and broadening the network of contacts. The author conducted the online interviews with the target companies in Chinese, ensuring all interviews were audio-recorded with the consent of interviewees. After these interviews, the recordings were translated from Chinese to English using the online translation service DeepL. While DeepL was used for translating interviews conducted in Chinese, steps were taken to safeguard translation accuracy and participant confidentiality. These included participant consent updates, selective back-translation, and bilingual review of key extracts. Additionally, all the documents were maintained to track translation challenges, ensuring transparency in data handling.

The interviews were conducted with a purposive sample of 25 construction based in China, selected according to their project experience, organisational size, and degree of involvement in multi-tier supply chain activities as shown in Table 3.5. A purposive approach was appropriate because it allows the deliberate inclusion of participants who possess specific knowledge relevant to the research focus (Ahmad and Wilkins 2025). The sample size of 25 is consistent with established qualitative research standards, which suggest that data saturation in semi-structured interviews is often achieved between 20 and 30 participants, depending on the complexity of the topic and diversity of perspectives (Islam and Aldaihani 2022).

Of the 25 organisations involved in the construction SME supply chain, 16 were identified as construction SMEs, including main contractors, subcontractors, and suppliers. Additionally, there were two agencies, four supervisors from companies and government departments, and three large construction companies. The working experience ranged from 2 to 34 years, with an average of 12.6 years. The length of the interviews ranged from 24 to 48 minutes, with an average of 33.3 minutes. The number of employees in the companies ranged from 2 to 4,300, with a median of 30.

To capture the diversity and interdependence characteristic of construction supply chains, the sample included a mix of small, medium, and larger firms. This diversity

enabled comparative analysis of how firm size influences exposure to ripple effects. Participants were drawn from various sectors within the construction industry, including general contracting, design, materials supply, and project management, reflecting the multi stakeholders and cross-functional nature of construction projects. Such variation allows the identification of both firm-specific and systemic factors driving disruption propagation (Park et al. 2022). To mitigate potential respondent bias, participants were selected from diverse organisational levels and functional roles, including managerial, technical, and supervisory positions. Triangulation was also applied by comparing responses across different participant categories (e.g., SMEs, agencies, and large contractors) to identify consistent themes and reduce reliance on individual perspectives.

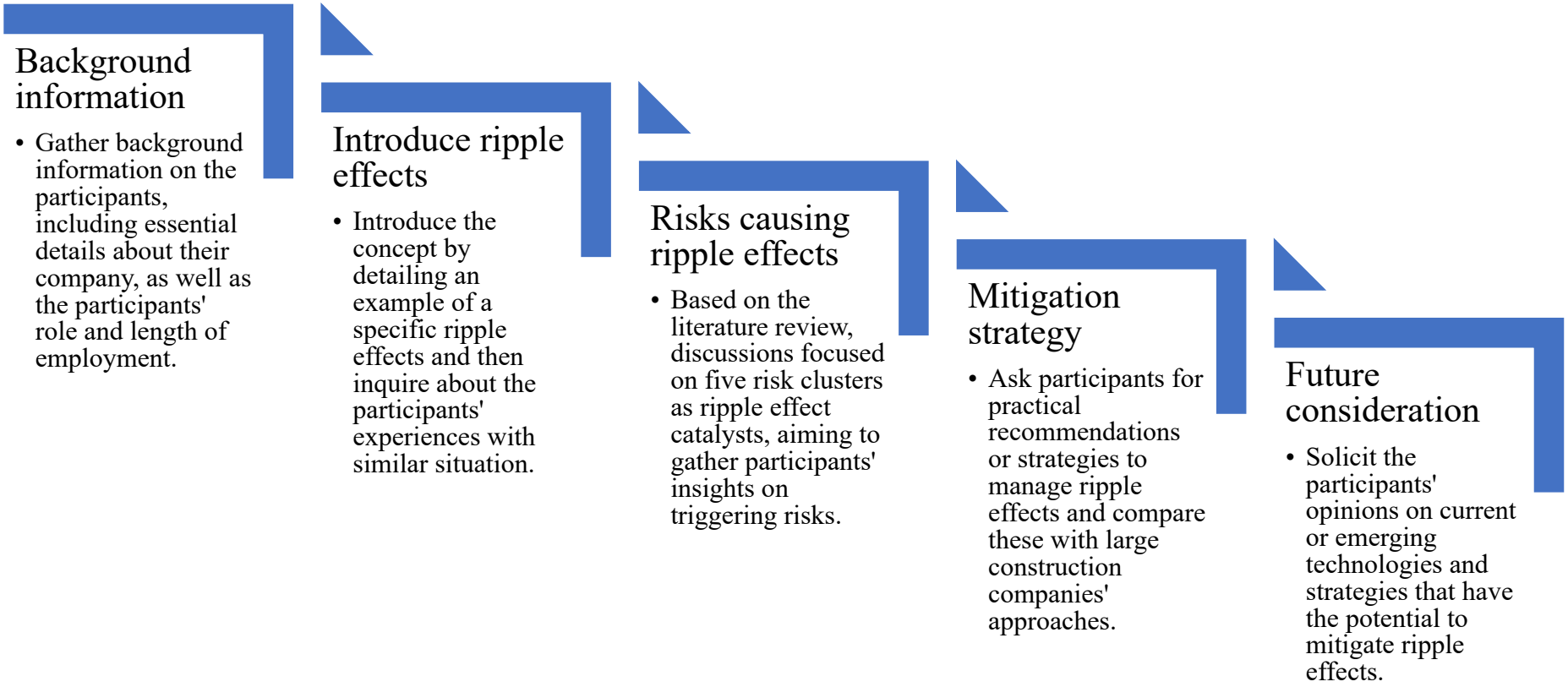


Figure 3.1: Interview procedures

Source: The author

Table 3.5: Interviewees information

ID	Supply chain role	Project type	Organizational role	Working experience (Years)	Interview length (Minutes)	Number of employees
62701	Agency	Government Apartment	Project manager	20	36	N/A
62702	Contractor	Bank renovation	Project manager	25	34	30
62703	Manufactory; Contractor	House customization	Owner	5	33	20
62704	Building supervision	Building inspector	Supervisor	3	41	300
62705	Supplier	Cable company	Sales	12	34	4300
62706	Supplier	Concrete supplier	Manager	34	32	300
62707	Supplier	Concrete Mixing Plant	Site crew	15	25	30
62708	Sub-contractor	Construction company	Owner	21	24	30
62709	Contractor	Housing construction	Cost control	20	48	1200
62710	Supplier	Equipment rental	Owner	15	32	10
62711	Supplier	Fly ash supplier	Owner	15	37	5
62712	Government	Government supervision	Site supervision	2	33	N/A

62713	Government	Government supervision	Marketing executive	10	34	N/A
62714	Sub-contractor	Construction company	Owner	14	36	20
62715	Sub-contractor	Wall construction	Owner	24	29	20
62716	Contractor	House customization	Owner	4	30	5
62717	Contractor	House renovation	Owner	7	36	2
62718	Contractor	House design	Owner	15	29	10
62719	Contractor	Housing construction	Project manager	9	32	40
62720	Contractor	Housing reconstruction	Site crew	3	32	2000
62721	Sub-contractor	Construction company	Technique Manger	4	41	80
62722	Contractor	Restaurant renovation	Owner	24	42	4
62723	Agency	Research institute construction	Project manager	6	35	300
62724	Supplier	Tile manufactory	Owner	20	31	100
62725	Contractor	Tunnelling construction	Cost control	6	31	60

Source: The author

3.4.1 Thematic analysis

In analysing the interview transcripts, the author adopted thematic analysis, a method for identifying, analysing, and reporting themes in the data (Braun and Clarke 2006). Given that the interviews were semi-structured and focused on different SCR themes, NVivo was used to provide a comparative analysis of the risk themes identified in each session, reflecting the different perspectives of the various supply chain roles. The Appendix B shows the NVivo word frequency and clouds base on the interview. In term of the thematical process, there are six steps in thematic analysis: (1) Familiarising with the data (2) Generating initial codes (3) Searching for themes (4) Reviewing themes (5) Defining and naming themes (6) Generating reports (Braun and Clarke 2006). The following paragraph detailed each of the process.

Step 1: Familiarising with the data

In the step 1, the interview transcripts were meticulously transcribed verbatim and reviewed repeatedly. This repeated engagement allowed the author to immerse thoroughly in the data, recording preliminary notes and reflections, such as identifying explicit financial constraints or contractual complexities highlighted by interviewees.

Step 2: Generating initial codes (Open Coding)

Through open coding, the relevant excerpts were carefully identified and labelled to capture direct meanings explicitly expressed by participants. These initial codes, such as ‘Advance funds for the project,’ ‘Delay in wage payment,’ and ‘Contractual ambiguity,’ were generated without interpretive grouping at this stage, ensuring an unbiased representation of participants statements.

Step 3: Searching for themes (Focused Coding)

These initial codes were then subjected to focused coding, in which related open codes were grouped based on thematic similarities. This process enabled the identification of clear patterns within the data. As a result, preliminary themes such as Financial Risks,

Safety Risks, Contractual Risks, and Design Risks emerged, each corresponding to the specific types of risks articulated by the interviewees.

Step 4: Reviewing themes

These preliminary themes were rigorously validated and refined. Codes within each theme were reviewed for internal coherence and external distinctiveness. This iterative verification ensured each theme accurately represented coherent sets of risks. For instance, the theme Contractual risks were refined by closely evaluating codes such as 'Failure to perform an obligation' and 'Contractual ambiguity' to ensure thematic consistency.

Step 5: Defining and naming themes

Each theme was explicitly defined to precisely represent its underlying patterns. The themes were labelled as Financial Risks (Economic pressures and constraints), Safety Risks (Worker's safety and logistic reliability), Contractual Risks (Ambiguities and unmet obligations), and Design Risks (Issues from flawed designs and miscommunications). Each definition clarified the essence of the theme, providing robust analytical clarity.

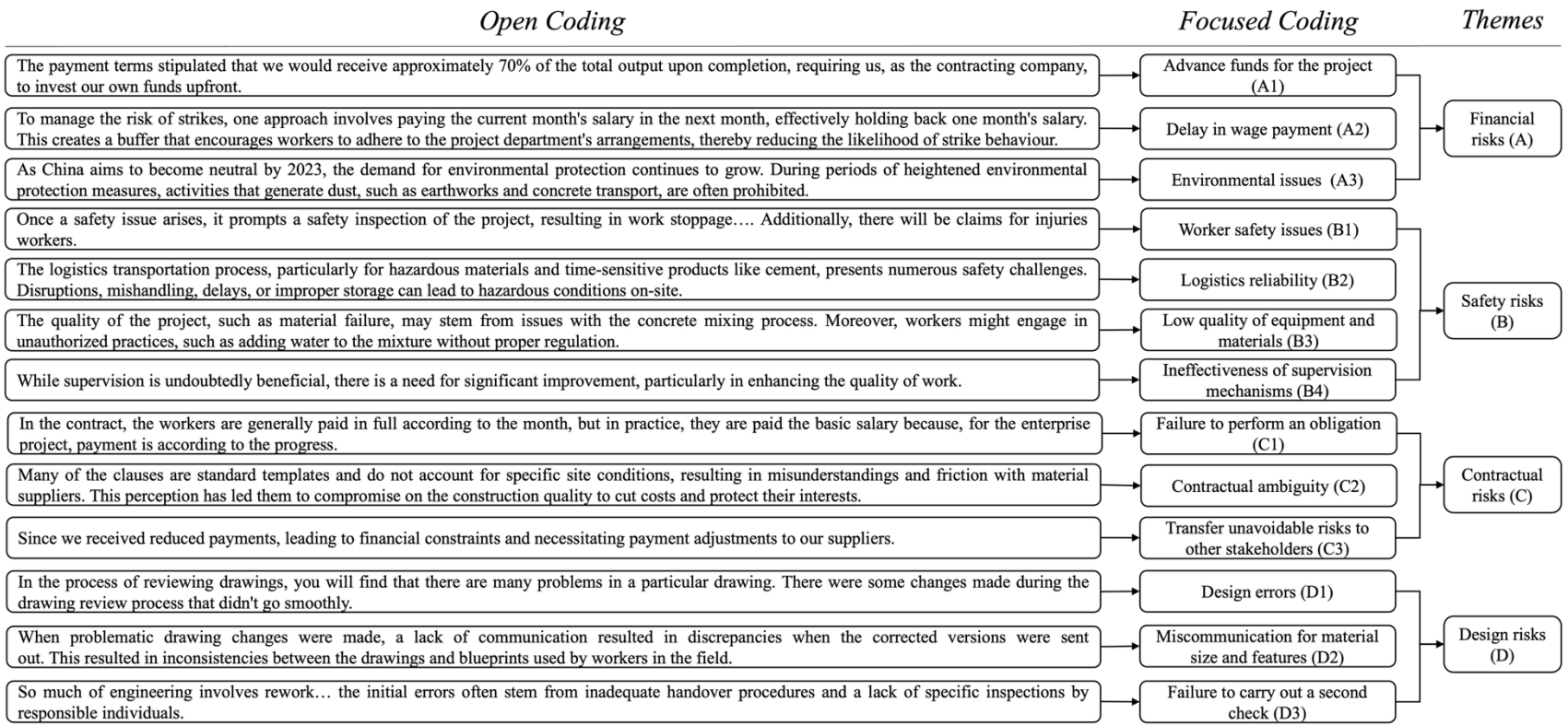
Step 6: Producing the report

The analysis culminated in an integrated narrative linking identified themes directly to the research objectives regarding ripple effects in supply chains as shown in Table 3.6. The final report employed direct participant quotations and visualizations to substantiate thematic insights, offering a comprehensive discussion of how financial, safety, contractual, and design risks propagate throughout construction SMEs supply chains.

In open coding, the codes reflected the language that participants initially used when describing their experiences of supply chain risks. For example, a subcontractor mentioned, "*When material deliveries are delayed, our workers have to wait on site doing nothing, but we still need to pay them every day*."

In the second stage, focused coding was conducted to develop connections between first-order concepts, synthesising and interpreting large volumes of interview data. For instance, the above statement was categorised under the concept of financial pressure caused by delivery delays and subsequently grouped into higher-order themes such as financial vulnerability and project delay risks. Finally, the author identified overarching themes representing the ripple effects of supply chain disruptions in construction SMEs. This iterative and recursive analytical process continued until the emerging theoretical concepts were fully understood and theoretical saturation was achieved (Gioia et al. 2013; Roeth et al. 2019).

Table 3.6: The coding process of the thematic analysis



Source: The author

3.4.2 Root cause analysis

Root cause analysis (RCA) is a diagnostic tool used by academics and practitioners to identify the fundamental causes of problems, thereby enabling the development of strategies to prevent their recurrence (Andersen and Fagerhaug 2006). RCA is widely applied across various industries, including construction, manufacturing, and healthcare (Peerally et al. 2017). For instance, in the construction sector, equipment malfunction may initially be attributed to poor maintenance. However, a deeper RCA might reveal that the true underlying issue is the absence of a systematic monitoring mechanism for routine servicing. While immediate causes often provide short-term fixes, failure to address the root cause increases the likelihood of problem recurrence. Thus, effective problem-solving requires interventions that target both the symptoms and their underlying causes (Rosenfeld 2014).

Scholars have proposed and employed a range of RCA techniques. Common approaches include Ishikawa (fishbone) diagrams, matrix diagrams, Pareto charts, and the widely adopted 5 Whys technique (Serrat and Serrat 2017; Suárez-Barraza and Rodríguez-González 2018). For instance, Al-Zwainy et al. (2018) used Ishikawa diagrams, Pareto analysis, and the 5-Whys to identify and diagnose 35 root causes of failure in construction projects. Furthermore, the methodology has evolved over time; Gangidi (2019) expanded the traditional 5-Whys by introducing a 3 × 5 Whys framework that integrates three analytical layers: the event itself, human factors, and systemic issues. Despite the growing use of RCA in construction research, its application has not been sufficiently tailored to the context of construction SMEs.

Budling on Desai et al. (2015) who applied fishbone diagrams to map supply chain risk causes, and drawing inspiration from applications in construction claims, this study employs RCA to systematically investigate the underlying causes of risks faced by construction SMEs, as identified through interviews. This analytical tool facilitates the structured organisation of problem-solving efforts by categorising the potential drivers of risk-related issues. In this thesis, the RCA is applied to the qualitative interview data

to trace the root causes of risk events across four principal risk categories: Financial, safety, design, and contractual risks, as experienced by various types of construction SMEs. The RCA process enables the identification of both immediate and underlying factors contributing to these risks, supporting a clearer understanding of their propagation mechanisms within the construction supply chain. The four steps are shown in the following paragraph.

Step 1: Define the problem

Begin by identifying the primary problem, placing it on the far left of the diagram with a central arrow pointing toward it. In this study, the core issue is the key risks faced by construction SMEs. For instance, one immediate manifestation of financial risk is the need for advance payments for materials, labour, or equipment leases, which can cause significant cash flow challenges.

Step 2: Identify major contributing categories

The core risk categories identified through the interviews in this study include financial, safety, design, and contractual risks. Drawing upon insights from both the literature and empirical data, the analysis further identifies the key factors influencing these risks. For example, the coding of interview data was used to distil the underlying causes within each risk category: Payment delays, worker safety, design errors, and vague contract terms.

Step 3: Analyse sub-causes through expert input

Following the initial coding process, the author engaged a panel of experienced practitioners and interview participants in a structured brainstorming during the interview in to validate and refine the preliminary Diagrams. Using the 5-Whys technique, each major risk category (financial, safety, design, and contractual) was examined to trace underlying causal chains and align the findings with existing literature.

Step 4: Construct and Interpret the Diagram

After identifying all relevant causes, construct the full fishbone diagram to visually map out the hierarchy of causes leading to the central problem. This diagram illustrates both the primary and underlying causes of financial, safety, design, and contractual risks. The completed diagram offers a comprehensive view of risk propagation in the construction SME supply chain, facilitating both diagnosis and targeted mitigation strategies.

3.5 Survey with AHP method

A survey integrated with the AHP method was employed as data collection technique. (Singh and Nachtnebel 2016). The survey aimed to collect primary data through questionnaires. The decision to use a survey stemmed from the findings of the structured literature review in Chapter 2. Additionally, interviews revealed that the importance of the factors contributing to the ripple effect varies across different construction supply chain contexts. Therefore, the author decided to explore this issue through a survey, incorporating the AHP method into the questionnaire as a basis for judgment. This approach was chosen due to the limited availability of empirical studies and data on SMEs in the construction industry (Rao et al. 2023). Purposive sampling was employed to collect data from a targeted group of construction SMEs in China, selected for their direct involvement in multi-tier supply chain activities and experience in managing related risks. This sampling method has a long history in supply chain research (Chang et al. 2007; Tieman 2011) and is designed to align with the RQ 2 of the study. Since specific individuals may hold distinct and valuable perspectives on the topics under investigation, purposive sampling is particularly well suited to the segmentation approach applied to construction SMEs in this study.

Questionnaires have long been the popular methodology for business management research (Clark et al. 2021). Questionnaires are designed to allow researchers to obtain necessary responses in a structured format from real-life scenarios (Mathers et al. 1998). One of the advantages of questionnaires is that they are not geographically restricted (Fowler 2014). With the help of the Internet, data can be collected almost anywhere,

regardless of population area. Additionally, the absence of an interviewer allows respondents to decide for themselves whether to answer, thus reducing the possibility of bias (Allan and Skinner 2020). Finally, the questionnaire offers a high degree of flexibility, reducing data bias and facilitating statistical analysis by incorporating the data needed for the AHP method into the questionnaire.

Table 3.7 provides an overview of alternative tools and techniques that could be applied in the ripple effect context and their adaptation. It is worth noting that although the AHP methodology has evolved since its inception, this study applies AHP to prioritise risk factors rather than to model multi-level managerial decision structures within organisations. Therefore, the AHP method is appropriate for this study. Additionally, numerous studies have adopted the AHP approach in their research. For example, Ciceri et al. (2025) employed an AHP approach to prioritise risks in 15 pharmaceutical supply chains from literature review. Their work aimed to highlight the need for more collaborative and systematic risk management in the pharmaceutical supply chain.

In the context of this research, the AHP methodology offers several advantages for the analysis of construction SMEs. First, it allows for integration into questionnaire-based research, combining both qualitative data (e.g., assessments by participants, business size, and number of employees) and quantitative data (e.g., pairwise comparisons of factors influencing ripple effects) (Luthra et al. 2016). Second, AHP ensures that the analysis reflects a diversity of perspectives by enabling stakeholders to assign relative importance to different criteria (Gaudenzi and Borghesi 2006; Kwatra et al. 2021). Third, it facilitates sensitivity analysis and testing, which are crucial for understanding how changes in one factor (e.g., advance funding) can trigger ripple effects in other areas (e.g., safety risk, design risk). This is particularly valuable for SMEs that anticipate and manage risks effectively. Finally, AHP has been widely applied in construction management research to address complex, multidimensional problems, further demonstrating its suitability for this study (Singh 2013; Kumar and Kansara

2018). Figure 3.2 illustrates the general AHP process, with the four steps of the unpacking process described below.

Table 3.7: AHP method justification

Method	AHP	ANP	Fuzzy AHP	TOPSIS	DEMATEL	BWM
Concept	A hierarchical decision-making method using pairwise comparisons to determine criteria weights (Saaty 1990).	An extension of AHP that considers interdependencies among criteria (Meade and Sarkis 1999).	Introduces fuzzy logic to AHP, handling uncertainty and ambiguity in decision-making (Mangla et al. 2015).	Rank and select the best alternative from a set of options based on their distance to the ideal solution and negative ideal solution (Kim et al. 1997).	Analyses causal relationships between factors to identify key factors (Gandhi et al. 2015).	A straightforward method based on pairwise comparisons using the best and worst criteria to assign weights (Rezaei 2015).
Advantages	Simple and easy to use, suitable for well-structured problems.	Suitable for complex systems, capable of handling interdependencies among criteria.	Effectively handles fuzziness and uncertainty, enhancing judgment reliability.	Easy to compute and suitable for handling many alternatives.	Identifies causal relationships and analyses factor propagation paths and ripple effects.	Simple judgment process that reduces subjective bias, ideal for weight assignment.

Disadvantages	Assumes criteria independence, struggles with complex interdependent systems.	Computationally intensive, leading to high matrix complexity.	Application of fuzzy logic increases computational complexity and subjectivity.	Limited in handling complex interrelationships among factors.	Requires extensive data and is computationally complex.	Suitable for fewer criteria and challenging to scale to multi-level systems.
Applicable to ripple effect	Yes, it is widely used in supply chain. Also, the study aims to select the most important case and then conduct case study.	No, the alternatives level was not considered in this study. Considering multi-factor interactions reflect on the questionnaire which increases the difficulty for respondents.	Possible, however fuzzy answer scales increase uncertainty. Fuzzy AHPs are designed to deal with multiple environments and fuzzy situations.	Possible, TOPSIS focuses on prioritizing require more calculation compares to AHP. Also, it more suitable for situations where the alternatives are independent.	No, causal relationships were analysed using root cause analysis, yielding results that were not restricted to predefined ripple effect criteria.	Possible, however BWM applies to a smaller number of participants and standards.

Source: The author

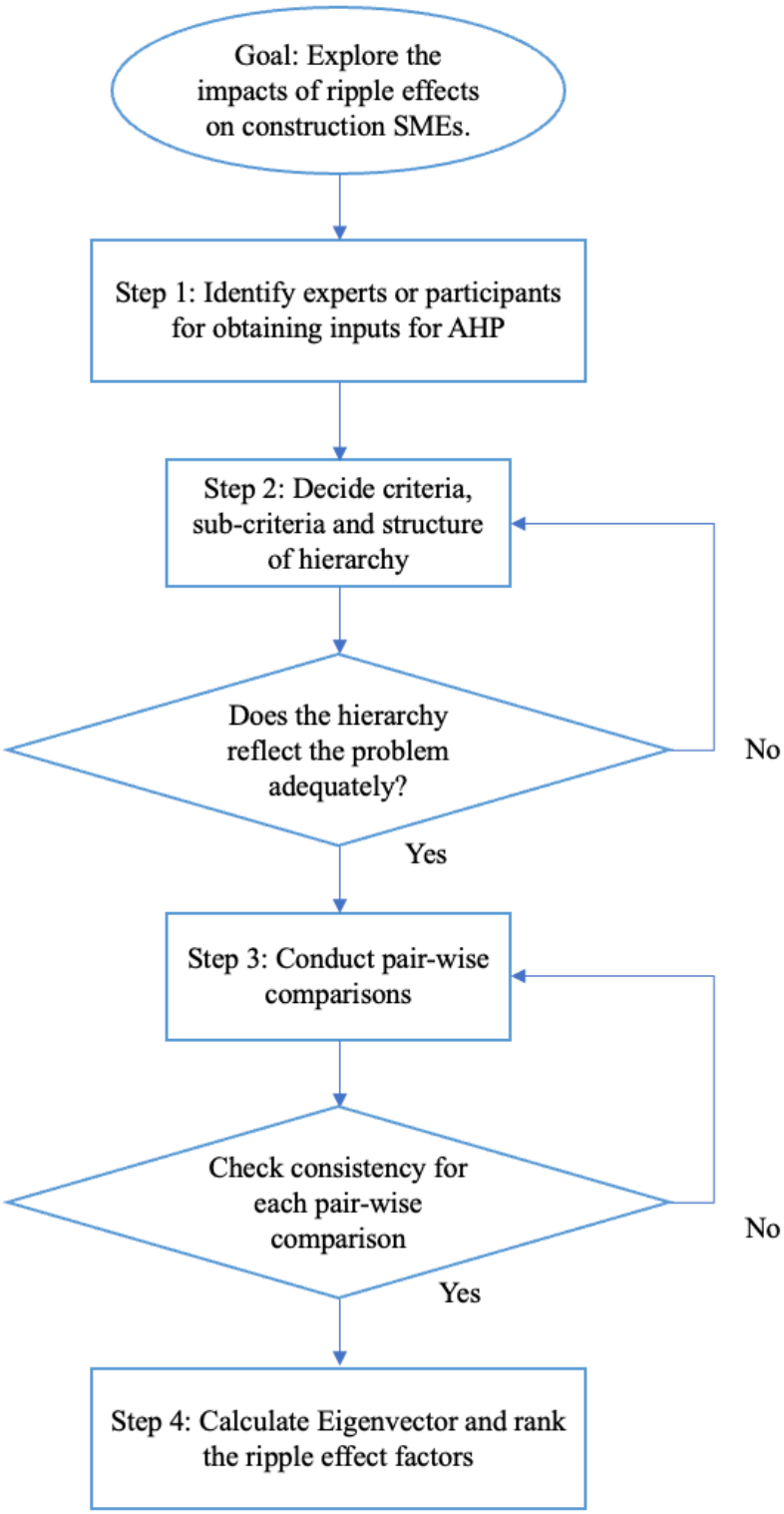


Figure 3.2:AHP process

Source: The author, adapted from Thakkar (2021)

3.5.1 Step 1: Identify experts or participants for obtaining impacts for AHP

The questionnaire incorporated the AHP methodology to examine four risk themes and their associated factors, which were identified through thematic analysis of the interview data and subsequently adopted as the structure of the AHP hierarchy. Participants were selected from different tiers of the construction supply chain, including main contractors, subcontractors, suppliers, and project supervisors, to capture a diversity of professional perspectives while maintaining relevance to the research focus. This approach was intended not to achieve statistical representativeness, but rather to ensure that the data reflected information-rich cases capable of providing valid judgments for pairwise comparisons within the AHP model.

An additional section of the questionnaire collected background information on field of work of the respondents, organisational role, and years of industry experience, allowing subsequent analysis to explore variations in judgment patterns across respondent groups. The questionnaire was initially written in English, translated into Chinese by the author (a bilingual researcher), and then back translated to English to ensure linguistic accuracy. The questionnaire was then converted into an online format and distributed to potential respondents through professional and industry-related social media platforms that cater to the Chinese construction sector. Snowball sampling strategies were employed to ensure that participants were individuals with direct involvement in construction supply chain activities and decision-making related to project risks. Initial invitations were sent to professionals identified through the existing network of industry and their associations, and these participants were encouraged to share the link with colleagues who met the inclusion criteria.

Of the 470 responses received, only 240 passed the initial screening, while the remaining questionnaires were excluded due to missing or invalid answers. The respondents represented various departments, including production, finance, sales, engineering, and management. Their professional experience ranged from 5 to 40 years, and the surveyed companies employed anywhere from a single employee to tens of

thousands. After conducting data validity checks, the author finalised a sample of 54 experts, selected according to the definition of construction SMEs and departmental criteria. The selection process is illustrated in Figure 3.3.

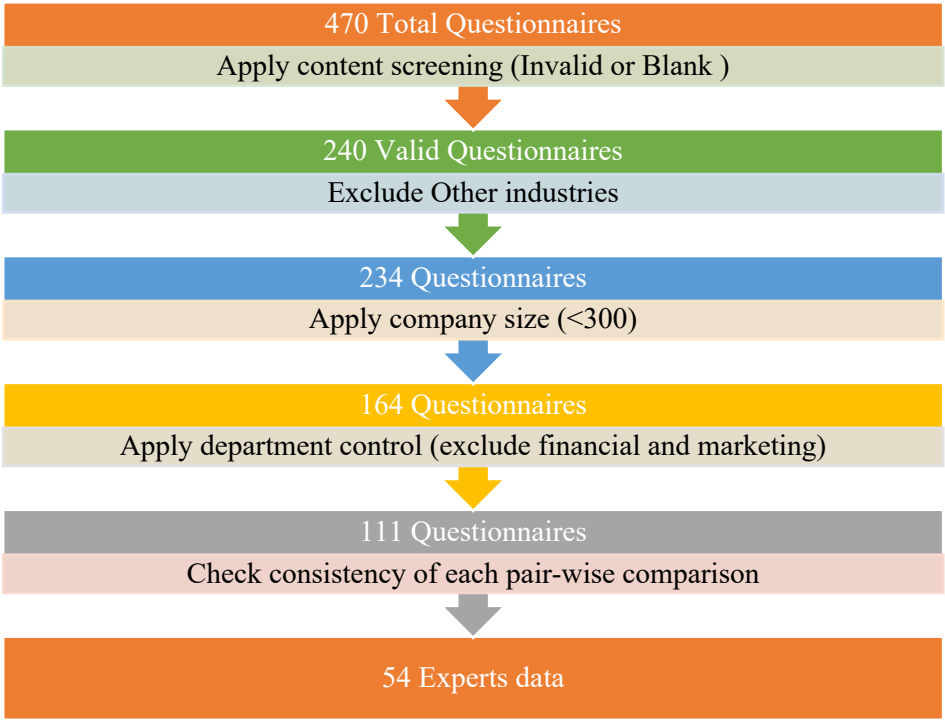


Figure 3.3: Experts survey screening process

Source: The author

3.5.2 Step 2: Decide criteria, sub-criteria, and structure of hierarchy

Based on the interview and thematic analysis, this thesis identifies four key risks that trigger ripple effects and 13 associated risk factors. Using the AHP method, these risks are structured into criteria, sub-criteria, and a hierarchical framework, as shown in Table 3.8. In this hierarchy, financial risk, contractual risk, and design risk each contain three sub-criteria, while safety risk includes four sub-criteria. According to the requirements of the AHP methodology, at least two sub-criteria are necessary for pairwise comparisons (de FSM Russo and Camanho 2015). The hierarchical structure developed in this study satisfies these requirements, enabling pairwise comparisons to be conducted in the next step.

Table 3.8: Hierarchical structure for construction SMEs ripple effect

Objective	Criteria	Sub-Criteria
Examine the ranking of risks that trigger ripple effects within the segmented supply chains of construction SMEs	Financial risks(A)	Advance funds for the project (A_1)
		Delay in wage payment (A_2)
		Environmental issues (A_3)
	Safety risks (B)	Worker safety issues (B_1)
		Logistics reliability (B_2)
		Low quality of equipment and materials (B_3)
		Ineffectiveness of supervision mechanisms (B_4)
	Contractual risks (C)	Failure to perform an obligation (C_1)
		Contractual ambiguity (C_2)
		Transfer unavoidable risks to other stakeholders (C_3)
	Design risks (D)	Design errors (D_1)
		Miscommunication for material size and features (D_2)
		Failure to carry out a second check (D_3)

Source: The author

3.5.3 Step 3: Conduct pair-wise comparisons

The questionnaire was designed to incorporate the AHP method throughout the survey process. Saaty (1990) introduced the AHP method, which uses pairwise comparisons to assess the significance of factors at the same hierarchical level, as shown in Table 3.9. The AHP scale consists of nine grades, where values 9, 7, 5, 3, and 1 represent varying degrees of importance, ranging from 'extreme' to 'equally important.' Intermediate values (8, 6, 4, and 2) indicate importance levels that fall between two adjacent categories.

Table 3.9: 1-9 Fundamental scale for pairwise comparison

Priority intensity	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective

2		Weak or Slight
3	Moderate Importance	Experience and judgement slightly favour one activity over another
4		Moderate Plus
5	Strong Importance	Experience and judgement strongly favour one activity over another
6		Strong Plus
7	Very Strong	An activity is favoured very strongly over another
8		Very, very Strong
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Source: Saaty (1990)

Based on the questionnaire screening process, Table 3.10 presents a set of criteria developed by one expert through four risk comparisons. Once the pairwise comparisons of risk factors are completed, the next step involves determining their weights and verifying the validity of the comparisons.

Table 3.10: Example of pair-wise comparisons for criteria

Ranking ripple effect factors	A	B	C	D	w_i
A	1	1/5	1/3	1/4	0.0699
B	5	1	4	3	0.5376
C	3	1/4	1	1/2	0.1493
D	4	1/3	2	1	0.2430
CR=0.04≤ 0.1 λ_{max}=4.11					

Source: The author

3.5.4 Step 4: Calculate Eigenvector and rank the ripple effect factors

The final step in the AHP process is to determine the weights of the components, specifically by calculating eigenvector values. In this thesis, the eigenvector method is applied to assess the risk importance for construction SMEs. This step is implemented using Yaahp version 3.0, a widely used AHP calculation software in supply chain

research and other fields (Zhu 2022). In addition to calculating eigenvectors, an essential step in the AHP process is the consistency test, which evaluates whether expert judgments are reasonable. This is determined by measuring the consistency ratio (CR) of each matrix, where a CR value of $\leqslant 0.1$ is considered acceptable. A higher CR suggests the need for the decision-maker to revise their judgments (Chang et al. 2007). Since this study employs a multi-expert decision-making model, the validity of each matrix is assessed using a composite CCR, which is weighted by the CR of each expert. A CCR of $\leqslant 0.10$ is generally regarded as valid (Sadiq and Tesfamariam 2009).

One of the key advantages of the AHP method is its ability to synthesize the perspectives of interviewees (Sipahi and Timor 2010). The AHP-based questionnaire is designed to be clear and straightforward, presenting respondents with a precise numerical format, with questions arranged in a transparent and pre-determined order. Churchill and Iacobucci (2002) developed procedure for questionnaire as show in the Figure 3.4. As noted by Badea et al. (2014) this approach is particularly effective when prioritising and evaluating options or converting subjective data into a quantifiable form. Since this study involves input from multiple experts, the process begins by categorising them according to their backgrounds. Their assessments are subsequently aggregated, with arithmetic averaging applied to determine the final importance ranking of ripple effects across different segments of construction SMEs.

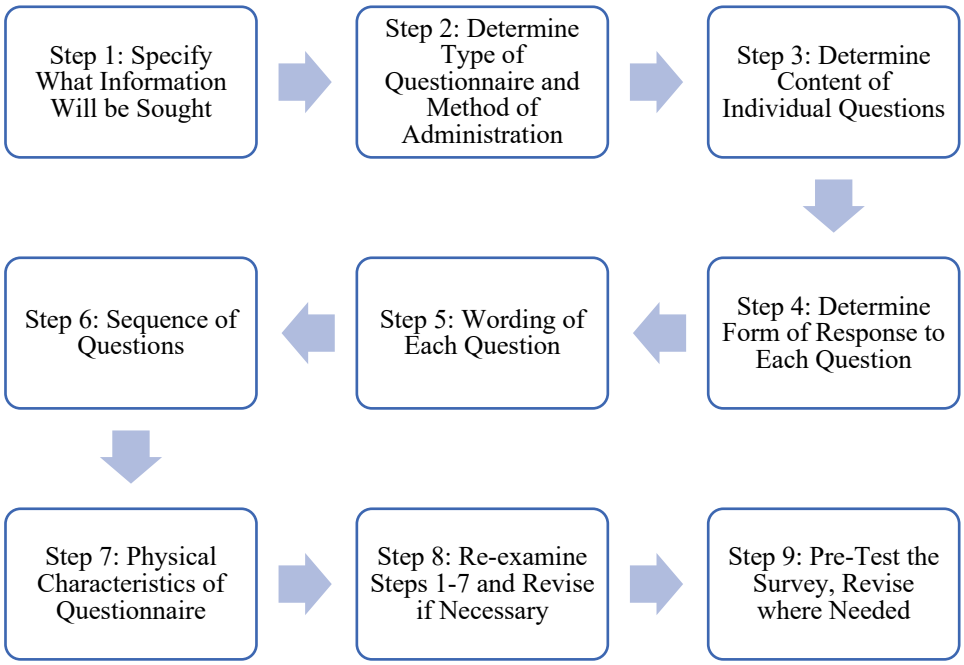


Figure 3.4: Questionnaire design procedure

Source: (Churchill and Iacobucci 2002)

Step 1: Determining Information Needs

The focus of this thesis is to explore the ripple effects in the supply chains of construction SMEs. Therefore, it is crucial to contextualise the construction SMEs and investigate the factors causing the ripple effect. Consequently, the questionnaire is divided into two parts: the first part focuses on categorizing construction SMEs, and the second part prioritise the ripple effect factors.

Step 2: Designing the Questionnaire

The type of questionnaire selected was a semi-structured questionnaire, incorporating both multiple-choice and fill-in-the-blank questions. Respondents were informed about the purpose of this questionnaire, the collection team, and the method for the objectives, data storage, and accessibility. Additionally, respondents were informed of their rights, including the ability to opt out at any time.

Step 3: Determining the questionnaire content

The questionnaire first included four fill-in-the-blank sections to collect basic information about the respondents, such as their industry, department, years of experience, and company size, to identify whether the background is in construction SMEs. Secondly, based on the identified supply chain ripple effect factors of construction SMEs, the scoring model of the AHP method was converted to collect the impact scores of respondents on different ripple effect factors.

Step 4: Formatting the responses

The 21 questions were presented as multiple-choice questions, except for the four fill-in-the-blank sections. Participants were able to compare two factors and make a choice based on the subjective opinions. This format enabled the author to compare and analyse the different factors effectively.

Step 5: Checking each question

Each question was checked in detail, including its spelling, possible variants, and explanations of some terminology to ensure the generality of the questionnaire. Each of the risks involved was explained in detail, ensuring there were no biased words.

Step 6: Structuring the questionnaire

The author helped the participants understand the background and content of the questionnaire by explaining in detail the four fill-in-the-blank questions. In the multiple-choice section, participants were guided through the questionnaire by highlighting key questions, especially at the beginning, to show the influencing factors of the overall ripple effect and provide examples.

Step 7: Modifying the questionnaire features

The questionnaire used in this thesis is an online questionnaire. Therefore, this study focused on the readability of the questionnaire on different devices used by participants. Tests were conducted on computers (Mac and Windows) and mobile phones to determine the completeness and operability of the questionnaire.

Step 8: Reviewing the steps

To ensure the feasibility of the questionnaire, a pilot study was conducted. The format, content, and order of the questionnaire were modified three iterations based on feedback from participants using different devices.

Step 9: Pre-testing the questionnaire

During the formal data collection process, no significant issues with the questionnaire were encountered, apart from those identified during the pilot study. Moreover, when the questionnaire was distributed to construction SMEs, it effectively captured responses from relevant groups within the sector. The details of the questionnaire are provided in Appendix C.

3.6 Case study

A case study approach serves as a methodological tool designed to provide a comprehensive and in-depth analysis of specific instances, events, or circumstances (Walsham 1995; Baxter and Jack 2008; Yin 2009). Case studies are inherently meticulous, synthesising evidence from multiple sources to construct a rich and comprehensive understanding (Van Lier 2005). This approach is especially effective when exploring complex, real-world phenomena within their natural contexts, making it a particularly fitting choice for business research (Eisenhardt and Graebner 2007). Given the unique challenges and complexities inherent in analysing such effects, the case study methodology proved particularly suitable. As advocated by Yin (2009), case studies are optimal for addressing ‘how’ and ‘why’ questions, particularly when the events are contemporary and the researcher adopts an observational role rather than an active one.

The case study approach, deeply embedded in operations research and supply chain fields, serves as a robust methodological tool for both elucidating real-world challenges and empirically validating theoretical frameworks (Binder and Edwards 2010; Melnyk et al. 2018; Russo et al. 2024). For instance, Ngo et al. (2023) examined 923

Vietnamese enterprises to investigate the differences in the drivers of digital supply chain transformation between SMEs and large enterprises. The study provided empirical evidence highlighting how environmental dynamism, technological advancement, and organisational capabilities jointly influenced digital transformation processes during the pandemic period. Furthermore, Shen and Sun (2023) analyses the impact of the COVID-19 on supply chain resilience, highlighting the challenging scenarios faced by retail supply chains in China through single case study.

Single Case Study

Academics have long debated the optimal number of cases to include in research. A single case study offers the opportunity for an in-depth, context-rich exploration, frequently resulting in nuanced, detailed, and refined theoretical insights (Dyer Jr and Wilkins 1991; Yin 2009; Gustafsson 2017). Conversely, multiple case studies, encompassing diverse scenarios, provide broader perspectives and greater generalizability. However, this approach typically requires significantly more resources, time, and effort (Gerring 2004; Baxter and Jack 2008). Currently, in the field of supply chain research, many scholars adopt a single case analysis approach across various industries, including pharmaceuticals, food, and construction (Haszlinna Mustaffa and Potter 2009; Nasir et al. 2017; Oyedijo et al. 2024).

In this research, the choice of a single case study involving renovation SMEs was deliberately made to leverage specific advantages inherent to this approach. The selection of a single, clearly defined project, a 41-days renovation of a phone store, enabled a deep and focused analysis of ripple effects within the construction SME context. This single case was purposefully selected based on several critical considerations: it provided readily accessible, real-world data and drew on existing familiarity with the operational dynamics of the construction industry and the typical challenges encountered in renovation projects. Additionally, the relatively short duration of the renovation project, in comparison to longer projects common in housebuilding or extensive supplier arrangements (Allen et al. 2017), enabled a more

immediate and tangible assessment of risks such as project delays and associated financial implications.

Furthermore, the single case approach allowed the researcher to gain richer insights into the practical interactions between key supply chain stakeholders, including supervisors, suppliers, clients, contractors, and designers. Direct access to these stakeholders and their explicit experiences through focused interviews significantly strengthened the empirical robustness of the research findings. Consequently, this methodological choice facilitated a thorough examination of the identified risks, financial, safety, contractual, and design, provided deeper insights into the mechanisms underpinning ripple effects in the construction SME supply chain context.

Given the holistic and interconnected nature of the RQs, particular emphasis has been placed on ensuring the reliability and validity of the research design. Reliability and validity are addressed by implementing systematic data collection procedures and maintaining accurate documentation throughout the research process, thereby ensuring that the findings accurately reflect the phenomena under investigation. This study draws on the experiences of construction SMEs, which represent a significant portion of the broader construction industry. However, it is acknowledged that concluding these findings to larger construction entities may yield different insights.

Section 3.6.1 discusses the issues of validity and reliability associated with the case study design, ensuring that the research follows rigorous academic standards. Section 3.6.2 interprets the unit of analysis, detailing the specific phenomena under investigation to contextualize the research. Section 3.6.3 explains the data collection and analysis methods, emphasising the integration of interviews and observational techniques to triangulate findings and enhance the robustness of the study. Section 3.6.4 further discusses the systems thinking approach applied within the case study, explaining how ripple effects are identified and validated, and providing a worked example to illustrate the analytical process.

3.6.1 Validity and reliability of the case study

While case studies have become a prevalent research methodology in the supply chain field, they have also faced criticism, particularly regarding the robustness of their design, the clarity of their processes, and the adherence to established quality criteria. (Gerring 2011; Starman 2013). Scholars often debate core principles such as content validity, construct validity, internal and external validity, reliability, and replication (Brewer and Crano 2000; Cypress 2017). For example, reliability underscores the consistency and trustworthiness of research tools and techniques. To bolster reliability, researchers are often advised to ensure traceability in their methods and to support their findings with established literature or extant datasets (Baxter and Jack 2008). Such triangulation enhances the robustness of the conclusions drawn. Therefore, it is necessary to clearly demonstrate key elements of the study to help readers understand the case context as well as its design and objectives.

Content validity

Content validity focuses on whether the data support causal inferences (Sireci 1998; Schmitz and Storey 2020). In this study, risks causing ripple effects and their manage strategies were derived from interviews and validated through feedback. The interview process explored the root causes of risks, while ongoing observations and interviews helped identify risks encountered during the project and their ripple effects. The research design was periodically discussed with academic professionals and industry practitioners to ensure its integrity.

Construct validity

Construct validity refers to the alignment between data collection and analysis methods and the overall purpose of the study (Gibbert et al. 2008; Yin 2009). This ensures that other researchers can achieve similar results when using the same data (Riege 2003). In line with this principle, the study begins by detailing the interview questions and observation procedures used to explore the risks and their associated ripple effects.

Furthermore, this thesis enhances construct validity by comparing the manage strategies taken during the project with recommended measures derived from multiple sources, including the literature review, expert consultations, shared process documentation, and supervisory evaluations (Baskarada 2014).

Internal and external validity

Internal validity emphasizes the use of research methodologies across perspectives to verify findings (Cypress 2017). This thesis employs a case study approach integrating multiple methods, including interviews and observations, to enable triangulation and ensure methodological robustness. For external validity, while critics argue that findings from a single case lack generalizability, Flyvbjerg et al. (2003) counter that an in-depth single case study can provide valuable insights into specific contexts.

Reliability

Reliability ensures consistency and credibility of the research tools and techniques (Haq et al. 2023). This study incorporates triangulation through observations, regular interviews with stakeholders, and established literature to enhance the robustness of findings. For instance, interviews with contractors and supervisor offered cross-validated insights into risks and ripple effects, ensuring a comprehensive understanding of the studied phenomena. In addition, this study develops a protocol for the interviews and observations conducted during the case study. Both the content of the interviews and the observation procedures are thoroughly documented, thereby enhancing the transparency and replicability of the research (Yin 2009).

Replicability

The detailed explanation of objectives and design enhances replicability (Roberts et al. 2019). This study specifically focuses on construction SMEs, a significant segment within the construction industry. To ensure replicability, the research procedures including data collection instruments, sampling criteria, and analytical steps, have been clearly documented, enabling other researchers to reproduce the study under similar

conditions. While the findings are grounded in the context of construction SMEs, the methodological framework is adaptable to other segments of the construction sector and to related industries, allowing for broader comparative insights and practical applications.

3.6.2 Unit of analysis

In a case study, the unit of analysis represents the phenomenon being investigated. Clearly defining this unit helps readers better understand the context and objectives of the study, while also enabling researchers to engage in a comprehensive process of data collection and analysis (Moser and Korstjens 2018). For this case study on the renovation of a mobile phone shop, the unit of analysis is delineated across the following dimensions:

Stakeholder analysis unit

The stakeholders involved in this case study, including the design team, brand representatives, suppliers, the project manager, contractors, and the supervisor, each play a critical role in project delivery and risk management. The design team is responsible for liaising with the brand and overseeing the design process, with their proposals playing a crucial role in shaping the subsequent construction workflow. The brand representatives are responsible for design approval, operational management, and final acceptance checks. Suppliers, including material and furniture providers, supply essential resources such as cement, bricks, and tiles, as well as tables and chairs, during the initial and closeout phases. The project manager, as the project initiator and main decision-maker, ensures adequate funding, coordinates among stakeholders, and responds to risks as the project progresses. Contractors are tasked with construction, with their operational efficiency, schedule management, and capacity to handle external risks being key factors in maintaining project timelines and standards. Supervisors, responsible for daily monitoring of project quality and progress, play a pivotal role in initiating change requests and addressing emergent risks. Together, these stakeholders

influence the quality of the project, timeline, and ability to manage ripple effects, highlighting the intricate dynamics within the supply chain of construction SMEs.

Risk analysis unit

The analysis focuses on four primary risk categories: Financial, safety, design, and contractual risks, which were identified through the thematic analysis presented in Chapter 4. Among these, financial risks are identified as the most significant contributor to ripple effects in the renovation sector base on the Chapter 5. The analysis delves into financial risks by exploring their causes, timing, and consequences during the project, while also examining their interconnectedness with safety, design, and contractual risks. Specifically, in this study, the concept of early warning signs is introduced and defined as initial indicators that signal the potential emergence of risks before they escalate into major disruptions. Employing a systematic approach, the study identifies potential management strategies and pinpoints critical intervention points to manage the impact of the ripple effect.

Observation and interviews as data collection unit

Temporal data and insights into risk emergence were gathered through a combination of observation and stakeholder interviews. Observation during the design, construction, and final phases enabled the identification of risks and their actual manifestations, providing comparative insights into how risks originate and escalate over time. Interviews with key stakeholders, including the project manager, contractors, and the supervisor, facilitated a deeper understanding of potential mitigation strategies and how ripple effects propagate through risk events. These discussions offered valuable perspectives on ripple effects mitigation and resolution throughout the project lifecycle.

3.6.3 Data collection and analysis

The collection and analysis of data in a case study can pose significant challenges, particularly due to the potential for unconscious bias by researchers, which may result in discrepancies between the findings and actual facts (Flyvbjerg 2011; Adamides et al.

2012). To mitigate this, researchers must provide sufficient evidence to substantiate their claims while explicitly justifying why alternative explanations were excluded (Shanks and Bekmamedova 2018). A systematic description of the data collection and analysis process not only minimizes potential bias but also enables readers to understand the theoretical foundation of the results (Corbin and Strauss 2014). In the case of the phone shop renovation, the author employed two well-established methods: Interviews and observations to collect and analyse data.

Through interviews with project stakeholders, guided by the Critical Incident Technique (Hughes 2007), this study identified the causes, characteristics, and impacts of key events that potentially triggered ripple effects within the construction supply chain. Alongside interviews, the author conducted fieldwork and structured observations to examine the financial status of project, early warning events, and mitigation strategies. Fieldwork refers to the systematic process of collecting primary data directly within the project environment through on-site engagement, document review, and contextual recording of project (Cleland et al. 2021). Unlike interviews, which capture perceptions of participants, reflections, and narratives, fieldwork provides contextual and behavioural evidence, enabling the researcher to verify statements against actual practices observed in situation (Tracy 2024). By observing the project, the study provides valuable lessons and practical insights for mitigating ripple effects in future construction projects.

3.6.3.1 Interview

While the broader interview methodology for identifying risks in construction SMEs has been discussed in Section 3.4, this section focuses on its application in the mobile phone shop case. As Brinkmann (2013) highlights, qualitative interviewing serves as a dynamic framework where practices and standards are documented, challenged, and refined, while also allowing respondents the freedom to articulate their experiences and insights (Choak 2013). This approach provided both analytical depth and methodological structure, enabling a focused exploration of the key research issues.

The interviews were conducted during different phases of the project, including the preparation phase, construction phase (March 26 to May 5), and the follow-up research phase.

Unstructured interviews were conducted as part of long-term fieldwork, allowing respondents the freedom to express their experiences, reflections, and perceptions without constraints. In qualitative research, unstructured interviews are informal, open-ended conversations that do not follow a predetermined set of questions but rather evolve naturally around key themes relevant to the study (Chauhan 2022). These interviews helped the author gain a better understanding of the background of the case and supported the observation process by clarifying the procedures of the project. The objectives of these interviews were twofold:

1. Understanding stakeholder concerns: Capture the activities and events of the stakeholders, including staff, supervisor, and project managers, during different phases of the project.
2. Identifying risk mitigation strategies: Explore existing mitigation strategies for ripple effect, particularly during project acceptance, and compare these with theoretical approaches.

These interviews primarily aimed to provide an in-depth understanding of the project processes and associated events, serving as a foundation for the subsequent semi-structured interviews. This approach facilitated natural conversations and enabled the timely identification of key events and the mitigation strategies employed during the project. Table 3.11 summarises the interview, follow-up, and fieldwork activities undertaken to explore ripple effects and mitigation strategies within the construction project.

Table 3.11: Summary of interview and fieldwork activities

Interview Type	Participants	Duration	Dates	Purpose

Semi-structured interviews	Project Manager	76 minutes	February, 2025	To obtain a comprehensive understanding of project coordination, risk management decisions, and overall supply chain performance.
	Supervisor	29 minutes	February, 2025	To examine on-site management, safety issues, and communication between subcontractors and suppliers.
	Project Owner and Staff	37 minutes	January, 2025	To understand financial flows, contractual relationships, and administrative mitigation strategies.
Unstructured interviews	Project teams	~30 minutes each at beginning, mid-process, and completion stages	April, May, 2024	To capture evolving perceptions and emerging events across project milestones.
Follow-up interviews	Selected previous participants	25–40 minutes, conducted after project completion	September, 2025	To verify interpretations from earlier interviews, reflect on outcomes.
Observation during project cycle	On-site project teams and stakeholders	Continuous throughout project execution	April, 2024	To witness behaviours, coordination patterns, and responses to disruptions in their natural setting.

Source: The author

Semi-structured interviews were then conducted to gain deeper insights into the ripple effect events in the phone shop renovation case. These interviews combined open-ended questions with flexibility, enabling respondents to elaborate on their experiences while aligning discussions with the questions. Key areas explored included the causes and consequences of event emergence and the role of decision-making in managing ripple effects. Conducted during the preparation, construction, and later research phases, these interviews provided a comprehensive perspective risk management practices, ripple-effect mechanisms, stakeholder interactions, and lessons learned. Lasting between 29 minutes and 76 minutes, the interviews targeted project manager and contractors to uncover both existing and potential mitigation strategies. The full text of the interview questions is shown in the Appendix D.

The dual-format methodology, combining unstructured and semi-structured interviews, allowed the author to balance depth with adaptability. The unstructured interviews captured insights into stakeholder concerns during the construction process and into mitigation measures at the project acceptance stage, serving as an entry point for the more focused semi-structured interviews. Together, these approaches enabled the study to identify the dynamics of events, stakeholder roles, and effective mitigation strategies, offering a detailed understanding of the ripple effect and its management within construction SMEs. This integration of interview formats contributed to the development of targeted strategies for minimizing ripple effects and enhancing project performance.

3.6.3.2 Observation

Observation is a supplementary tool within case study methodologies, as it enables researchers to triangulate data from multiple sources, enhancing the reliability of findings (Morgan et al. 2017). By combining observation with interviews, researchers can address the limitations inherent in each method (Abowitz and Toole 2010). For example, interviews depend on the willingness of respondents and their ability to share information, whereas observation enables researchers to capture unspoken aspects and

uncover insights that may otherwise go unnoticed or unreported. This study employed a mixed observation approach, integrating structured observation with fieldwork to ensure comprehensive and systematic data collection. The structured observation methods, as outlined by Punch (2013), required a pre-established plan to document specific behaviours and events systematically. The four identified risks: financial, safety, design, and contractual, served as a baseline framework for systematic observation. During observation, the researcher recorded on-site activities, decision-making processes, and stakeholder interactions that reflected the manifestation of these risks. These events were documented through field notes, progress records, and informal discussions, allowing the researcher to capture both the timing and causal linkages of risk-related occurrences as they unfolded in real time.

To enhance the reliability of observations, this study incorporated improvements inspired by Connaway and Powell (2017) recommendations, as well as methodologies from Williamson (2018) observation chapter. These enhancements included:

1. Defining risk behaviours: Risk behaviours were clearly defined and contextualised for building renovation projects to ensure alignment with the objectives of the study and facilitate consistent observation.

2. Observer competence: The author was equipped with the necessary skills and judgment to effectively identify and evaluate risks, enhancing the accuracy of the data collection process.

3. Avoiding bias: Observers were instructed to document behaviours without subjective interpretation during the observation phase, maintaining impartiality and ensuring the integrity of the data.

The fieldwork observations were conducted systematically during the process of project, providing an immersive lens into the complexities of activities (Allen 2010). This approach enabled the author to focus on specific events, countermeasures, and outcomes, thereby enhancing the understanding of risks and associated ripple effects.

Throughout the phone shop renovation project, author conducted systematic fieldwork, capturing spatial and contextual details via floor plans, photographs, and visual maps. Data collection was rigorously structured around detailed critical milestones, encompassing construction activities, personnel involvement, safety hazards, financial changes, and project completion metrics. Observation records were maintained online and updated regularly throughout the project duration. In addition, interviews and observations with stakeholders, including the project manager, contractor, and supervisor, provided a multidimensional perspective on risk emergence and mitigation.

To reduce potential bias from relying on single respondents, participants were drawn from multiple organisational levels. This diversity allowed the researcher to capture contrasting viewpoints on the same events, such as delays, design changes, and payment disputes. For instance, when a material delivery delay occurred, the project manager emphasised financial implications and client communication, while the site supervisor described its effect on labour scheduling and safety risks. Comparing these perspectives provided a more complete understanding of how ripple effects propagated through daily operations.

Over time, the researcher developed an observer role within the project team, regularly attending meetings, site inspections, and informal discussions. This proximity facilitated trust and open dialogue, enabling access to sensitive information such as cost adjustments and on-site risk mitigation decisions. The implication for the research is that the findings reflect not only reported experiences but also observed behaviours and interactions, increasing both the credibility and validity of the analysis, such as daily safety logs and progress reports, to verify the accuracy and completeness of recorded events.

3.6.4 System thinking

Systems thinking applied in Chapter 6 through the analysis of ripple effects within the supply chains of SMEs in the construction industry. With a long-standing presence in supply chain research, systems thinking has been widely adopted for quantitative

modelling and simulation in studies (Elia et al. 2021; Wilden et al. 2022). A fundamental premise is that a system constitutes an integrated whole composed of interdependent parts, where each part influences the performance and attributes of the whole, thereby providing a holistic perspective (Ackoff 1994). Within this framework, the case study in Chapter 6 treats the project as an integrated entity involving multiple stakeholders, in which ripple effects triggered by key events collectively influence overall project performance. Accordingly, systems thinking offers a suitable lens for examining how key events generate interconnected responses among stakeholders, ultimately shaping project performance (Ghamarimajd et al. 2024).

This thesis applies systems thinking to a phone-store renovation case study to examine the specific dynamics of the ripple effect within construction supply chains. The application followed a structured process (Aikenhead et al. 2015). First, the system boundaries were defined as the supply chain of a construction SMEs project, encompassing the design team, contractors, supervisor, and customer. Within these boundaries, the roles and responsibilities of stakeholders were carefully mapped to identify potential interaction points and possible pathways through which ripple effects could emerge.

Second, the sequence of ripple effect events was reconstructed using in-depth interviews and project documentation. This reconstruction enabled the identification of antecedents (e.g., design errors and supervision oversights) and their associated consequences, thereby establishing causal chains that reflect the propagation of ripple effects. Third, causal loop diagrams (CLD) were developed to present these relationships. Variables were linked using polarity symbols (‘+’ and ‘–’) to indicate whether changes moved in the same or opposite directions (Schaffernicht 2010). The analysis revealed two feedback loops, demonstrating stabilising mechanisms within the system. Each feedback loop was explicitly associated with stakeholder actions, allowing the CLD to function as a dynamic representation of ripple effect evolution

across the project process. To ensure the robustness, reliability, and readiness of the CLD, several measures were undertaken, as summarised in the Table 3.12.

Table 3.12 CLD analysis Procedure

Stage / Measure	Description of Action
Iterative validation with stakeholders	Conducted repeated reviews of the preliminary CLD with project stakeholders (Manager and Supervisor) to assess causal logic and feedback consistency. Feedback was integrated into successive diagram revisions.
Integration of multiple ripple effect perspectives	Expanded the CLD to include financial, human resource, and timeline dimensions based on project records, interviews, and field observations of disruption events.
Validation of system relationships	Conducted follow-up consultations with project manager to confirm whether identified causal relationships aligned with their practical experience of disruption propagation.
Expert review by academic peers	The revised CLD was reviewed by two scholars experienced in system dynamics and CLD methodology. Their comments informed structural refinement and ensured the readiness.

Source: The author, adapted from Barbrook-Johnson and Penn (2022)

Finally, the CLD was extended by incorporating stakeholder performance levels. A performance map was constructed to illustrate how different performance of stakeholders is affected under various ripple effect scenarios. This integration not only visualised the causal pathways of disruptions but also highlighted the concrete impacts of performance changes, including time delays and losses in labour, materials, and equipment, as well as quality considerations, therefore providing a comprehensive view of the actual impacts of ripple effects.

3.6.4.1 Identifying ripple effects causal chains

A key challenge in ripple effect research lies not only in identifying disruption events, but also in substantiating and validating the causal chains through which these events propagate across the supply chain (Zhang et al. 2025). Existing studies often infer ripple effects conceptually or through simulation-based assumptions, with limited empirical validation of how causal mechanisms unfold in real project environments, particularly

within construction SMEs (Ye et al. 2025). While these studies are valuable for illustrating potential propagation pathways, they frequently rely on simplifying assumptions regarding actor behaviour, information flow, and response timing, which may not reflect the fragmented and dynamic nature of construction supply chains.

From a systems thinking perspective, causal chains are understood as dynamic interaction patterns embedded within a wider system, rather than linear cause effect relationships (Ghufran et al. 2022). Ripple effects therefore emerge through feedback loops, delayed responses, and cross-stakeholder interactions, making their validation inherently multi-dimensional. Accordingly, this study substantiates ripple effect causal chains by integrating multiple sources of empirical evidence. Risks and their associated early warning signs are traced across project phases using direct interviews and documentary records, while interviews of stakeholders provide insight into decision rationales, response actions, and perceived dependencies between events. The overall flowchart of the ripple effect case is presented in Figure 3.5. These qualitative accounts are further triangulated with quantitative indicators, such as cost variances and timeline deviations, enabling the validation of both how ripple effects propagate and why their consequences escalate at different stages of the project lifecycle.

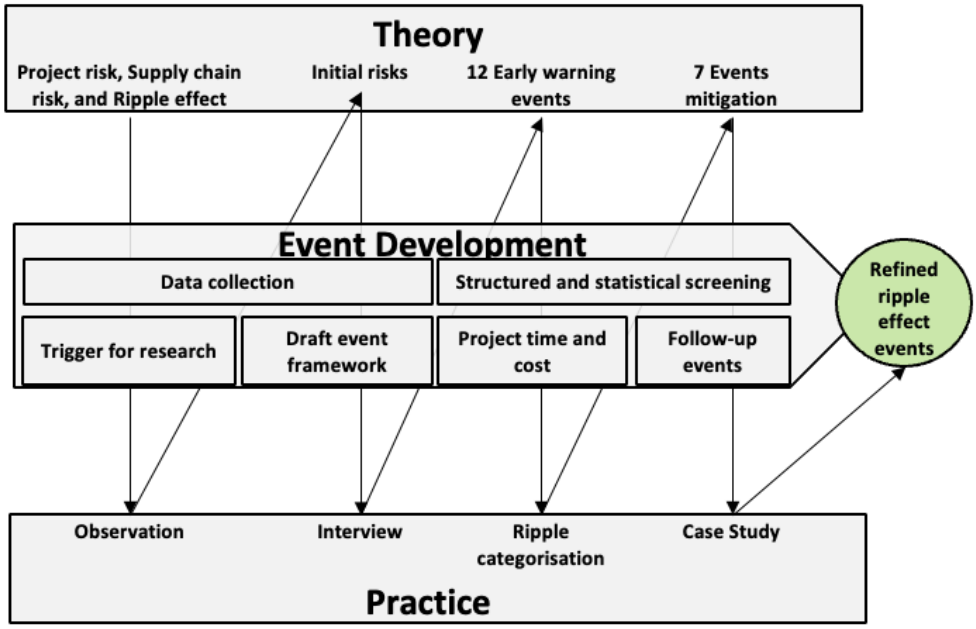


Figure 3.5: Ripple effect case flowchart

Source: The author, adapted from Gosling et al. (2017)

3.6.4.2 Validating ripple effect causal chains

The validation of ripple effect causal chains in this study extends beyond descriptive sequencing of disruption events and adopts a structured and replicable analytical procedure to substantiate causal relationships. Rather than assuming possible causal propagation, the study applies multi-stage validation process to distinguish ripple mechanisms from the evidence.

First, all disruption-related incidents identified during interviews were extracted and coded according to project phase (design, beginning, process, closeout), risk category (financial, safety, contractual, design), stakeholder involvement, and approximate timing.

Second, proposed causal sequences were subjected to cross-stakeholder triangulation. A relationship between two events was considered credible only when validated by multiple sources. This included instances where independent stakeholders described the same event sequence, or where one stakeholder reported an initiating disruption while another described its downstream consequence. This process reduced reliance on single-source interpretation and strengthened internal consistency in identifying propagation pathways. These events were then arranged into a causal loop diagram to establish preliminary sequences of disruption.

Third, interview-derived sequences were cross-checked against available project documentation, including progress reports, pictures, videos, cost comparisons, and change orders. For a causal link to be substantiated, documentary evidence had to confirm that the alleged consequence occurred after the triggering event and that measurable deviations in cost, time, quality, or resource allocation aligned with the reported disruption. This alignment between narrative accounts and documentary evidence reinforced empirical validity and addressed concerns regarding retrospective bias.

Finally, each proposed ripple link was examined through mechanism-based reasoning. Beyond interview and documentary confirmation, the researcher evaluated whether a plausible dependency pathway connected the events. For example, a design error leading to installation mismatch, subsequent rework, and additional labour costs was validated not merely because these events occurred sequentially, but because physical and operational dependency logically connected them. Only when a clear operational, contractual, financial, or coordination mechanism could explain the transition from one event to the next was the link retained as part of a validated ripple chain.

A ripple effect causal chain was therefore considered substantiated when three conditions were met: interview evidence, documentary verification, and dependency linkage. By integrating these three elements, this study establishes a transparent and

transferable framework for validating ripple propagation in construction SME supply chains, which is ultimately represented through a performance diagram.

3.6.4.3 Worked example

To illustrate how ripple effect causal chains were identified and validated, a worked example from the renovation case study is presented. This example demonstrates how an initial disruption originating from design-stage miscommunication propagated across stakeholders and project activities, resulting in cost escalation, contractor replacement, and operational difficulties.

The causal chain began with miscommunication between the design team and the construction team regarding façade specifications. Interview evidence from the contractor indicated that unclear material instructions led to the adoption of an alternative façade material during installation. This decision created conflicts over quotation responsibilities and cost allocation for the assigned contractor, as confirmed by both contractor and client interviews. As installation progressed, disagreements emerged over reinstallation costs when discrepancies between the design drawing and the installed materials became evident. Project documentation further supported this sequence by showing adjustments in installation records and revised cost allocations. These issues collectively led to the termination of the existing construction team, a decision confirmed through stakeholder interviews and project records.

In response, a new construction team was introduced, and renegotiations took place to continue the project. However, the disruption had already propagated through the project system. Subsequent site observations and interviews revealed practical consequences, including difficulties in façade wiring and levelling due to the earlier material change and installation inconsistencies. Additional supporting evidence was obtained through the project timeline comparison. As shown in the project schedule, the actual installation period significantly exceeded the planned duration, indicating the operational impact of the disruption.

This example demonstrates how a localised design-stage issue triggered a sequence of interconnected events involving contractual, financial, and operational responses. The causal chain was validated through triangulation of multiple data sources, including interview narratives, project documentation, and observable schedule deviations.

3.7 Research ethics

Given the empirical basis of the thesis, strict adherence to the ethical protocols delineated by Cardiff Business School was deemed imperative. This thesis passed the ethical review by Cardiff University Business School and was promptly reviewed through the School Research Ethics Committee whenever there were changes in the experimental stage shown in the Appendix A.

In the latter stage of the literature review, a structured literature review was adopted to synthesise relevant research findings. The ethical considerations at this stage were twofold: ensuring the integrity, credibility, and transparency of the data was critical and accurate representation and interpretation of the findings to avoid bias and misrepresentation (Suri 2020). To uphold these principles, rigorous selection criteria were applied, focusing primarily on peer-reviewed academic articles derived from empirical studies, particularly those based on interviews and surveys (Nightingale 2009). Additionally, a transparent and replicable search process was presented in the context, including the use of multiple databases and exclusion criteria, this approach helped to reinforce the ethical standard of methodological transparency and ensured that the review process contributed meaningfully to the academic discourse on SCR and ripple effects.

In line with best practices in research ethics (Saunders et al. 2009; Bryman 2016). particular attention was given to informed consent, confidentiality, voluntary participation, and data protection. During the qualitative stage, interviews were conducted with construction industry professionals. Participants were provided with an information sheet and consent form prior to the interviews, clearly explaining the

purpose of the research, their right to withdraw at any time, and the procedures for data storage and use. All interviews were recorded with the consent of participants, and transcripts were anonymised to ensure confidentiality. The data were stored securely and accessed only by the research team, in accordance with ethical guidelines and institutional policy.

For the survey, a questionnaire format was used, and participants were similarly informed of the privacy of the questionnaires and their right to opt out at any time during the process (Fox et al. 2003; Buchanan and Hvizdak 2009). To ensure informed participation, the author created a standard template outlining the purpose of the study, the terms of participation, rights of respondents, and information storage procedures. Respondents were required to read and agree to this statement before proceeding with the survey. During the writing part of the thesis, careful citation of scholars was ensured to maintain the original meaning and implications of their work. Additionally, multiple rounds of proofreading were conducted, especially in the statistical section, to eliminate any computational or interpretative anomalies.

In the case study stage, particular care was taken to respect the ethical sensitivities associated with accessing organisational practices and stakeholder experiences in construction SMEs. Firms were approached formally, and participation was strictly voluntary. Prior to data collection, organisational consent was secured, followed by individual informed consent from participating staff members. Each participant was assured that their responses would remain confidential and that no identifiable company or personal information would be disclosed in the thesis or related outputs. The researcher also remained mindful of avoiding any undue influence during the data collection process, ensuring that observations and interviews did not disrupt daily operations or impose additional burdens on workers. Field notes and observation records were anonymised, securely stored, and triangulated with other data sources to ensure both accuracy and ethical integrity.

3.8 Chapter summary

This chapter delves into the research paradigm and philosophical foundation underpinning this thesis. Among the various philosophical methodologies, critical realism emerges as the central focus of this thesis, with abductive reasoning serving as the primary means of theory development. Given that this study is situated in the field of supply chain research, and aims to bridge practical applications with theoretical insights, a multi-method approach was deemed appropriate. On the qualitative side, approaches such as survey, interviews, case studies, and system thinking are utilised. For the quantitative research method, the AHP method is employed. This chapter details the methodology adopted in this study, including the rationale for its selection and the procedures involved in its implementation. Furthermore, each research method is described in detail, along with the validation procedures applied to ensure the rigour and credibility of the research process. Finally, the chapter discusses the ethical considerations involved in the implementation of the research.

Chapter 4 Ripple effect factors

4.1 Chapter overview

This chapter addresses RQ1: *What are the risks that trigger ripple effects in the supply chains of construction SMEs?* Drawing on insights from both the interviews and the literature, this chapter aims to identify and analyse the key risks that may lead to ripple effects within construction SME supply chains as illustrated in Figure 4.1. Section 4.2 introduces an integrated supply chain map, illustrating the sources of risk within the supply chain. Section 4.3 identifies and examines four categories of SCR, including financial, safety, design, and contractual risks, which may trigger ripple effects and their associated consequences. Section 4.4 discusses the findings, emphasising their implications and significance for both academic research and industry practice. Finally, Section 4.5 provides a concise summary of the chapter, highlighting the key insights and their broader relevance.

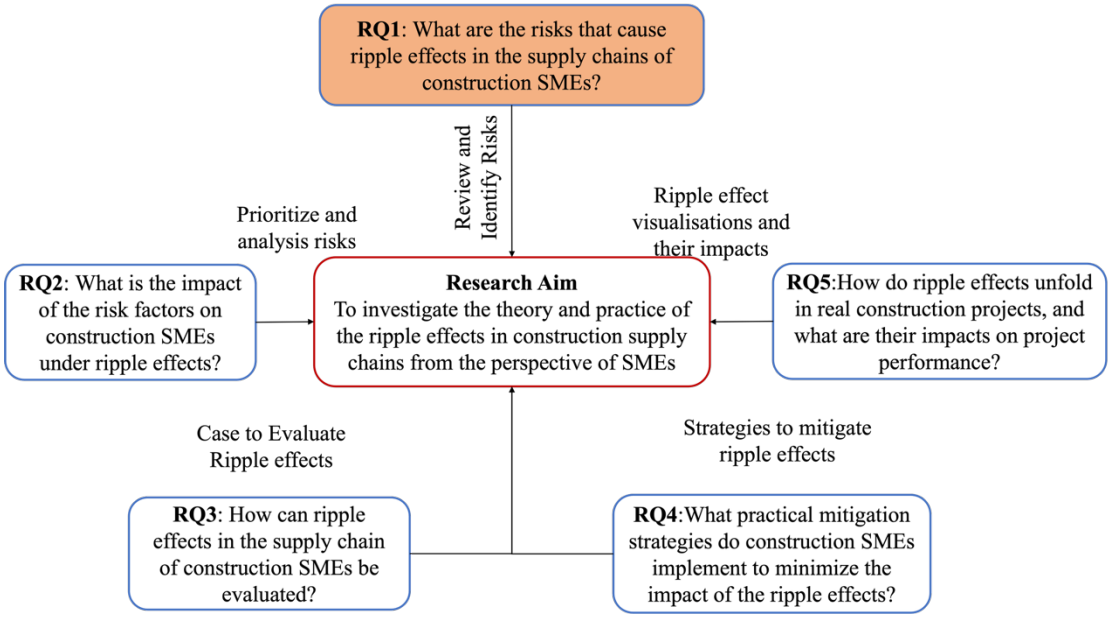


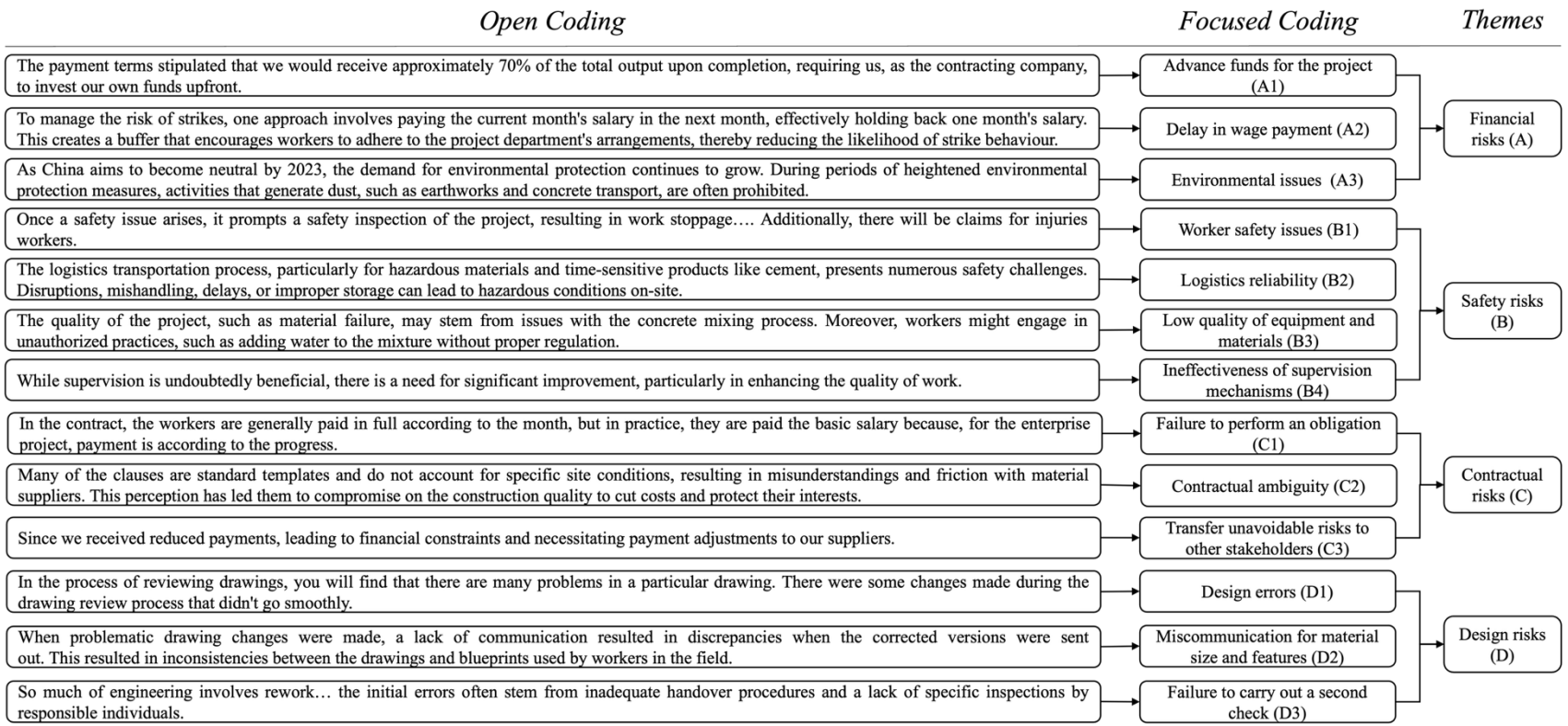
Figure 4.1: Chapter 4 Thesis Structure

Source: The author

The structured literature review in Chapter 2 highlights an important gap in existing research, as there has been no comprehensive study to identify the factors that trigger ripple effects in construction supply chains (Duong et al. 2023). To address this gap, semi-structured interviews were employed in this chapter to identify the factors contributing to this phenomenon. Interviews served as the primary data collection technique for the qualitative research (Cooper and Schindler 2014). The interviews were conducted online in 2024 with participants based in China. Each session lasted between 24 and 48 minutes, supplemented by follow-up discussions to clarify emerging issues. The final dataset comprised 25 participants, representing 16 SMEs, 9 supervisory agencies, as well as representatives from large construction companies and government departments. In addition, thematic analysis was adopted as the qualitative analytical method to interpret and generalise the interview data. These findings served as the basis for subsequent research in the study.

The themes were identified through a systematic coding and categorisation process following the six-phase approach to thematic analysis (Terry et al. 2017), as outlined in Section 3.4.1. Initially, all interview transcripts were read to achieve familiarisation, after which significant statements relating to disruptions, risks, and project performance were coded in NVivo. Similar codes were grouped into subthemes based on conceptual similarity and frequency of occurrence. For example, codes such as “delayed payment,” “funding gap,” and “financial pressure” were clustered under *financial risk*, while “design changes” and “drawing inconsistencies” were combined into *design risk*. Themes were then refined through iterative comparison of the interview data to ensure that each represented a valid and interconnected area of risk within construction SME supply chains. This step-by-step analytical procedure enabled the systematic identification of ripple effect factors in construction SMEs, as presented in Table 4.1.

Table 4.1: The coding process of the thematic analysis



Source: The author

The four major risk themes: Financial, safety, contractual, and design risks were derived through thematic analysis of interview transcripts collected from 25 participants representing SMEs, supervisory agencies, and large contractors. Financial risks (A) emerged from advance funds to cash flow pressure (A1), delayed payments (A2), and the project environment (A3). Safety risks were identified through participant accounts highlighting worker injuries (B1), logistical constraints (B2), the use of low-quality equipment (B3), and supervision issues (B4). Contractual risks were characterised by fail to perform an obligation (C1), contract terms (C2), and shifting of risk responsibilities (C3). Finally, design risks were identified from activities involving inconsistent drawings (D1), miscommunication (D2), and fail to carry out a second check (D3).

Based on these findings, an integrated construction supply chain map was developed to visually represent how these risk categories are embedded within stakeholder relationships and project interactions. The map reflects not only the classification of risks but also their distribution across different actors within the supply chain network. Furthermore, the integrated construction supply chain map was constructed using the experiences and insights shared by interviewees, considering their professional roles and positions within the project structure.

Each participant provided narratives describing their direct involvement in decision-making processes, disruptions, and inter-organizational interactions. These narratives were coded thematically to identify recurring patterns of risk occurrence and stakeholder interdependencies. Through this process, risks were linked to specific supply chain actors and relational interfaces. This multi-source triangulation combining interview narratives, role-based contextual interpretation, and thematic-coding, enhanced the reliability of the map, allowed the researcher to capture not only the structural linkages within the supply chain but also the dynamic processes of risk emergence and propagation.

To deepen the analysis, the researcher employed an RCA, which is widely used in supply chain related fields to uncover connections between factors and to gain insights into the underlying causes of various situation (Gosling et al. 2015; Alfnes et al. 2021). It helps identify whether disruptions arise from coordination failures, contractual design, resource dependency, or information breakdown. Building on the previous thematic analysis and RCA, the author developed a consequence map to illustrate how the four major risks: Financial, safety, contractual, and design generated ripple effects across the project. The mapping process involved systematically linking root causes to their direct consequences (e.g., cash outflow, worker strikes, project delays, legal issues, and safety incidents), which then escalated into indirect impacts such as resource reallocation, reduced efficiency, stakeholder conflicts, and compromised project quality. Over the longer term, these cascades evolved into long term consequences, including reputational damage, legal and financial liabilities, regulatory challenges, and potential project failure.

4.2 Integrated construction SMEs SCRs map

Following interviews with construction SMEs and their associated stakeholders, the author developed an integrated SCR map, as shown in Figure 4.2. On the map, different colours are used to distinguish the types of risks: brown denotes financial risks, yellow indicates safety risks, blue represents contractual risks, and green corresponds to design-related risks. The seven key stakeholders in the construction SME supply chain map are material vendors, equipment leasing companies, labour subcontractors, design companies, supervision, agency institutions, and clients (Koc and Gurgun 2021).

From left to right, the stakeholders represented include labour subcontractors, material vendors, and equipment lease providers. From the perspective of labour stakeholders, worker safety (B1) emerged as a dominant concern. An interviewee overseeing government-affiliated projects noted the rigorous oversight imposed on construction activities:

> *The project site is subject to quality and safety supervision by the relevant management departments, which involves official registration. Inspectors visit the site to conduct oversight. If a safety incident occurs on site, there's a potential for project shutdown and mandatory rectification.*

Delayed wage payments (A2) also pose a significant risk to the labour, particularly when contractual payment terms are not honoured during the construction phase. Such delays can lead to worker strikes or reduced productivity, often resulting in costly rework and schedule disruptions (VU et al. 2020).

For material vendors, although the local procurement of raw materials may help avoid supply shortages, it simultaneously introduces logistics-related risks on the supplier side (B2). This behaviour has also been observed by Ellegaard (2008), who highlights that sourcing strategies designed to enhance supply continuity may create additional coordination and transportation risks. This is attributed to the dependence on extensive logistics operations and specific qualifications, potentially leading to delays or shortages. A tile supplier described their logistics strategy as follows:

> *In cases of ongoing collaboration, selecting a provider for its reliability becomes preferable, even if freight costs remain constant. However, insufficient logistics capacity necessitates arranging our logistics solutions, introducing risks related to timeliness and safety.*

Finally, equipment lease and materials-related stakeholders raised concerns regarding the use of low-quality equipment and materials (B3). These factors were commonly cited in interviews (10 out of 25 participants) as critical threats to project, with consequences ranging from failed regulatory inspections to compromised structural integrity.

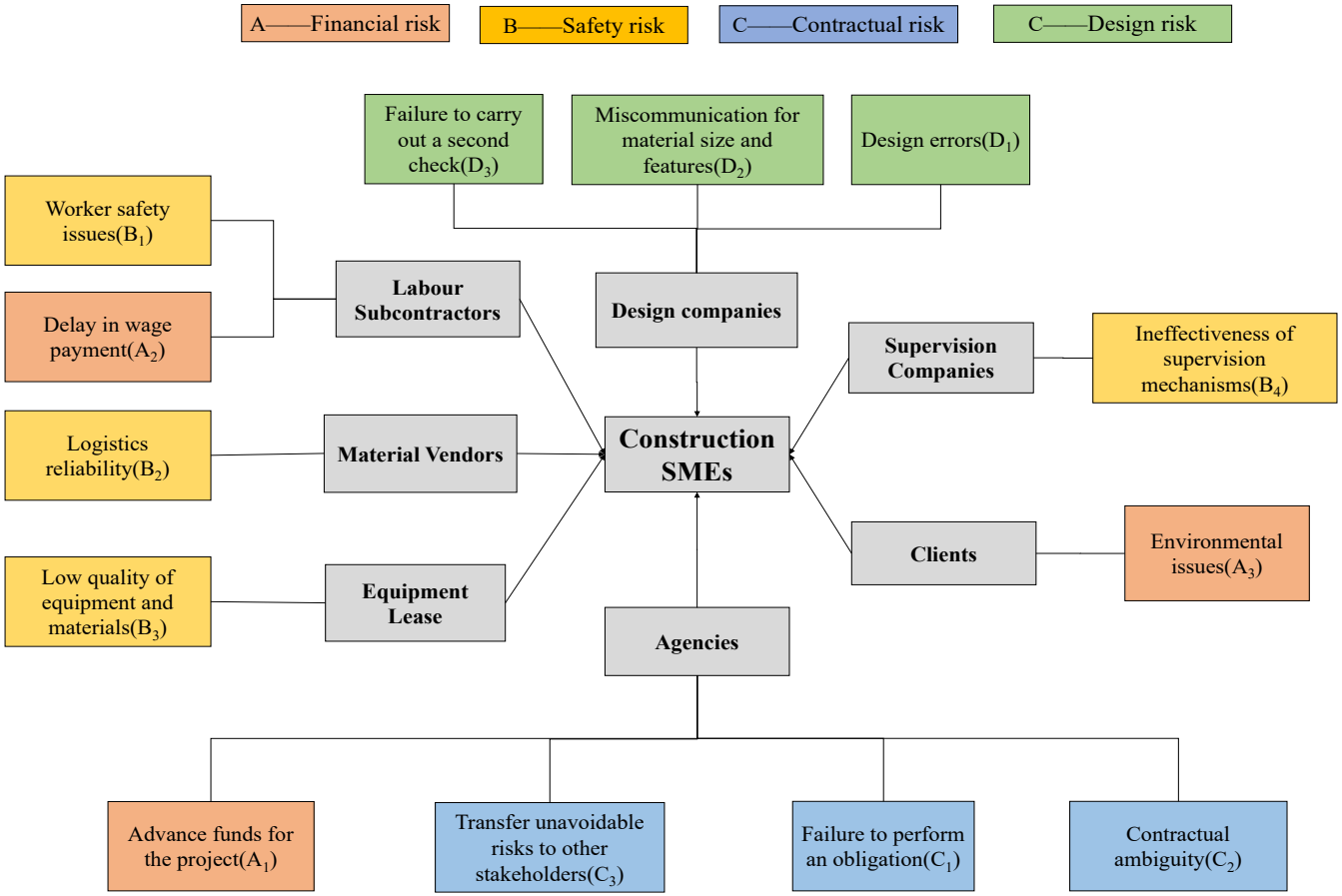


Figure 4.2: Integrated construction SMEs SCRs map

Source: The author

Within the construction supply chain, design facilities and supervisory companies maintain close operational ties with construction SMEs (Pablo and London 2020). Design-related risks were a recurring theme in the interviews, particularly design errors (D1), which were widely recognised during project execution. Both the interview findings and the existing literature indicate that one of the primary causes of these discrepancies is inaccurate data during the initial design stage (Babalola et al. 2019). A project manager commented:

> *When construction teams begin work, design firms are expected to provide accurate drawings and communicate with contractors to ensure a smooth construction process. However, in practice, construction workers often discover mismatches between the drawings and on-site conditions, resulting in project delays and additional communication efforts. This often occurs because the design firm did not conduct a second review after completing the initial design.*

In addition to general design errors, interviewees highlighted poor communication regarding material size and features (D2) as a significant ripple effect trigger. Furthermore, the absence of a secondary check process during construction (D3) was consistently reported across multiple stakeholders.

In addition, environmental conditions were identified by interviewees from the perspective of clients as a significant concern (A3). Specifically, economic downturns were cited as reducing the incentive to initiate or sustain construction activities, further limiting the financial viability of projects. Supervisory companies also play a critical role in construction process. However, interviewees noted that the ineffectiveness of supervisory mechanisms (B4) often contributes to safety-related risks. As one renovation industry professional observed:

> *During the project, the supervision mechanism is intended to ensure compliance with construction standards. However, in many cases, supervisors fail to communicate effectively with contractors. Rather than facilitating coordination between the design firm and the construction company, they often only identify problems without offering constructive support, which ultimately causes project delays.*

Agencies within the construction SME supply chain primarily function as intermediaries between clients and SMEs. From the perspective of agencies, financial risks are closely linked to contractual obligations, particularly where SMEs are required to advance payments for material procurement and equipment rentals under contract stipulations (A1). An agencies representative explained:

> *At the beginning of the project, SMEs are often required to prepay for materials and equipment. Payment from the client is typically tied to project milestones or completion, which increases contract-related risks. In some cases, final payments are delayed due to ambiguous contract clauses, or certain force majeure risks are transferred to SMEs.*

The interview also identified a series of contract-related risks affecting construction SMEs. These included the transfer unavoidable risks to other stakeholders (C3), the failure to perform an obligation (C1), and the risks arising from ambiguous contract terms (C2). The transfer of unavoidable risks (C3) refers to situations in which contractual arrangements allocate disproportionate responsibilities to SMEs, often requiring them to assume liabilities beyond their operational control. The failure to perform contractual obligations (C1) occurs when agency do not fulfil the duties specified in the contract, such as completing work payment according to contract, changing project timelines, or adhering to agreed quality standards. Risks arising from ambiguous contract terms (C2) refer to situations in which unclear wording or incomplete contractual specifications lead to differing interpretations from agency.

4.3 Four risks across supply chain

Based on the thematic analysis, this study identified four primary categories of risk: financial, safety, contractual, and design risks. Each category was observed to affect construction SMEs to varying degrees. In this section, RCA further revealed that these patterns are consistent with findings reported in the existing literature (Dziadosz et al. 2015; Al Mawli et al. 2021). For each risk category, incidents identified during the interviews were further examined by distinguishing between immediate triggers and

underlying structural causes. For example, financial risks were traced not only to advance payment requirements (Eyiah and Cook 2003; Abdul-Rahman et al. 2014), but also to uncleared or ambiguous contracts that transferred risks to suppliers (Trauner 2009). They were further associated with external environmental pressures, such as regulatory issues (Zhao et al. 2015), and project function changes that altered original plans and increased costs (Killip 2011). The following section provides a detailed result of the four identified risks.

4.3.1 Financial risks

A significant number of respondents (13 out of 25) highlighted concerns over financial risks, which are connected to contractual, safety, and design risks, often leading in project delays or failures that subsequently impact other projects. Financial risk stems from the common practice within the construction sector, requiring SMEs to advance payments for materials, labour, and equipment (Eyiah and Cook 2003; Beck 2007). One of the interviewees highlighted their concern regarding this issue:

> *The time for such investments typically ranges from 6-12 months, with note that returns are only realised upon project completion.*

Delay payments and non-payment are a common problem in the construction industry, recurring consistently across projects (Abdul-Rahman et al. 2014). Figure 4.3 shows the root cause of financial risks. Uncleared contract emerges as another source of financial risk, frequently resulting in the transferring of risks (Trauner 2009). Downstream parties may employ vague terms or fail to clearly define responsibilities, aiming to offload personnel safety and financial burdens onto the constructor (Loosemore and McCarthy 2008). In response, constructors often mitigate financial risks by making payments to suppliers in instalments. This scenario also occurs in labour situations, where contractors prefer to manage financial and safety risks through instalment payments and collaborative agreements (Burtonshaw-Gunn 2017).

The environmental impact of construction activities (A3) is also one of the causes of financial risk identified by the respondents, as regulatory requirements for pollution emissions can affect the normal operation of the business (Zhao et al. 2015). Participants also expressed concern about the impact of the economic downturn on demand for housing and property, noting a perceived decline in quality and reduced demand at a time when housing needs were largely met (Deng et al. 2023). In addition, changes in building redevelopment create additional financial risks. For example, functional changes in older homes are often perceived as more challenging than new builds, as longer project timescales and more complex procedures can exacerbate financial pressures on construction SMEs (Killip 2011).

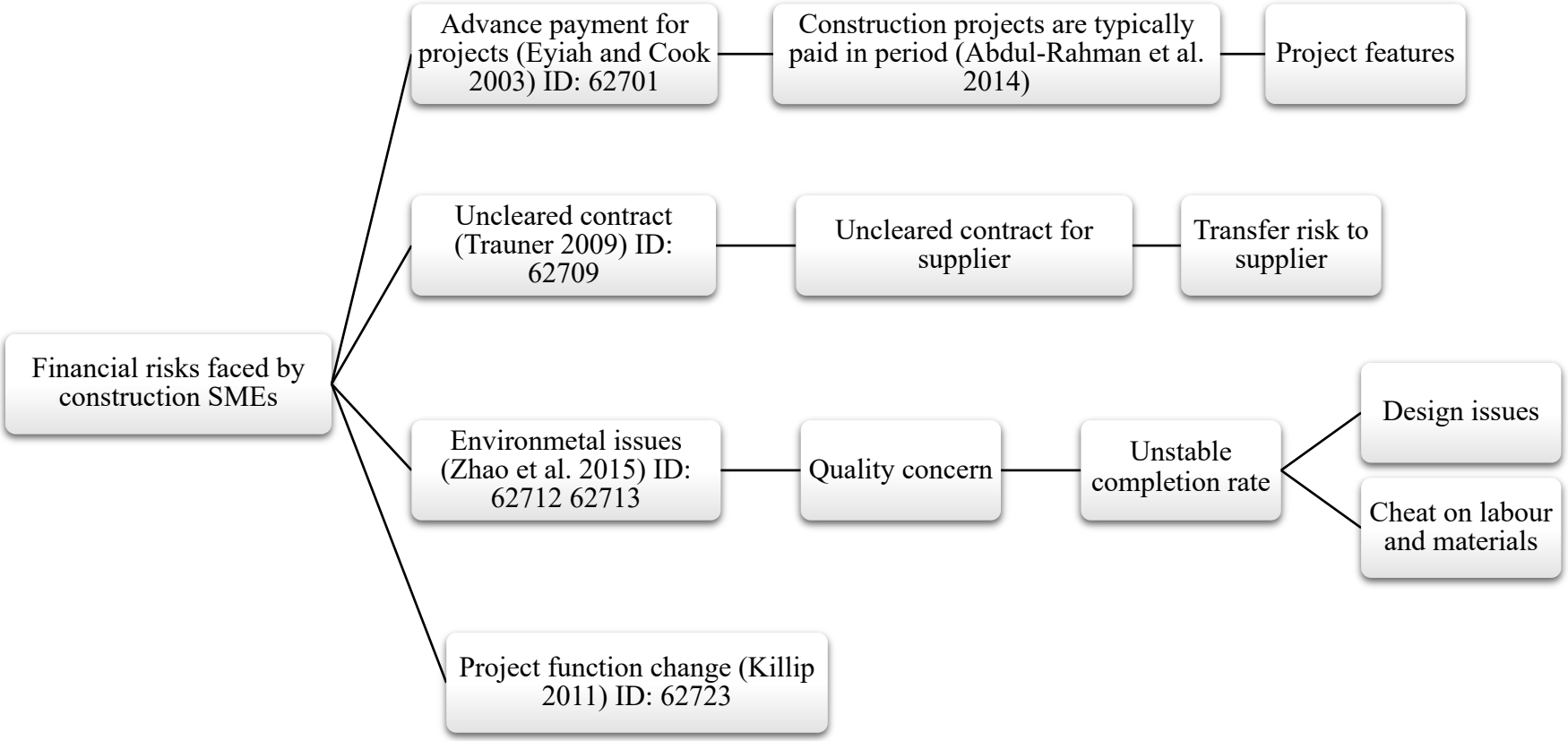


Figure 4.3: Root cause analysis of financial risks

Source: The author

4.3.2 Safety risks

Regarding safety risks, interviewees acknowledged that while the likelihood of occurrence was relatively low, the potential impact was significantly high. One key factor contributing to safety risks was logistics reliability (B2) (Shahbaz et al. 2019), particularly in the transportation of specialized materials and time-sensitive products such as cement. Disruptions in the logistics process could introduce hazards that directly affect the safety of construction activities. Additionally, a representative from the governmental supervisory authority highlighted a concerning practice in the industry:

> *In the construction phase, issues like failing to meet design specifications for load-bearing capacity arise. The initial step involves assessing the severity of the issue. If modifications to adhere to the design are feasible, or if other solutions, such as load reduction, are necessary to ensure structural safety without compromising the superstructure. This review process, potentially extending project timelines by one or two months, prompts most builders to expedite construction discussions to maintain the schedule, planning to address paperwork later.*

Equipment and material quality was another highlighted safety risk (B3), with some suppliers possibly compromising on quality to cut costs, a practice also integrated with contractual terms and financial risk (Haider 2009; Niati 2019; Noorizadeh et al. 2019). Additionally, the effectiveness of supervision mechanisms (B4) was questioned by multiple interviewees, with the supervisory role often perceived more as a hindrance than assistance (Ye et al. 2015). Finally, inexperienced operators and ignorance of safety procedure are one of the main causes of safety risks, with workers carrying out construction work without proper training (Choudhry and Fang 2008). Figure 4.4 shows the root cause of safety risks.

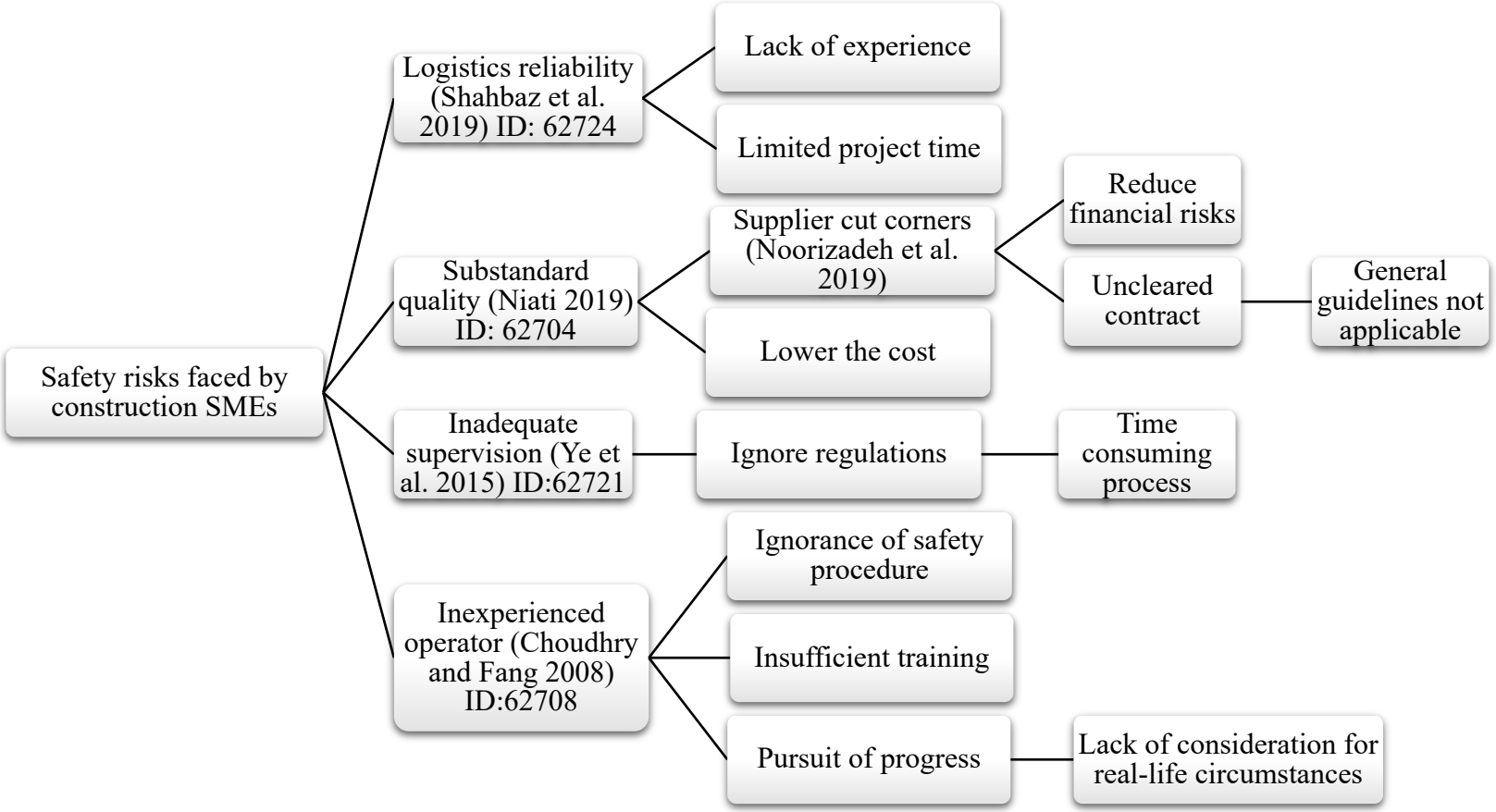


Figure 4.4: Root cause analysis of safety risks

Source: The author

4.3.3 Contractual risks

Contractual risk in the construction industry is partly due to its inherent complexity and the failure to comprehensively identify project risks (Paulsson 2004), along with numerous uncertainties that lead to flaws in contracts (Bloomfield et al. 2019). These flaws are often attributed to unanticipated situations arising from unforeseen future events and inadequate risk identification (Chapman 2001). In discussing financial risk during the interview, it was noted that the transfer of risk is often facilitated through project contracts (Moazzami et al. 2011). For instance, a builder recalled an experience where contract-induced risk was cascaded down the supply chain:

> *In the past year, our project encountered some challenges in production and operations, largely due to contractual arrangements. The payment terms stipulated that we would receive approximately 70% of the total output upon completion, requiring us, as the contracting company, to invest our own funds upfront. Additionally, the construction market downturn resulted in sluggish house sales, affecting both our agency partners' liquidity and their ability to pay us promptly. Consequently, we received reduced payments, leading to financial constraints and necessitating payment adjustments to suppliers.*

This scenario illustrates how contractual risks can trigger a ripple effect throughout the supply chain and even impact other supply chains. Another cause of contractual risks is the unclear contract terms with upstream supply chain partners (Koc and Gurgun 2021). In response, some interviewees suggested that sharing contracts information could mitigate this risk. However, interviews surprisingly revealed minimal interaction among SMEs, potentially due to inadequate facilities and a prevailing sense of competition between them (Akintoye and Main 2007). Furthermore, contractual risk includes the failure to perform an obligation (C1) by contract holder, where recovering funds becomes challenging and often involves lengthy legal processes, thereby increasing contractual risk (El-Hoteiby et al. 2017). Figure 4.5 shows the root cause of contractual risks.

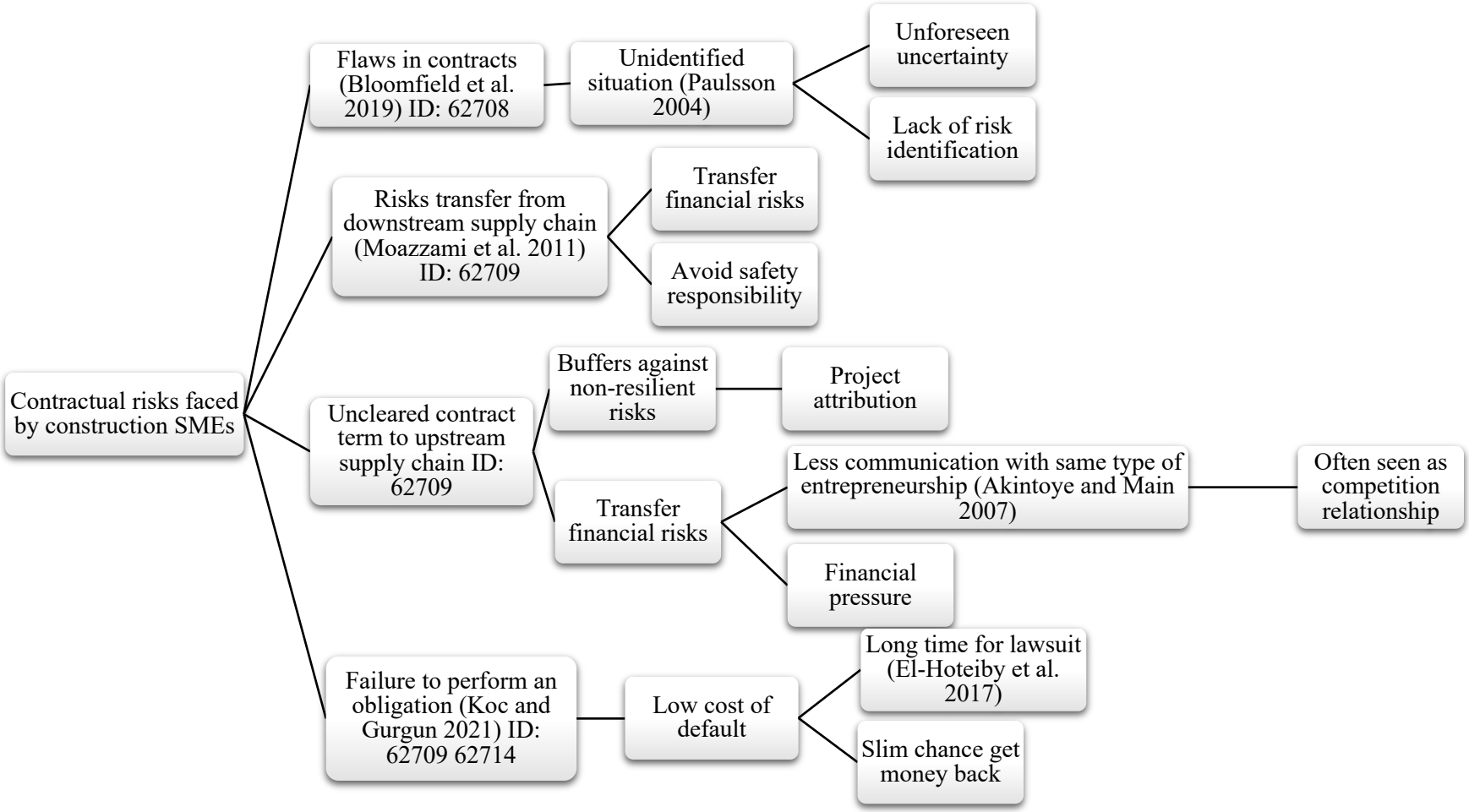


Figure 4.5: Root cause analysis of contractual risks

Source: The author

4.3.4 Design risks

Design risk primarily originates from the design company, where its limited experience can lead to inconsistency between projects and plans (Che Ibrahim Che Khairil et al. 2022). Specifically, modifications and rework may influence project acceptance and subsequent fire safety compliance when the materials or specialized construction procedures required for a project deviate from standard practice (Chapman 2001). In addition to this, the inaccurate data is also one of the reasons for the variability in the drawings (Agyekum - Mensah 2019), as one project manager commented：

> *In the process of review drawings, you will find that there are many problems in a particular drawing. Possible drawings and drawings between the architectural and structural conflicts, and then structural drawings themselves are filled with many problems that need to be solved by the workers on site, that is, from the rigor of the design of the drawings is very poor.*

Two possible reasons contribute to inaccurate data, the first issue is miscommunication (D2) with the site team, caused by limited site visits and the prioritisation of construction progress without a proper understanding of site conditions (Xu and Luo 2014). The second is the failure to conduct a second check (D3) of the site after completing the drawings or the delay of designer in making timely modifications following the plan, ultimately leading to rework. Pressure from stakeholders is also a significant factor contributing to inaccurate data (Olander and Landin 2005). Furthermore, this study identified that special client requirements, such as the use of unique materials or specific demands, can lead to design risks if the designer is unfamiliar with the properties of the materials requested (Rezgui and Miles 2010). Figure 4.6 presents the root cause of design risks.

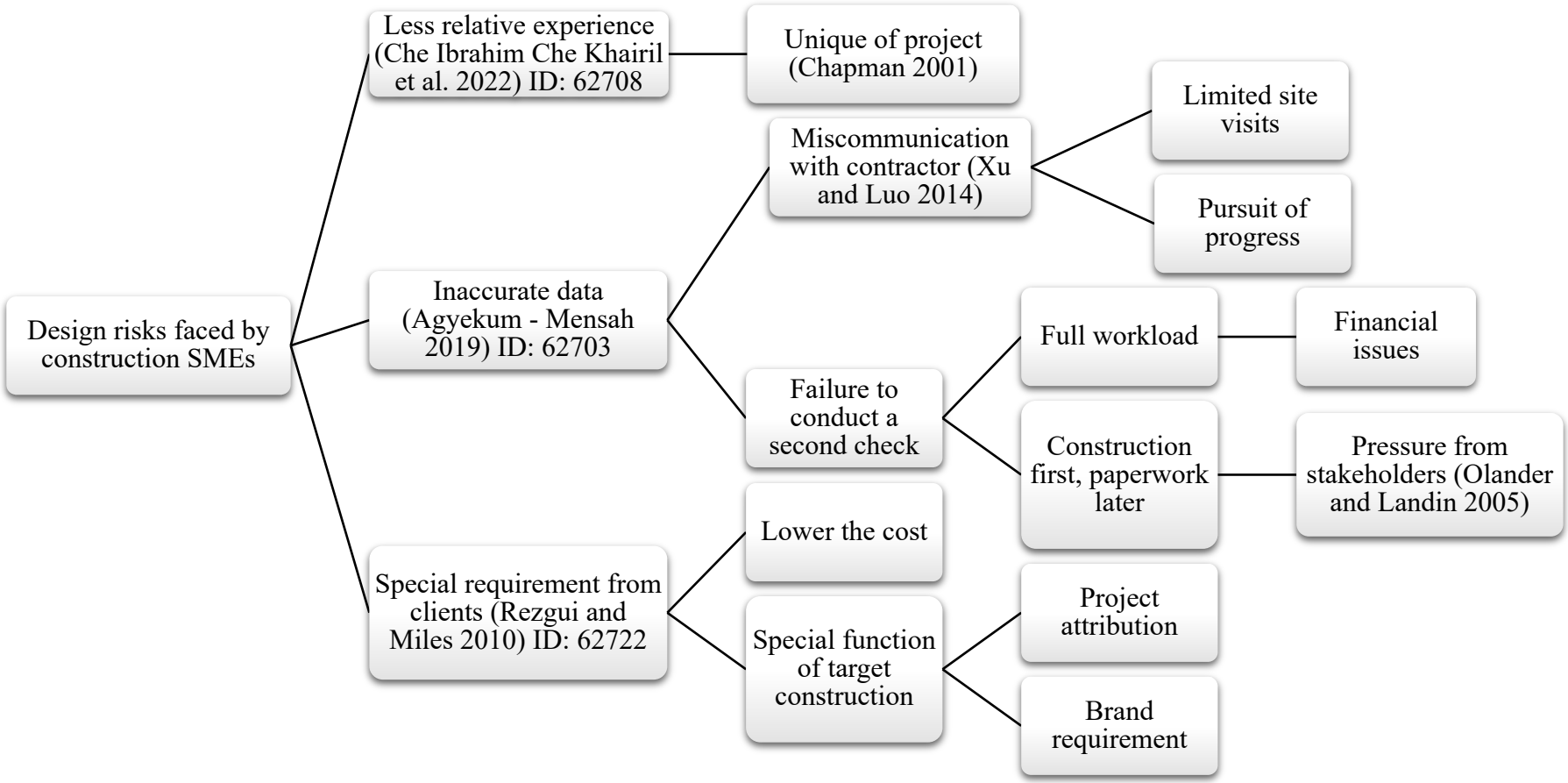


Figure 4.6: Root cause analysis of design risks

Source: The author

4.3.5 Consequences among four risks

The thesis synthesises the root causes of the four risks and identifies the possible consequences derived from the interviews, as illustrated in Figure 4.7. These consequences play a critical role as threads that construct the ripple effect. If practitioners can identify and address these threads, they can effectively reduce or even prevent the associated ripple effects. For instance, by addressing the direct consequences of design risks, such as safety risks at the construction site, practitioners can significantly minimise or even eliminate safety risks within a specific supply chain during that phase of the process. This underscores the necessity of a systematic understanding of both the antecedents and consequences of risks.

The Figure 4.7 illustrates the multi-layered consequences of the ripple effects triggered by four core categories of risk within construction supply chains. The first layer of direct consequences represents the immediate outcomes arising at project level, such as project delays (ID: 62701 presented in Table 3.5), injure to worker (ID: 62723), on-site adjust and rework (ID: 62722) and resource reallocation (ID: 62725). As these direct consequences accumulate and interact, they evolve into second-layer indirect consequences that extend beyond the project boundary and adversely affect wider supply chain performance. These include increased worker turnover (ID: 62720), project delays arising from investigations and safety reviews (ID: 62712), reduced efficiency and productivity (ID: 62722), and heightened disputes among project stakeholders (ID: 62720).

Over time, the compounding effects of these disruptions give rise to third-layer long-term consequences, which can jeopardise the strategic sustainability of construction SMEs. These include long-term financial instability (ID: 62705), legal consequences and potential litigation (ID: 62711), increased maintenance and rectification costs (ID: 62722), and damage to company reputation (ID: 62701). The Figure 4.7 illustrates how

initial risk events propagate through multiple layers of impact, highlighting the systemic and cumulative nature of ripple effects within construction SME supply chains.

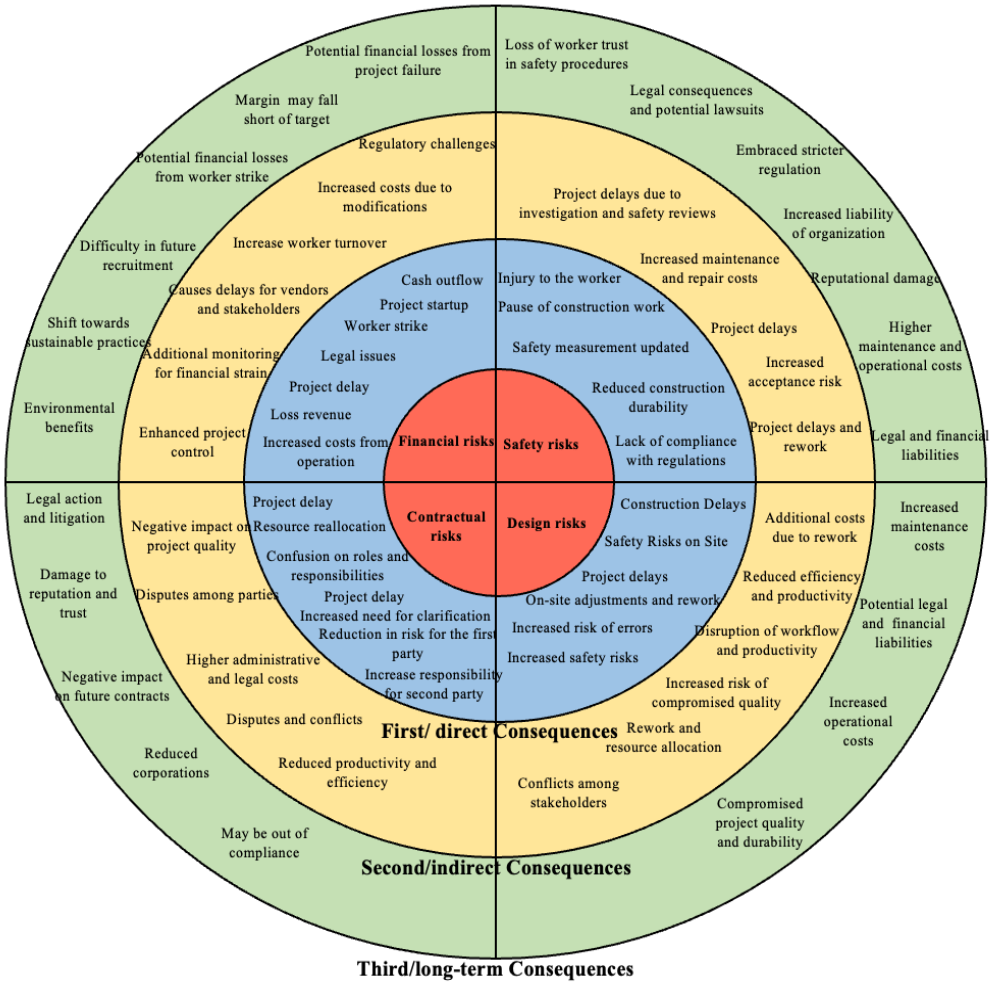


Figure 4.7: Consequences of four risks in construction supply chain
Source: The author

4.4 Discussion

This chapter explores the ripple effects experienced by construction SMEs through a semi-structured interview method. Through thematic analysis of the interviews, the author identifies 13 risk factors that trigger the ripple effect, including financial, safety, design, and contractual risks. In addition, this chapter presents a risk map of the supply chains of construction SMEs, in which 13 risk factors are identified and explained in detail to illustrate their impact on construction SMEs. Moreover, this thesis examines

the root causes and consequences of four types of risk to better understand the sources of vulnerability faced by construction SMEs. The findings indicate that within construction SME supply chains, risks trigger disruptions through complex antecedents that are amplified by the vulnerabilities of SMEs. In addition, stakeholder interactions further intensify these dynamics, ultimately leading to ripple effects in construction SMEs.

The chapter also reveals that ripple effects are amplified by the structural vulnerabilities of SMEs, such as limited financial reserves, weaker bargaining power in contracts, and reliance on a small pool of suppliers. Compared to large enterprises, SMEs exhibit lower resilience to absorbing shocks, which makes the consequences of ripple effects more severe. This aligns with earlier conceptual work suggesting that SMEs are disproportionately exposed to risks due to their structural constraints, but the present findings empirically validate this claim in the Chinese construction context. Furthermore, stakeholder interactions play a pivotal role in shaping ripple effects within construction SME supply chains. The results show that the performance of supervisory agencies and the communication between design firms and contractors are critical in either containing or amplifying disruptions. In many interviews, ineffective supervision or inadequate design reviews were identified as triggers that prolonged project delays and escalated costs.

Through the development of a integrated supply chain map, this chapter found that although SMEs in the construction industry operate within a relatively narrow scope, the nature of their work exposes them to risks originating from a wide range of stakeholders. For example, worker safety issues may arise from labour-related factors, while logistics problems can emerge from material vendors. Based on the root causes of safety risks, it was found that safety risks are often linked to worker skills, design, and material quality. This study highlights the importance of researching ripple effect pathways as well as specific supply chains. It underscores the need to understand how

different types of risks interact and affect the overall performance of construction SMEs, emphasizing the unique risk profiles of supply chain within the construction industry.

4.5 Chapter summary

This chapter identifies the ripple effect factors in the supply chain of construction SMEs through semi-structured interviews with construction project practitioners. In particular, the chapter summarises integrated supply chain risk map and provides root cause analysis and consequences for four common risks. Through the above research, the author found that for construction SMEs, the ripple effect impacts project performance mainly through the transfer of risk and project attributes, resources, and risks. Additionally, this chapter based on the empirical study reveals the real-life perceptions of construction SMEs regarding the ripple effect and the main sources of risk that contribute to it. Furthermore, this chapter serves as a rare realisation of the fundamental analysis of risk for SMEs in construction supply chain. Due to the inherent attributes of construction SMEs, there is a lack of effective ranking and recognition of the importance of the summarised ripple effect factors. Therefore, this chapter also provides a rationale for the subsequent chapters.

Chapter 5 Impact of ripple effect factors

5.1 Chapter overview

This chapter prioritises the key risk factors that contribute to ripple effects within construction SME supply chains by evaluating their relative importance, thereby addressing RQ2: *What is the impact of these risk factors on construction SMEs in the context of ripple effects (Figure 5.1)?* By prioritising the relative significance of different risk factors, this chapter provides insights into how ripple effects emerge and vary in intensity across construction SME contexts, thereby illustrating how risk propagation affects different types of SMEs and ultimately influences project performance and supply chain outcomes. Section 5.2 presents the AHP results for six types of construction SMEs, highlighting the relative importance of the four risks. Section 5.3 explains the findings of the sensitivity analysis, while Section 5.4 discusses the underlying reasons for the risk rankings and their implications for both academia and industry. Finally, Section 5.5 provides a summary of the chapter.

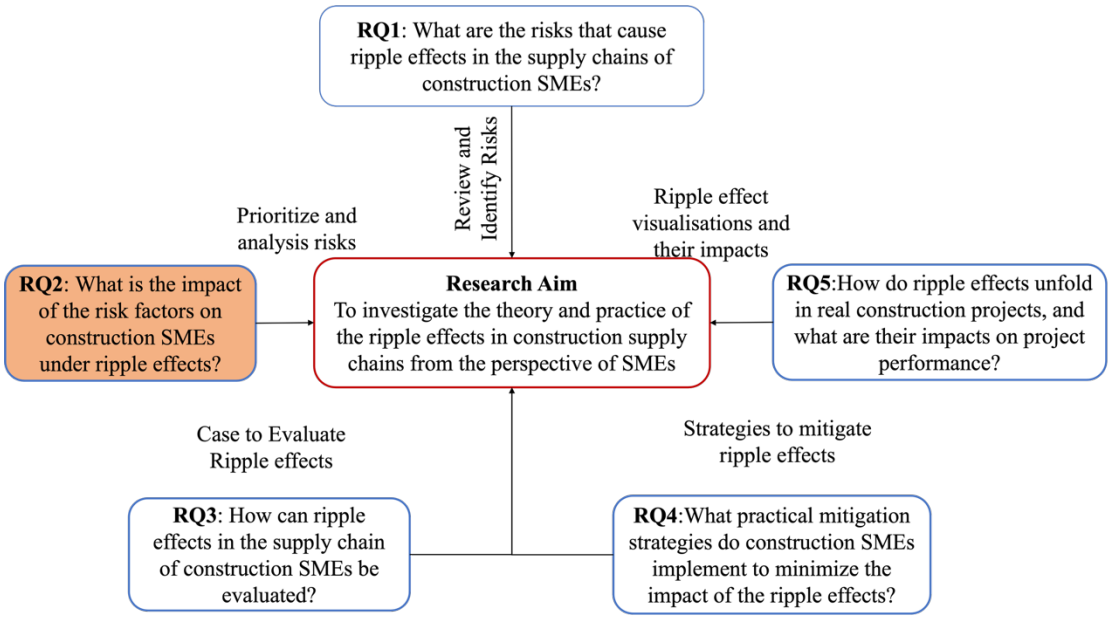


Figure 5.1: Chapter 5 Thesis Structure

Source: The author

Guided by the research questions, a survey incorporating the AHP was used to examine the relative importance of factors contributing to supply chain ripple effects. This approach was selected due to the limited availability of empirical evidence and the scarcity of reliable data on construction SMEs. As highlighted in Chapter 3, the use of a survey method was appropriate for generating broader empirical insights, and its design was informed by the qualitative interview findings. The questionnaire was structured according to the AHP methodology, enabling respondents to perform pairwise comparisons of risk factors. An additional section was included to collect respondent background information, such as industry segment and years of experience to allow for further segmentation of results. The questionnaire was initially drafted in English, translated into Chinese by the author, and subsequently back translated to ensure linguistic accuracy (Appendix C).

Prior to formal distribution, a pilot test was conducted to check for errors, ensure conceptual clarity, and confirm alignment with AHP methodological standards. Minor revisions were made to improve wording and the sequencing of items. The final questionnaire was distributed to 1,440 potential respondents through social media platforms, resulting in 470 responses, of which 240 were retained after screening for completeness and validity. Validity screening involved removing responses with excessive missing data, logical inconsistencies, or failure to meet the predefined eligibility and consistency criteria. Based on the characteristics of the respondents and their organisational roles within the construction supply chain, the valid responses were further categorised into six SME segments: Design companies, material suppliers, renovation firms, engineering companies, construction management firms, and general contractors. This segmentation enabled a more detailed comparison of risk priorities across different types of construction SMEs.

The AHP was then applied to evaluate the relative importance of the identified risk factors across these six SME categories. To further assess the robustness of the results, a sensitivity analysis was conducted to examine how variations in weighting parameters

might influence the ranking outcomes. The results of the sensitivity analysis confirmed the stability of the risk prioritisation, indicating that the model remained consistent under different weighting scenarios.

5.2 Results

The AHP method identifies ranking for six different types of construction SMEs ripple effect factors. Table 5.1 summarizes participant information. All participants informed consent for the questionnaire, and the data were anonymised. The screening process resulted in a total of 54 experts: 7 from design companies, 13 from material suppliers, 4 from renovation firms, 17 from engineering companies, 4 from construction management, and 9 from general contractors. The AHP requires a sufficient number of respondents to produce reliable and generalisable weightings at the group level. Therefore, aggregation was necessary to attain a robust sample size (with a minimum of four respondents per subgroup) for sector-level interpretation, while subgroup analyses were conducted to preserve the nuance of role-specific perceptions (Darko et al. 2019). Although the AHP results were aggregated to generate an overall set of priority weights, the data were also analysed according to company type to identify potential differences across respondent groups. This approach ensured that the aggregation process did not obscure meaningful variations in perspectives across different roles within the construction supply chain. Based on the questionnaire results, respondents represented a diverse range of firm types corresponding to different supply chain roles. Table 5.1 presents the frequency distribution of experts according to supply chain role, department, years of experience, and company size. The largest departmental representation is from the production sector, with 16 experts. Among the participants, 26 out of 54 experts have been in the industry for 5 to 10 years. In terms of company size, 16 experts locate companies with 50 to 100 employees, while 11 locate companies with 200 to 250 employees.

Table 5.1: Participants information

Respondent Characteristics		Frequency
Supply chain role	Design company	7
	Material supplier	13
	Renovation	4
	Engineering company	17
	Construction management	4
	General contractor	9
Department	Management	14
	Production	16
	Design	10
	Engineering	4
	Construction	2
	Project	5
	Technical	3
Year of experience (x)	x<5	12
	5<=x<10	26
	10<=x<15	3
	15<=x<20	3
	20<=x<25	3
	25<=x<30	2
	30<=x<50	5
Company size (y)	y<10	3
	10<=y<50	6
	50<=y<100	16
	100<=y<150	6
	150<=y<200	6
	200<=y<250	11
	250<=y<300	6

Source: The author

Table 5.2 presents the weight evaluation of financial, safety, contractual, and design risks in construction SMEs, as assessed by experts from six different sectors. These four risk categories were originally identified through thematic analysis in Chapter 4. The AHP results therefore serve to quantitatively validate and prioritise the qualitatively derived risk framework, allowing for a more structured comparison of their relative importance across different segments of the construction supply chain. The results indicate that construction SMEs across different sectors assign varying

levels of importance to these risks. Specifically, SMEs in the renovation and general contracting sectors consider financial risks to be the most significant, whereas SMEs in project design, material supply, engineering, and construction management prioritize safety risks.

Table 5.2: Importance rating of risks criteria

	Financial risks (A)	Safety risks (B)	Contractual risks (C)	Design risks (D)
Design company	0.2788	**0.4076**	0.1038	0.2098
Material supplier	0.2057	**0.4395**	0.1911	0.1638
Renovation	**0.3518**	0.2197	0.1642	0.2643
Engineering company	0.2280	**0.2996**	0.1968	0.2756
Construction management	0.0990	**0.5447**	0.2471	0.1092
General contractor	**0.4180**	0.2882	0.1722	0.1217
Average	0.2635	**0.3665**	0.1792	0.1704

Source: The author

Table 5.3 presents the prioritised weightings of the criteria across the 13 identified risk factors. When aggregating the ratings from experts in the design, material supply, engineering, and construction management sectors, worker safety issues receive the highest weighting (0.1782, 0.2282, 0.1302, and 0.2787), underscoring the critical importance of safety risks in their respective domains. Additionally, experts in the renovation and general contracting sectors place greater emphasis on financial risks (0.1567 and 0.1778). The significance of risks and contributing factors across different industry sectors will be further analysed in the following discussion.

Table 5.3: Importance rating of risks factors criteria

Industry	Advance funds for the project	Delay in wage payment	Environmental issues	Worker safety issues	Logistics reliability	Low quality of equipment and materials	Ineffectiveness of supervision mechanisms	Failure to perform an obligation	Contractual ambiguity	Transfer unavoidable risks to other stakeholders	Design errors	Miscommunication for material size and features	Failure to carry out a second check
Design company	0.1438	0.1003	0.0347	0.1782	0.0798	0.0914	0.0582	0.0451	0.0406	0.0181	0.1194	0.0549	0.0356
Material supplier	0.0463	0.0797	0.0797	0.2282	0.0533	0.0852	0.0728	0.0682	0.0446	0.0783	0.0653	0.0404	0.0581
Renovation	0.1567	0.0881	0.1070	0.0616	0.0290	0.0710	0.0581	0.0547	0.0556	0.0539	0.0772	0.0659	0.1213
Engineering company	0.0895	0.0723	0.0663	0.1302	0.0471	0.0526	0.0696	0.0638	0.0753	0.0577	0.1222	0.0736	0.0799
Construction management	0.0536	0.0369	0.0085	0.2787	0.0379	0.1383	0.0897	0.0842	0.0736	0.0894	0.0266	0.0342	0.0483
General contractor	0.1778	0.1772	0.0630	0.1152	0.0934	0.0531	0.0265	0.0762	0.0709	0.0250	0.0555	0.0543	0.0118

Source: The author

5.2.1 Design company

In the field of project design, seven experts ranked the ripple effect of risks in the following order of importance: Safety risk (B), financial risk (A), design risk (D), and contractual risk (C). According to project guidelines, safety issues are a primary cause of project failure, as they frequently lead to disruptions (Qian and Lin 2016). Within the safety category, worker safety issue (B_1) holds the highest importance, with a weighting of 0.1782. Analysis showed a consistent pattern across design company types, indicating broad agreement that worker safety is the most critical safety-related concern for construction SMEs. This observation aligns with the strong emphasis that design companies place on construction-stage safety management, including the development of material safety controls and adherence to safety guidelines, as highlighted by Lingard et al. (2012). The importance of ripple effects for design companies is illustrated in Table 5.4.

Table 5.4: Project design importance of ripple effects on construction SMEs

Objective	Criteria	Weights	Ranks	Sub-Criteria	Weights	Sub-Ranks
Examine the ranking of risks that trigger ripple effects within the segmented supply chains of construction SMEs.	A	0.2788	2	($A_{1)}$	0.1438	1
				(A_2)	0.1003	2
				(A_3)	0.0347	3
	B	0.4075	1	(B_1)	0.1782	1
				(B_2)	0.0798	3
				(B_3)	0.0914	2
				(B_4)	0.0582	4
	C	0.1038	4	(C_1)	0.0451	1
				(C_2)	0.0406	2
				(C_3)	0.0181	3
	(D)	0.2098	3	(D_1)	0.1194	1
				(D_2)	0.0549	2
				(D_3)	0.0356	3
CCR= 0.0300 ≤ 0.1						

Source: The author

Beyond safety risk, financial risk is the second most significant factor contributing to the ripple effect (0.2788), with advance funds accounting for the largest proportion.

Surprisingly, design risk ranked third in importance (0.2098). Given the frequent occurrence of design-related issues in real cases, further exploration of design risk factors, such as design errors (0.1194), is necessary in future studies. Contractual risk ranked the lowest among the four risk categories. From the perspective of design companies, many contract-related risks are mitigated by completing the initial drawings, for which clients provide upfront payment (Abdul Nabi et al. 2020)

5.2.2 Material supplier

In the field of material supply, 13 experts ranked the ripple effect factors in the following order of importance: Safety risk (B), financial risk (A), contractual risk (C), and design risk (D). Among safety risk factors, worker safety issues (B_1) are considered the most critical (0.2282). The material supplier industry relies heavily on workers to process materials such as steel, wood, and glass based on design specifications, leading companies to prioritise worker safety (King 2013). Additionally, worker safety issues can have severe consequences, often resulting in prolonged production disruptions and extended safety inspections (James et al. 2015). Table 5.5 presents the importance of ripple effects from the perspective of material suppliers.

Table 5.5: Material importance of ripple effects on construction SMEs

Objective	Criteria	Weights	Ranks	Sub-Criteria	Weights	Sub-Ranks
Examine the ranking of risks that trigger ripple effects within the segmented supply chains of construction SMEs.	A	0.2057	2	(A1)	0.0463	2
				(A2)	0.0797	1
				(A3)	0.0797	1
	B	0.4394	1	(B1)	0.2282	1
				(B2)	0.0533	4
				(B3)	0.0852	2
				(B4)	0.0728	3
	C	0.1910	3	(C1)	0.0682	2
				(C2)	0.0446	3
				(C3)	0.0783	1
	(D)	0.1637	4	(D1)	0.0653	1
				(D2)	0.0404	3
				(D3)	0.0581	2
CCR= 0.0432 ≤ 0.1						

Source: The author

On the other hand, Material suppliers rely heavily on the consistent productivity of their workers, making financial risk the second most significant factor contributing to the ripple effect (Barbosa et al. 2017). Furthermore, environmental issues (A_2) and delayed wage payments ($A_{3)}$ within financial risk were also identified as potential triggers of ripple effects. Among contractual risk factors, the transfer of unavoidable risks to other stakeholders (0.0783) is identified as the most critical factor, while design errors (D_1) rank highest within design risk (0.0653). These challenges are common among material supplier companies in practice.

5.2.3 Renovation

In the renovation sector of construction SMEs, experts confirmed the significant impact of the ripple effect caused by financial risks (0.3517). Design risk ranked second in importance, followed by safety risk and contractual risk. Among financial risks, advance funding was identified as the most critical factor (0.1567). Within design risks, failure to carry out a second check (0.1213) was identified as the most important factor. This reflects the reality that renovations often rely on customised drawings, and failing to conduct a second check can lead to rework and incorrect construction (Mitropoulos and Howell 2002). Table 5.6 presents the importance rankings assigned by renovation experts.

Safety risk (0.2197) was ranked third, with low quality of equipment and materials (0.0710) as the most significant contributor. This finding highlights how material substitution or the procurement of substandard products, influencing quality outcomes and project performance. It demonstrates the interconnectedness between financial pressures and safety-related risks, since SMEs with limited financial reserves may prioritise cost-saving measures over quality assurance (Kima et al. 2024), inadvertently creating ripple effects across other dimensions.

Finally, contractual risk (0.1641), though ranked lowest overall, still plays a non-negligible role in shaping ripple effects. Within this category, contractual ambiguity (0.0556) was perceived as the most critical factor. Ambiguities in contract terms can create disputes between SMEs and their clients or subcontractors, particularly regarding payment schedules, scope of work, or responsibility for defects (Koc and Gurgun 2022). Such disputes often delay project execution and escalate into legal or reputational risks that extend ripple effects into future projects.

Table 5.6: Renovation importance of ripple effects on construction SMEs

Objective	Criteria	Weights	Ranks	Sub-Criteria	Weights	Sub-Ranks
Examine the ranking of risks that trigger ripple effects within the segmented supply chains of construction SMEs.	A	0.3517	1	($A_{1)}$	0.1567	1
				(A_2)	0.0881	3
				(A_3)	0.107	2
	B	0.2197	3	(B_1)	0.0616	2
				(B_2)	0.0290	4
				(B_3)	0.0710	1
				(B_4)	0.0581	3
	C	0.1641	4	(C_1)	0.0547	2
				(C_2)	0.0556	1
				(C_3)	0.0539	3
	(D)	0.2643	2	(D_1)	0.0772	2
				(D_2)	0.0659	3
				(D_3)	0.1213	1
CCR= 0.0355 ≤ 0.1						

Source: The author

5.2.4 Engineering company

In construction SMEs related to engineering companies, safety risk (0.2995) is the most significant factor contributing to the ripple effect. Among safety risk factors, worker safety issues are particularly critical (0.1302). Given the nature of construction work, worker safety remains a constant concern throughout the project (Lingard and Rowlinson 2004). Design risk ranked second in importance, with design errors identified as the most significant risk within this category (0.1222). Beyond design

concerns, the ripple effect of advance payments (0.0895) within financial risk is also significant for building construction companies. Advance payments for projects, particularly those related to materials and labour, are common in engineering construction (Alaghbari et al. 2007). Additionally, contractual ambiguity (0.0753) is a notable risk factor within contractual risk for engineering companies. Table 5.7 presents the importance rankings assigned by engineering construction experts.

Table 5.7: Engineering construction of ripple effects on construction SMEs

Objective	Criteria	Weights	Ranks	Sub-Criteria	Weights	Sub-Ranks
Examine the ranking of risks that trigger ripple effects within the segmented supply chains of construction SMEs.	A	0.2280	3	($A_{1)}$	0.0895	1
				(A_2)	0.0723	2
				(A_3)	0.0663	3
	B	0.2995	1	(B_1)	0.1302	1
				(B_2)	0.0471	4
				(B_3)	0.0526	3
				(B_4)	0.0696	2
	C	0.1967	4	(C_1)	0.0638	2
				(C_2)	0.0753	1
				(C_3)	0.0577	3
	(D)	0.2756	2	(D_1)	0.1222	1
				(D_2)	0.0736	3
				(D_3)	0.0799	2
CCR= 0.0470 ≤ 0.1						

Source: The author

5.2.5 Construction management

In the field of construction management, experts placed significant emphasis on safety risks (0.5447), with worker safety issues identified as the most critical factor (0.2787). From a supervisory and management perspective, disruptions caused by safety issues are particularly severe, as frequently observed in real-world scenarios (Leveson 2016). Beyond safety concerns, contractual risk was also considered important by construction management experts, with the transfer of unavoidable risks to other stakeholders (0.0894) identified as a critical issue. This concern stems from the absence of a robust

contractual framework in the management of construction SMEs (Offei et al. 2019). Meanwhile, among the design-related risk factors, the failure to carry out a second check (0.0483) was also highlighted by experts. Financial risk, which is widely recognised as one of the most critical risks across various domains, was surprisingly ranked fourth in importance (0.0989), which requires further exploration to understand the underlying reasons. Table 5.8 presents the importance rankings assigned by construction management experts.

Table 5.8: Construction management of ripple effects on construction SMEs

Objective	Criteria	Weights	Ranks	Sub-Criteria	Weights	Sub-Ranks
Examine the ranking of risks that trigger ripple effects within the segmented supply chains of construction SMEs.	A	0. 0989	4	($A_{1)}$	0.0536	1
				(A_2)	0.0369	2
				(A_3)	0.0085	3
	B	0. 5447	1	(B_1)	0.2787	1
				(B_2)	0.0379	4
				(B_3)	0.1383	2
				(B_4)	0.0897	3
	C	0.2471	2	(C_1)	0.0842	2
				(C_2)	0.0736	3
				(C_3)	0.0894	1
	(D)	0.1091	3	(D_1)	0.0266	3
				(D_2)	0.0342	2
				(D_3)	0.0483	1
CCR= 0.0660 ≤ 0.1						

Source: The author

5.2.6 General contractor

In the general contracting field, experts prioritise financial risks (0.4179), followed by safety risks, contractual risks, and design risks. Among financial risk factors, advance funding (0.1778) is identified as the most critical triggers of the ripple effect, highlighting the overall emphasis on financial risks and their impact. As general contractors, they often need to make upfront payments for equipment and wages before a project begins, increasing their financial burden (Cui et al. 2010). Beyond financial

concerns, worker safety (0.1152) was also highlighted as a key factor within the safety risk category.

Contractual risk ranked third in importance, with failure to perform an obligation (0.0762) identified as a significant issue. While design risk was acknowledged by experts, it ranked lowest in importance compared to the other risk categories. One possible explanation is that design risks occur frequently and are typically resolved quickly (Whang et al. 2023). However, if such risks persist or occur constantly, they may trigger significant ripple effects. The general contractor importance is demonstrated in the Table 5.9.

Table 5.9 : General contractors of ripple effects on construction SMEs

Objective	Criteria	Weights	Ranks	Sub-Criteria	Weights	Sub-Ranks
Examine the ranking of risks that trigger ripple effects within the segmented supply chains of construction SMEs.	A	0. 4179	1	A_1	0.1778	1
				(A_2)	0.1772	2
				(A_3)	0.063	3
	B	0. 2881	2	(B_1)	0.1152	1
				(B_2)	0.0934	2
				(B_3)	0.0531	3
				(B_4)	0.0265	4
	C	0.1721	3	(C_1)	0.0762	1
				(C_2)	0.0709	2
				(C_3)	0.0250	3
	(D)	0.1216	4	(D_1)	0.0555	1
				(D_2)	0.0543	2
				(D_3)	0.0118	3
CCR=0.0416 ≤ 0.1						

Source: The author

5.3 Sensitivity analysis

Based on the prioritization results from six types of construction SMEs, this study establishes the importance ranking of four risk categories. However, variations in the weights assigned to different risk factors can alter the final ranking, necessitating a stability assessment under different weight distributions (Pecchia et al. 2011). To

address this, sensitivity analyses have been conducted using scenarios that reflect varying perspectives on the future development of the relative importance of criteria. By adjusting the weight of a single criterion (increasing or decreasing), its impact on risk prioritization and the ranking of the four risk categories can be observed.

To ensure a comprehensive analysis, the weights of key criteria should be adjusted individually, simulating variations from 0% to 100%, while maintaining a total weight of 100% by proportionally adjusting the other criteria (Triantaphyllou and Sánchez 1997). Sensitivity analyses are essential for evaluating the influence of different risk factors across the six types of construction SMEs. If the ranking proves highly sensitive to minor weight adjustments, additional decision criteria should be considered, as such sensitivity indicates weak discriminatory power within the current set of criteria (Chang et al. 2007). Furthermore, if a weight fluctuates significantly across different assumptions or scenarios, signalling its critical role in the decision-making process, additional risk mitigation measures should be implemented to enhance decision robustness (Erkut and Tarimcilar 1991).

The local priority weights of the selected subjective factors were varied using the Yaahp software. The performance graph shown in the Figure 5.2 illustrates the impact of the four risk categories as their relative weights increase. Table 5.10 summarised weight ranges from 0-1 (equivalent to 0–100% of total weight) for risk factors. A cross-sectional analysis of the 13 identified risk factors revealed that delay in wage payment (0.10–0.38) in financial risk, failure to perform an obligation (0.06–0.37), logistics reliability (0.15–0.44) in safety risk, and design errors (0.08–0.42) in design risk exhibited the most significant variations under changing weight conditions. These findings underscore the critical need to mitigate these risks to prevent adverse ripple effects within the construction supply chain.

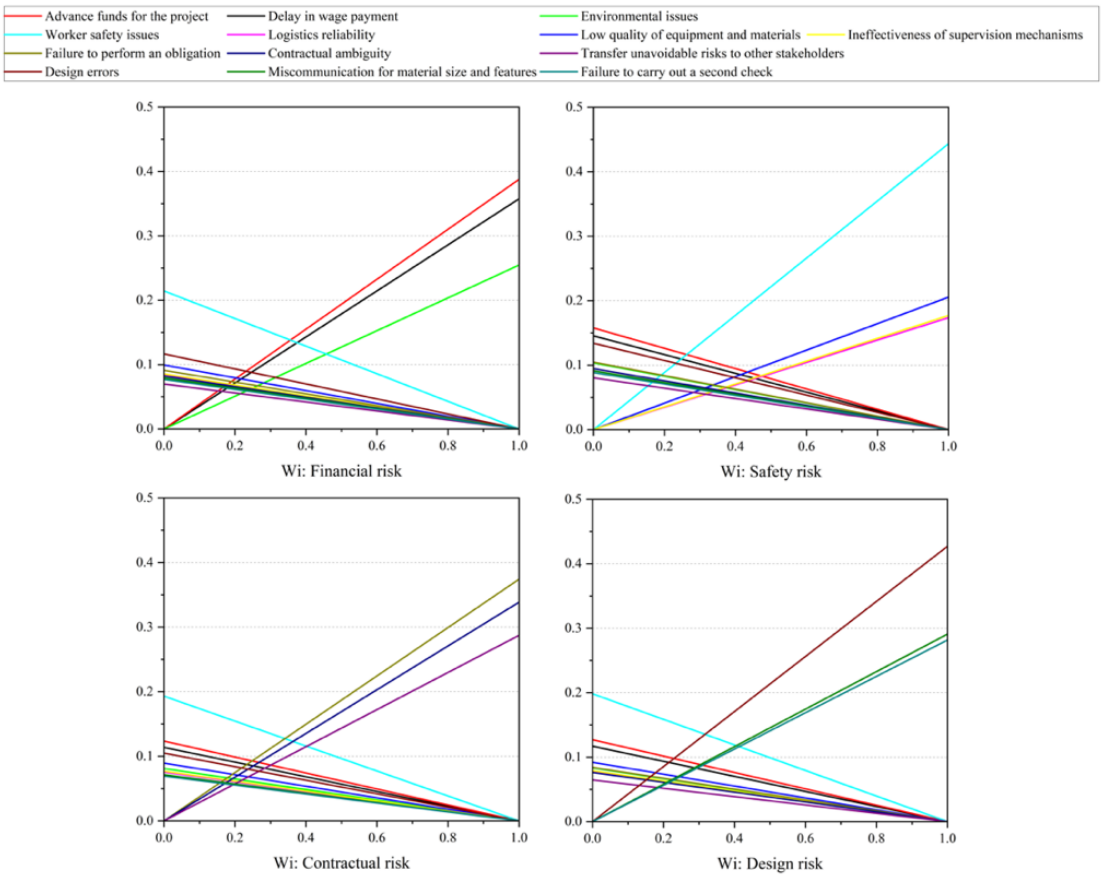


Figure 5.2: Performance sensitivity for four risk relative weights increases

Source: The author

These results underscore two key insights. First, the ranking of risk categories remains broadly stable under moderate weight adjustments, suggesting that the overall model demonstrates a reasonable degree of robustness. Second, certain factors are highly sensitive to weight shifts, indicating their decisive role in shaping the prioritisation outcome. In particular, the prominence of wage payments delays, contractual obligations, logistics reliability, and design errors aligns with both the interview evidence and the literature, highlighting their critical role in the ripple effects observed in construction SME supply chains.

Table 5.10: Weight ranges from 0-1 for four risks and factors

Criteria	Sub-Criteria	Weight Ranges
Financial risks(A)	Advance funds for the project (A_1)	0.09 - 0.35
	Delay in wage payment (A_2)	0.10 - 0.38
	Environmental issues (A_3)	0.06 - 0.25
Safety risks (B)	Worker safety issues (B_1)	0.07 - 0.20
	Logistics reliability (B_2)	0.15 - 0.44
	Low quality of equipment and materials (B_3)	0.06 - 0.17
	Ineffectiveness of supervision mechanisms (B_4)	0.06 - 0.17
Contractual risks (C)	Failure to perform an obligation (C_1)	0.06 - 0.37
	Contractual ambiguity (C_2)	0.06 - 0.33
	Transfer unavoidable risks to other stakeholders (C_3)	0.05 - 0.28
Design risks (D)	Design errors (D_1)	0.08 - 0.42
	Miscommunication for material size and features (D_2)	0.05 - 0.29
	Failure to carry out a second check (D_3)	0.05 - 0.28

Source: The author

5.4 Discussion

In the overall ranking of ripple effect importance by the 54 experts, safety and financial risk emerged as the most significant concerns, followed by contractual, and design risks. Furthermore, Sensitivity analysis was applied to test the stability of AHP rankings. By varying input weights and observing whether ranking orders changed, this analysis demonstrated the robustness and substantive significance of the prioritised risk factors beyond numerical differences. However, notable variations in risk importance rankings were identified across the six company categories. These differences underscore the need for tailored risk mitigation strategies for each firm type. Section 5.4.1 presents mitigation strategies for financial and safety risks across the six categories of construction SMEs, while Section 5.4.2 further examines the ranking of risks for each company type and outlines detailed mitigation approaches.

5.4.1 Mitigation strategies for financial and safety risks

From the results, the author found that advance funding for projects within financial risks and worker safety issues within safety risks were considered the most significant factors contributing to ripple effects across the six construction sectors assessed by 54 experts. Worker safety issues are regarded by experts as the most critical aspect of safety risks in design companies, material suppliers, engineering firms, and construction management. This risk has severe consequences, affecting both day-to-day operations and the design phase, and potentially leading to disruptions, legal liabilities, design complications, and financial losses (Cruz et al. 2015). Given the high stakes associated with worker safety, mitigation strategies are essential to reducing these risks. One of the primary mitigation strategies is to enhance worker safety training, including routine supervision and the strict enforcement of safety protocols (Benson et al. 2024). Ensuring that workers consistently wear appropriate safety equipment can significantly reduce the likelihood of accidents (Abdalla et al. 2018). Additionally, from a perspective of policymaker, increasing regulatory safety requirements and mandatory training programs can improve worker awareness of safety hazards, empowering them to proactively identify and address risks in their work environment. Strengthening safety education and enforcement across all levels of the construction supply chain is crucial to minimizing safety-related disruptions and ensuring a safer working environment for construction SMEs (Li and Poon 2013).

Advance funding for projects is widely recognised in the literature as a common practice in construction, particularly to cover personnel costs, equipment, and materials (Winch 2012). Furthermore, the findings of this study indicate that for construction SMEs, especially those operating in the renovation and general contracting sectors, managing pre-financing risks is critical to maintaining financial stability and ensuring project efficiency. As a mitigation strategy, SMEs can optimize the timing of equipment rentals by accurately controlling material expenditures (Schwab et al. 2019). This ensures that resources are allocated efficiently without unnecessary financial strain.

Additionally, scheduling the project in a step-by-step manner can help manage cash flow more effectively, allowing firms to align expenses with project milestones (Venkataraman and Pinto 2023). Furthermore, accessing SME-specific loan policies or financial assistance programs can alleviate the burden of pre-financing, providing firms with greater flexibility and reducing financial risks associated with advance payments (De la Torre et al. 2010). Implementing these strategies can enhance financial resilience and ensure smoother project execution for construction SMEs.

5.4.2 Ripple effect ranking importance for six different types of construction SMEs

The results for the six types of construction SMEs were presented in the previous section; this part further discusses each type of construction SMEs individually, providing a detailed explanation of the ranking results. For a design company, its primary role is to create accurate construction drawings based on field measurements and make real-time adjustments as needed during the construction process. One of its key responsibilities is ensuring worker safety, as errors in design can directly lead to hazardous conditions on-site. Additionally, financial risk is a critical factor, particularly for construction contractors, who must carefully allocate resources. Given that many SMEs operate with limited funds, design firms can collaborate with contractors early in the process to optimize material selection, ensuring compliance with project standards while reducing financial pressure (Fulford and Standing 2014).

Design errors are another significant risk, often surfacing during the construction phase. To mitigate this, early and effective communication between designers, contractors, and supervisors is essential (Sacks et al. 2018). Additionally, the findings indicate that failure to perform contractual obligations represents a significant concern. As design work is typically completed prior to the commencement of construction, discrepancies may arise when construction teams do not adhere to approved drawings. Such deviations often result in liability disputes and contractual conflicts. To address this, design companies should maintain active coordination with project supervisors

throughout the construction process to ensure adherence to the original plans, thus preventing misinterpretations and ensuring project consistency (Kerzner 2025).

For material suppliers, the primary responsibility is to produce and deliver materials in accordance with project specifications (Munyimi 2019). In addition to ensuring worker safety, they also face financial risks, particularly those arising from delayed wage payments and environmental issues. To mitigate these risks, suppliers should establish regular payment agreements, such as instalment payments or milestone-based payment schedules, ensuring that payments are made when supply reaches a predetermined level (Faraji et al. 2021). Moreover, contractual risks related to transferring unavoidable risks to other stakeholders should be carefully managed. By negotiating clear payment terms with downstream customers, suppliers can safeguard their financial stability and minimize disputes over delayed payments (Francis et al. 2016). Design errors also present potential risks, as misaligned material specifications can lead to costly rework. To prevent such issues, suppliers should ensure that material designs and specifications are clearly defined in contracts. Providing material samples to customers before production begins can further validate compatibility and prevent design-related supply chain disruptions (Khan et al. 2012). These proactive strategies strengthen supplier resilience, ensuring smooth project execution and minimizing ripple effects in the construction supply chain.

For renovation, its primary responsibility is as a contractor managing overall renovation and remodelling activities. The financial risk of advance funds for the project is common in this sector (Dandago et al. 2025). In addition, the failure to carry out a second check mainly arises during the construction process (Smith 2021). To mitigate these risks, renovation firms can be involved from the design stage to reduce design errors and understand the field measurement process (Qi et al. 2019). Regular communication with the supervisor can also minimize the impact of design risk. Beyond design risks, experts also highlighted the safety risk posed by low-quality equipment and materials. Mitigation measures include preventing material

incompatibility with construction requirements by ensuring a thorough understanding of material properties prior to use (Allen and Iano 2019). Additionally, contractual ambiguity in contractual risk can be mitigated through clear communication with experienced practitioners and by ensuring explicit and well-defined project agreements (Ryall and Sampson 2017).

For engineering companies specialising in structural and civil engineering construction and project technical support, safety risks are considered the primary concern by experts. Design errors rank as the second, as structural miscalculations can have severe consequences (Lopez et al. 2010). To mitigate this, practitioners should carefully evaluate functional structural relationships during the design stage and maintain close oversight throughout the construction process (Clough et al. 2015). Beyond design risk, financial risk is considered less significant in engineering companies compared to other sectors, as noted by experts. This is partly because engineering companies typically require payment before commencing work. Lastly, contractual risk ranked lowest in importance. However, contractual ambiguity remains a key issue, particularly regarding issue attribution. To address this, engineering companies must engage in thorough communication with stakeholders during the structural design phase to ensure clarity and alignment on project expectations (Ward and Chapman 2008).

For construction management, which is responsible for overseeing and coordinating projects, experts identified safety risks as the top priority. In addition, the transfer of unavoidable risks to other stakeholders, classified under contractual risk, is ranked as the second most significant ripple effect factor. This is primarily attributed to the uncertainty surrounding stakeholder roles throughout the project process. To mitigate this risk, clearly defining stakeholder responsibilities at the outset can help reduce disputes and enhance accountability (Oehmen et al. 2012). Design risk in construction management mainly manifests as failure to carry out a second check, which is particularly critical for construction SMEs. To address this, the management company should implement inspections early in the project to detect potential errors and gaps

between the plan and reality at an early stage (Park et al. 2013). Financial risks are often managed at higher organisational levels by project owners or senior management and therefore may be perceived as less immediate by site-level construction managers. Consequently, safety risks tend to receive greater priority in their assessments.

The general contractor is responsible for managing and coordinating the entire construction project. Experts highlighted the requirement for advance project funding as the primary concern, followed by worker safety issues as the second most significant concern. Additionally, failure to perform an obligation was recognized as a relative high importance. This occurs when workers or suppliers fail to fulfil their responsibilities, such as substandard work or delays in material deliveries. To mitigate this, contracts should clearly specify accountability for obligations and define consequences for non-compliance from the beginning (Tukamuhabwa 2012). Design risks in general contracting frequently arise in the form of design errors, which are common throughout the project lifecycle. To mitigate these risks, effective process management is essential, ensuring continuous coordination between design teams and construction teams to identify and rectify design issues early (Kerzner 2025).

5.5 Chapter summary

This chapter applies the AHP methodology, integrated into a survey of construction project practitioners, to prioritise the key ripple effect factors affecting SMEs in the construction industry. It summarises the ranked importance of six categories of construction SMEs: Design companies, material suppliers, renovation, engineering companies, construction management, and general contractors, providing a rationale for these rankings. Additionally, the chapter highlights the four risk factors that undergo the weight changes through sensitivity analyses. The findings suggest that ripple effects in construction SMEs are strongly influenced by segmentation within the sector, indicating that different types of construction SMEs experience varying risks associated with ripple effects. Consequently, further segmentation of construction SMEs could

enhance the understanding and management of these risks for both academics and practitioners. Moreover, this chapter presents the empirical ranking of the most critical ripple effect factors based on the results from six types of stakeholders within construction SMEs, offering valuable insights into their significance for the construction sector.

Chapter 6 Ripple effect case study

6.1 Chapter overview

The purpose of this chapter is to present a real-world case of a construction SME, illustrating the ripple effect challenges encountered in practice and examining the mitigation strategies adopted. In Chapter 5, the AHP analysis demonstrated that the relative importance of risks varies across different construction sectors. Building on these findings, this chapter applies a case study approach to examine the propagation of risks within a mobile phone shop renovation project to address Research Questions 3, 4, and 5, as illustrated in Figure 6.1.

Drawing on in-depth interviews with project personnel and direct observations, the chapter investigates how risk events evolve across four categories: financial, safety, contractual, and design, and how they interact to create ripple effects throughout the supply chain. A Causal Loop Diagram (CLD) was developed to map the dynamic interactions among stakeholders and assess their response mechanisms. The identified ripple effects were also classified into three types of impact, and an independent analysis was undertaken to distinguish those effects that were unforeseen by stakeholders. Overall, this chapter aims to illustrate how ripple effects occur within the project, examine their consequences, and explore strategies for managing them.

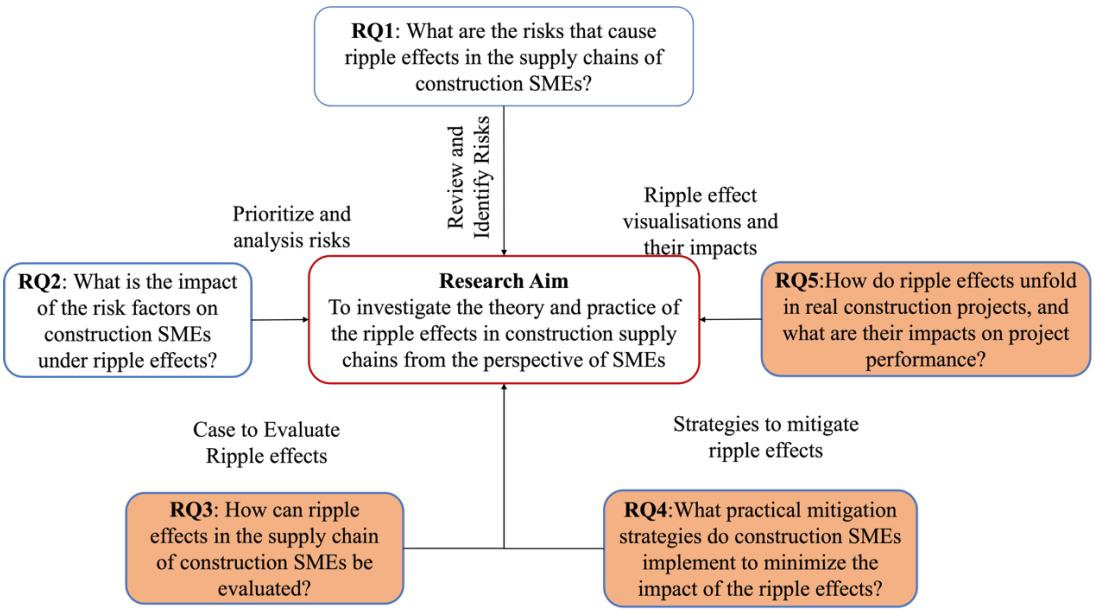


Figure 6.1: Chapter 6 Thesis Structure

Source: The author

The case study focuses on the renovation of a phone store in China, involving design team, brand representatives, supplier, project manager, contractors, and supervisor. Table 6.1 presents data from the Fourth National Economic Census of China, which shows the distribution of legal entities within the construction industry as of the end of 2018 (National Bureau of Statistics of China 2018). According to the census, 22.56% of legal entities were engaged in housebuilding, 24.83% in civil engineering construction, 13.95% in construction and installation, and 38.66% in building renovation or related activities. The mobile phone shop renovation examined here is therefore representative of typical renovation projects, as it did not involve any special materials or processes.

Table 6.1: Number of legal entity units and employees in the Chinese construction industry

	Number of Legal Entity Units	Number of Employees
Total	4157	172091
Residential Building Construction	938	90211

Civil Engineering Construction	1032	42014
Construction Installation Industry	580	18673
Renovation and Other Construction Industries	1607	21193

Source: The author, adapted from National Bureau of Statistics of China (2018)

As discussed in Section 3.6.3.1, this study investigates the operational processes across four project phases: Design, beginning, process, and closeout, using a case study methodology that integrates observations and interviews to examine the dynamics of ripple effects. The key elements observed at each phase are summarised in Table 3.11. The observational data capture daily activities across the different project stages, including the number of participants involved, the nature of work performed, compliance with safety protocols, material availability, and the handling of change requests. Simultaneously, interviews are conducted with project contractors, manager, and supervisor during the preparation, construction, and acceptance phases. These interviews delve into the sources of ripple effect events, their propagation mechanisms, and potential mitigation strategies. The approach involves assessing the interactions among risks and incorporating interviewee reflections on the challenges encountered and the countermeasures implemented. The results provide a comprehensive understanding of how and why ripple effect events emerge and propagate within construction SMEs.

Section 6.2 outlines the use of NVivo software to conduct thematic analysis of the interview data, capturing practitioners' perceptions across four key risk domains. Section 6.3 extends this by exploring practitioners lived experiences in managing ripple effects, highlighting the challenges encountered and the coping strategies adopted within their operational contexts. Section 6.4 presents the CLD and performance diagram developed from these insights, illustrating the mechanisms through which risks propagate and influence project performance. Section 6.5 details the identified ripple effects, their antecedents, resulting consequences, and how they interact each other.

Taken together, these four components provide a detailed understanding of how construction SMEs respond to disturbances and develop adaptive strategies to mitigate ripple effects. By identifying early warning signals and examining real-world mitigation practices, this chapter offers one of the few empirical studies to validate the ripple effect phenomenon in construction projects, contributing practical insights into how SMEs can better anticipate and manage risk propagation.

6.2 Manifestations of the risks in the project

To structure the analysis of risk emergence and propagation, this study adopts four practical project phases: Design, beginning, process, and closeout, which reflect the typical lifecycle stages observed in construction SME projects. this study identified 12 early warning signals that indicate potential supply chain disruptions and ripple effects. These signals are summarised in Table 6.2. These early warning signals exhibit characteristics that span different project phases, involve multiple stakeholders, and generate measurable impacts on project performance. Unlike isolated operational issues, these signals demonstrate the capacity to propagate across interconnected supply chain actors, thereby increasing the likelihood of ripple effect amplification. This section examines how each of the four risk categories manifests across different project phases, analyses their underlying causes and consequences, and evaluates the presence and characteristics of the resulting ripple effects.

Table 6.2: Events and risks during the construction

No.	Stage	Event	Risk type	Causes	Consequence
1	Design	Exterior wall installation	Design risk: Installation not meeting compliance standards due to design miscommunication and time constraints	Tight project timeline and limited quality assurance. Poor communication between design company and construction teams.	Causes delay in project timeline Disputes with the construction team over cost-sharing, further delaying progress
2	Design	Air-conditioning system was designed too close to the roof lights.	Safety risk due to the position between the air-conditioning system and roof lights leading to potential structural and operational issues.	Inadequate spatial planning and safety reviews from design company.	Delayed project timeline due to redesign efforts. Increased costs associated with new materials and labour
3	Design	Glass material selection	Financial risk: Incorrect selection of glass materials, possibly leading to poor durability and financial efficiency concerns.	Inadequate experiences from project manager and insufficient material testing.	Replacement of glass materials
4	Beginning	Disputes with original construction team	Financial and contractual risk: Disagreement over reinstallation costs and material pricing during wall installation	Unclear contractual terms regarding cost from construction team. Pricing disagreements regrading additional materials.	Additional time cost and renegotiation with new construction team. Extended project timelines

5	Process	Water pipes cut during underfloor heating work	Financial and design risk: Disruption to underfloor heating work	Inadequate communication, supervision, and planning within construction teams	Delays in floor finishing timeline. Increased material and labour costs.
6	Process	Floor tile reworked; levels did not meet the required standard	Safety risk: Uneven floor tile installation leading to potential structural instability and safety hazards.	Lack of planning and insufficient quality control during installation from construction team.	levelled into an incline to avoid subsequent work
7	Process	Delay in furniture and material delivery	Design risk for delays in furniture and material delivery	Poor supply chain management and lack of storage facilities.	Extended construction timeline. Additional expenses for delivery and labour
8	Process	Pillar not wide enough to accommodate fire valve and hydronic heating controller	Safety risk regarding structural integrity concerns	Construction team did not consider real fire valve placement and safety requirements.	Structural redesign caused delays
9	Process	Wall wiring and levelling	Design risk: Improper wall wiring and levelling, leading to level and functional issues.	Different wall surface materials were adopted during installation.	Rework caused delays in wall completion. Additional costs for wiring and labour.
10	Process	Hidden work process could not be closed due to wiring issue	Safety risk and construction disruptions due to incomplete electrical circuits.	Insufficient testing during construction.	Increased costs for rewiring and inspections.

11	Process	Observation holes added to ceiling for wiring observation and maintenance	Design risk: Additional observation holes in the ceiling to allow maintenance	Initial design did not consider maintenance accessibility.	Increased labour costs.
12	Closeout	Fire sprinkler system design error	Design risk: Improper placement of fire sprinklers failing to meet safety and design requirement	Inadequate site investigation during the design phase. Lack of communication with fire safety department.	Work suspension for two days to reposition the system, delaying other construction activities.

Source: The author

6.2.1 Financial risks

During an interview conducted in February 2025, the author spoke with a representative from the finance department of the shop to gain insights into the financial status of the project throughout its lifecycle. The financial situation of the project experienced significant strain due to unforeseen risks and their ripple effects (Proselkov et al. 2024). For the phone shop renovation project, the original construction team provided a quoted cost of RMB 388,585.4, whereas the actual expenditure incurred by the replacement team was RMB 336,658.83 with an additional RMB 610 in other costs. This cost difference likely highlights the financial impact of supply chain disruptions and ripple effects, demonstrating either cost savings or unexpected expenses due to the change in contractors (Figure 6.2). This interpretation is supported by cost comparisons and stakeholder interviews, which indicate that the change in contractors led to additional coordination efforts and operational adjustments. To better understand the financial impact of various project events, the costs were categorised into three main components: labour, materials, and equipment. While the labour cost increased by RMB 9,130 due to project delays, the material cost was reduced by RMB 45,796.39 compared to the budget, and the equipment cost decreased by RMB 15,260.18.

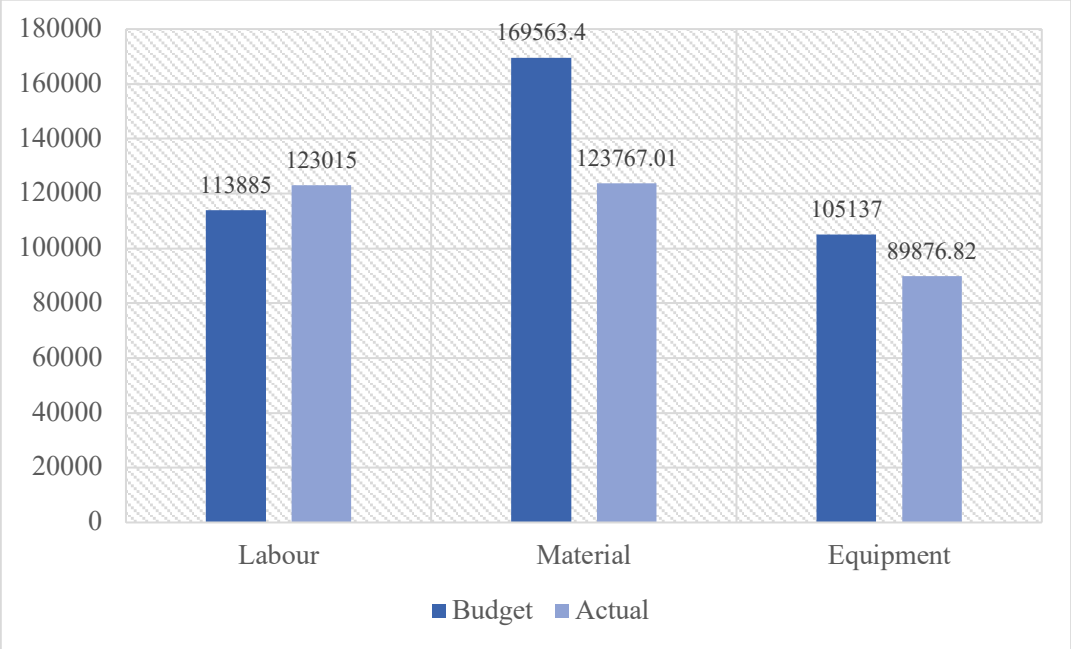


Figure 6.2: Budget compared to actual cost

Source: The author

The increase in labour costs beyond the initial budget was primarily attributed to unforeseen events during the construction process. One example was the difficulty in wall wiring and levelling caused by a change in materials, which extended working hours and resulted in increased overtime expenses for construction workers. These unexpected costs illustrate the financial ripple effects caused by project disruptions, reinforcing the importance of proactive risk management and contingency planning in construction SMEs. Further examination of procurement records and discussions with project stakeholders revealed that the raise in material and equipment costs was primarily associated with adjustments to the cost of glass doors and disputes over wall construction, which are discussed under contractual risk.

The selection of glass door materials also exposed significant inconsistencies between the quotations of construction team and the actual costs incurred. Specifically, the initial quotation included RMB 13,050 for glass doors, RMB 42,500 for windows, and RMB 226 for a glass crash bar, totalling RMB 55,776. However, the actual cost of the glass

doors alone amounted to RMB 36,017.82. In an interview with the project supervisor, the supervisor explained the reasoning behind this discrepancy:

> *The design team initially laid out the shop's requirements based on input from the shop. One crucial consideration was whether the material for the glass doors needed modification to withstand the region's cold winters. This issue might have gone unnoticed had it not been identified during the planning phase. As one first-time project manager noted, it is easy to overlook the impact of material choices on energy efficiency and insulation. However, with experience gained from managing multiple shop projects, such managers begin to recognise recurring patterns and refine their specifications accordingly.*

The supervisor explained that, during the design stage, discussions with the project manager regarding material selection allowed for cost reductions while still maintaining functional integrity. This early-stage coordination influenced procurement decisions (glass materials purchase) and construction activity (air-conditioning system design error), thereby reducing the likelihood of later-stage disruptions and mitigating potential ripple effects across the supply chain.

6.2.2 Design risks

Through the case study, it was found that design risks emerged throughout the construction process. For instance, in Event 5: Water pipes cut during underfloor heating work, the issue originated from miscommunication between the construction team and lack of supervision, leading to an incorrect cutting operation on the underfloor heating system. As a result, the water pipes were damaged, and when the system was tested, leakage occurred. The team had to pause other construction activities to hire a specialist to diagnose and fix the issue, which led to schedule delays and increased labour costs. This interruption not only affected immediate project tasks but also triggered further ripple effects across dependent activities within the supply chain. This local disruption propagated through multiple project stages, affecting task sequencing and resource allocation, and was therefore identified as part of the broader ripple effect

within the project. The shop owner described the scenario, highlighting the cost and schedule delays incurred:

> *In this case, you can't remove all the tiles after they have been laid. You can't go back and destroy them, especially since this was the only area affected. This delay set us back by one day. First, you need to determine the exact point of the problem. Even if water is leaking here, it doesn't necessarily mean that this is the source of the issue. Then, the specialist breaks the tiles, locate the cut pipe, fix it, and conduct the tests again. Once everything is confirmed to be in order, they replace the broken tiles. The cost of the repair is RMB 1,800.*

In addition to these events, further risks emerged due to design errors. For instance, the fire valve and hydronic heating controls were initially designed with inadequate strut widths, necessitating on-site modifications during construction. The fire sprinkler system layout also failed to comply with local fire regulations, resulting in rework during the project closeout phase. Similarly, the air-conditioning system was positioned too close to the rooflights, creating safety hazards. To mitigate this, the team proposed retrofitting the air-conditioning vents with flexible hoses and installing additional ceiling inspection holes to facilitate maintenance and monitoring. Furthermore, the inappropriate selection of glazing materials during the design phase raised concerns regarding both durability and energy efficiency. The project manager and supervisor attributed the primary causes of these risks to inadequate site visits and poor communication between stakeholders. These shortcomings not only complicated regulatory compliance but also contributed to significant delays during the project closeout phase. The resulting rework and modifications increased overall costs and further extended the project timeline.

6.2.3 Contractual risks

The contractual risk in this case centred on a dispute concerning the compliance of the façade wall. A further site assessment by the supervisor revealed discrepancies between the original design specifications and the actual layout of the shop. Specifically, a concrete wall had been erected, which led to a dispute over material compliance. The

design team argued that the selected material did not meet fire safety standards, whereas the manager contended that prior communication had taken place, although no explicit specifications regarding materials had been provided. This disagreement triggered multiple site visits and information exchanges, including an on-site inspection by brand representatives and an assessment by the design institute on potential design modifications. Ultimately, a compromise was reached in which plasterboards were installed over the concrete partition. However, this resolution caused a significant delay, with the completion of wall postponed to 14 April rather than the originally scheduled 3 April. A shop representative involved in the communication process described the situation as follows:

> *At the time, after the three walls were set up, the design team deemed them unqualified. According to the design, fireproof cotton needed to be added between the light-steel keels. The supervisor came in and immediately flagged the issue as unqualified, which caused a lot of trouble. The negotiation process with the brand and manufacturers took a long time, as the initial discussions only specified a solid wall without detailing the exact materials. Because of this dispute, the project was significantly delayed.*

On the other hand, the supervisor recalled about this argument:

> *After the wall was erected, I noticed that it did not match the design drawings, so I had to raise the issue. The design team was surprised, saying that there wasn't supposed to be a wall there. I sent them pictures, and they confirmed that the material was not compliant. They suggested replacing it with a light-steel keel structure, but that would incur additional costs. Essentially, this doubled the cost of the wall. When I informed the team, it sparked further disputes, highlighting early-stage miscommunication that contributed to these issues.*

Beyond causing delays, the façade wall dispute also resulted in the replacement of the construction team. The original quotation for wall installation was RMB 387,750, which already included light steel keels and fireproof insulation materials. However, after the shop owner proceeded with the façade wall independently, the construction team submitted a revised quotation, requesting an additional RMB 20,000 to cover the

cost of plasterboard installation. This financial disagreement between the project manager and the construction team ultimately led to a change of contractor, further extending the project timeline.

6.2.4 Safety risks

Safety risks in the project primarily manifested in several forms. The proximity between the air-conditioning system and rooflights posed potential fire hazards. Uneven flooring and undersized columns created difficulties in accommodating fire valve and hydronic heating controls, raising concerns about worker safety. In addition, incorrectly installed electrical wiring required corrective work to address electrical hazards. Collectively, these risks resulted in additional work and delays in the construction process.

According to the interviews, the project manager argued that, unlike financial, contractual, and design risks, safety risk events rarely triggered subsequent ripple effects in this case. The interviewees attributed this to the critical nature of safety issues, which must be addressed immediately before progressing to the next project stage. In addition, stakeholders imposed specific safety-related requirements. For example, because the project was in a shopping mall, the owner required that the floor tiles precisely match those of the mall. This proved particularly challenging due to the difficulty of controlling depth during the removal of existing flooring. As noted by the supervisor, this requirement introduced further construction challenges and delays:

> *During the tile-laying process, since we were working on the original foundation, the new tiles needed to align perfectly with the shopping mall's flooring on both sides. However, once we started levelling, we found discrepancies because the original floor was not even. A height difference between the left and right sides became apparent, making it extremely difficult to achieve perfect alignment. Realizing this, I consulted with the shop owner, and ultimately, they mandated that instead of further levelling, we should adhere to the existing plane and install the tiles accordingly.*

The uneven condition of the original floor, initially perceived as a routine construction issue, generated a series of ripple effects. The required tile alignment led to additional

adjustment time, increased labour effort, and stakeholder disagreement regarding the installation approach. The decision to proceed without levelling later resulted in concerns raised by mall management about aesthetics and safety, demonstrating how a minor technical issue evolved into a ripple effect across multiple stakeholders. Overall, in this case, safety risks were closely interlinked with design-related risks, as many safety hazards arose from design non-compliance or errors. These issues resulted in incidents during construction that necessitated the allocation of additional project resources, including labour and financial inputs, to implement corrective measures.

6.3 Resilience and robustness practices in renovation case

The mitigation strategies observed in this case can be interpreted considering existing ripple effect literature, which emphasizes robustness and resilience as the two primary mechanisms for disruption management (Ivanov et al., 2019a). While much of this literature is grounded in manufacturing and network simulation contexts, the construction SME case examined here demonstrates how these theoretical principles manifest differently in project-based environments. Specifically, construction SMEs in this study relied heavily on relational coordination, supervisor intervention, early-stage design adjustments, and flexible problem-solving to prevent or contain ripple amplification. Based on the four summarised risks and related events, this section discusses the strategies used to manage ripple effects, thereby providing justification for the differences between theoretical perspectives and real-world practices. By situating the case findings within the broader theoretical discourse on ripple mitigation, this section highlights both alignment and divergence between theory and practice. While the literature often emphasises formalised supply chain design strategies, the empirical evidence suggests that construction SME mitigation is more process-driven and stakeholder-centred, thereby extending existing ripple mitigation theory into construction SMEs supply chain contexts.

Although 12 early warning signals were initially identified, these were subsequently consolidated into 7 ripple effect events. This refinement was necessary because not all

early warning signals developed into ripple effects. The consolidation was based on three criteria: stakeholder relevance, project impact, and evidence of subsequent propagation. First, analysis of stakeholder perspectives showed that some signals were perceived as minor or self-contained issues that did not extend beyond a single party and therefore did not constitute ripple effects. Second, only the events that produced significant cost, time, or quality implications at the project level were retained, as these demonstrated material influence on project performance. Third, ripple effects require evidence of follow-on disruptions. Through this filtering process, the study captured the events that truly demonstrated cross-stakeholder influence and cascading disruption, enabling a more accurate representation of ripple effect behaviour within construction SME projects.

Current strategies to mitigating ripple effects primarily focus on the concepts of robustness and resilience (Ivanov et al. 2019a). This chapter explores how different risk responses align with these two concepts and presents mitigation strategies based on insights gained from actual practice. Robustness is often achieved through built-in redundancies, such as structural diversity, flexible response options, and adaptive systems (Wagner 2005). In contrast, resilience refers to the ability to maintain or restore functionality and performance following significant disruptions (Hosseini et al. 2016). Table 6.3 presents the mitigation strategies implemented, as well as suggested future measures, based on the interviews.

Table 6.3: Strategies for managing ripple effects through resilience and robustness

Stage	Risk	Risk Response	Adopted ripple effect mitigation	Suggestion for future ripple effect mitigation
Design	Design risk: Installation not meeting compliance standards due to design miscommunication and time constraints	Risk Transfer: Negotiation with designer and contractor to share risk collectively.	Resilience Approach: Adopted negotiation and rapid decision-making approach.	Resilience Approach: Utilise previous project experiences and implement a report-tracking system.
Design	Safety risk due to the position between the air-conditioning system and roof lights lead to potential structural and operational issues.	Risk Mitigation: Redesigning the air-conditioning layout to ensure safety standards.	Resilience Approach: Collaboration between the supplier, supervisor, and designer was undertaken to adjust the system position.	Resilience Approach: Adopt flexible designs for easy adjustments.
Design	Financial risk: Incorrect selection of glass materials, leading to poor durability and efficiency concerns.	Risk Mitigation: Consultation with the supervisor to procure high-quality glass materials from certified vendors.	Resilience Approach: Collaboration with the supervisor to procure alternative materials.	Robustness Approach: Avoid uncertainty by pre-testing materials before procurement.
Beginning	Financial risk and Contractual risk: Disagreement over reinstallation costs and material pricing during wall installation	Risk Transfer: Replaced the original team	Resilience Approach: Redundancy and flexibility were achieved by adopting multiple contractors, allowing for smoother project continuity.	Robustness Approach: Establishing predefined contractual agreements for dispute resolution to enhance supply chain visibility.

Process	Financial risk: Disruption on underfloor heating work	Risk Mitigation: Immediate repairs and inspections.	Resilience Approach: Cooperate with workers to conduct inspections.	Robustness Approach: Apply risk management by ensuring sufficient supervision throughout the construction process.
Process	Design risk: Improper wall wiring and levelling, leading to level and functional issues.	Risk Mitigation and Avoid: Conducting detailed inspections and engaging skilled electricians, also apply plasterboard to cover uneven surface.	Resilience Approach: Increasing temporary labour capacity and replacing unsuitable materials.	Robustness Approach: Detailed plan in place when changing wall materials to manage network complexity.
Closeout	Design risk: Improper placement of fire sprinklers failing to meet design requirement	Risk Mitigation: Collaborate with safety regulators and the project supervisor.	Resilience Approach: Collaborate with the supervisor and designer to develop alternative plans to enhancing flexibility.	Robustness Approach: Integrate design validation to prevent misplacement errors

Source: The author

This chapter analysed the responses to each type of risk, categorising them into the framework of risk acceptance, avoidance, transfer, and mitigation (Ahmadi-Javid et al. 2020; Zuo et al. 2023). Risk acceptance occurs when an organisation chooses to tolerate a risk, particularly when the cost of mitigation outweighs the potential impact (Renn 2017). Risk mitigation focuses on reducing the severity or likelihood of risk through systematic management approaches, such as implementing safety protocols to minimise workplace accidents (Kontogiannis et al. 2017). Risk transfer involves allocating the risk to a third party, often through insurance policies or outsourcing specific tasks to external contractors (Shrestha et al. 2017). Finally, risk avoidance entails modifying plans or operational strategies to eliminate potential threats, thereby preventing risks from materialising in the project (Hopkin 2018).

6.3.1 Manage design relate ripple effect

This chapter reveals how risk events in construction projects, often originating from design errors and miscommunication, can propagate across multiple project stages, leading to delays, cost escalations, and rework. By tracing the ripple effects in three critical cases: Exterior wall installation, wall wiring complications, and fire sprinkler system errors, this study identifies the management responses employed and lessons for future ripple mitigation.

In response to material-specification mismatches during exterior wall installation, the manager acted promptly by initiating multi-party negotiations with design team and brand representatives. Rather than opting for demolition and reinstallation, which would have significantly increased both cost and time, on-site inspections and compromise-based decision-making enabled work to continue. This flexible and decentralised decision-making model illustrates the importance of empowering frontline actors to resolve disruptions in real time. By opting for negotiation over demolition and reconstruction, the project was able to cut costs and save time, as confirmed in the interviews:

> *If we were to directly reinstall light-steel inside, the cost would be quite high. It's almost comparable to the cost of building a concrete wall. Essentially, this would double the overall cost, specifically for the wall. So, this requires communication with the brand office. They did send representatives to the site to inspect the situation. After the inspection, they acknowledged the issue and made some concessions.*

In terms of resilience, the manager adopted a rapid decision-making approach through negotiation to mitigate disruptions, aiming to reduce response time to supply chain interruptions and ensure quick project resumption. For future improvements, interviewees suggested formalising these measures by drawing on past experiences and implementing a reporting system to track every change before it is executed.

To address delays caused by wall material choices that affected wiring and levelling, the contractor increased the number of wiring workers and adopted plasterboard as a levelling solution. From a resilience perspective, the contractor increased the capacity of temporary labour and replaced materials where necessary, enabling the project team to absorb the immediate disruption and maintain progress despite unexpected design-related challenges. This adaptive resource deployment reflects the ability of SMEs to reconfigure available resources rapidly, thereby limiting the escalation of ripple effects. A key recommendation emerging from this case is integrated planning and verification mechanisms. Specifically, renovation SMEs should formalise second-level inspections of design execution, supported by coordination meetings to anticipate consequence of any changing.

The fire sprinkler system contained design errors that were only identified during the final stages of the project, highlighting the absence of early validation procedures. The subsequent modification works and re-approval process by the fire authority caused significant delays. As the supervisor stated:

> *As the project neared completion, no additional redundancy could be introduced to mitigate the impact of this incident.*

This case demonstrates the substantial costs incurred by neglecting compliance checks and underscores the necessity of implementing robust design validation mechanisms at the early stages of the project lifecycle.

6.3.2 Manage safety relate ripple effect

Incorrect spatial positioning between air-conditioning vents and adjacent lighting fixtures can pose significant safety risks. During the installation stage, it was discovered that the proximity between the air-conditioning system and the roof lights created a risk of condensation dripping onto the lighting equipment, thereby posing a significant safety hazard. To manage this hazard and prevent potential ripple effects, an on-site redesign was implemented. This solution eliminated direct interference with the lighting, restored appropriate airflow, and avoided the need for extensive rework. Effective collaboration between the on-site supervisory team and the design team facilitated rapid validation of the revised layout, while stakeholder communication enabled immediate approval of changes, thereby containing the spread of safety-related risks.

To mitigate similar ripple effects in future projects, supervisor and manager recommend that the overall height, orientation, and spacing of all fixed installations, such as air-conditioning units, be accurately measured and documented during the design phase. These parameters should be embedded in the design specifications to alert both designers and contractors to potential conflicts with lighting systems, ceiling structures, or other fixed components. Finally, the pre-approval of a range of ducting configurations is recommended to enable faster on-site adaptations when unforeseen spatial conflicts arise.

6.3.3 Manage financial and contract relate ripple effect

In relation to financial and contractual ripple effects, three primary factors were identified: (1) the incorrect selection of glazing materials, (2) disputes with the original

construction team, and (3) disruptions during the installation of the underfloor heating system. These events highlight the connection of procurement decisions, on-site construction practices, and stakeholder coordination. When mismanaged, such interactions can trigger ripple effects, causing delays, increasing project costs, and compromising overall project performance. This underscores the importance of integrated planning and proactive communication among stakeholders to manage the propagation of contractual and financial ripple effects within the construction supply chain.

In the glass material selection process, risks arose from a misalignment between the chosen glass type and the thermal insulation requirements dictated by the local climate. To address this, the shop collaborated proactively with an experienced supervisor to identify and procure glass materials better suited to the geographical and environmental conditions of project. This approach not only ensured compliance with thermal performance standards but also reduced the risk of future rework and associated costs. By leveraging experiential knowledge from previous projects, the team was able to avoid the pitfalls of inappropriate material use and make informed procurement decisions. To further minimise financial ripple effects in future projects, it is recommended that materials be tested prior to procurement and that structured knowledge sharing sessions be conducted with supervisors and contractors during the planning phase. Such a knowledge transfer mechanism supports proactive risk identification, strengthens supply chain decision-making, and enhances the overall resilience of the project.

A significant contractual and financial ripple effect arose when the original construction team contested the cost of wall reinstallation, demanding additional payment beyond the initial agreement. A review of the quotation revealed discrepancies between the specified materials and the actual use of concrete, which led to a breakdown in negotiations and ultimately to the replacement of the construction team. To manage the

disruption and prevent further delays, the shop side chose to transfer the risk by disengaging the original team, thereby ensuring continuity of the project. This event highlights the importance of contractual clarity and specification compliance in mitigating downstream conflicts. For future projects, both the manager and the supervisor recommended strengthening contractual robustness by implementing pre contractual material verification, conducting specification audits, and screening contractors in advance to ensure alignment with project requirements. Furthermore, engaging multiple contractors as contingency resources can enhance supply chain flexibility and improve recovery speed when disputes or performance issues occur.

A technical disruption causing financial risk occurred when a water pipe was accidentally cut during concurrent construction activities, resulting in leakage during the testing phase of the underfloor heating system. This incident forced the suspension of ongoing work to locate and repair the damage. The contractor responded promptly by initiating on-site inspection and immediate repairs, thereby effectively containing the disruption and preventing further impact on the project cost. This case study illustrates the importance of real-time collaboration in resolving issues and preventing further cost escalation when managing unexpected risks. To mitigate similar ripple effects in future projects, it is recommended to strengthen project robustness by ensuring continuous supervision and cross-task oversight during installation, particularly for embedded or sensitive systems. Additionally, improved scheduling and clearer sequencing of construction activities can help prevent spatial and operational overlaps, thereby reducing the likelihood and financial impact of accidental damage.

6.4 CLD and performance diagram

Based on a synthesis of the ripple effects involving all parties in the case study, the author developed a CLD, shown in Figure 6.3, to visualise the interconnected series of reactions that unfolded within the supply chain during the phone store renovation project. This approach draws on the work of Ghadge et al. (2022) in modelling supply

chain ripple effects under disruption. The primary triggers of these reactions were miscommunication with the design team, design errors, and inadequate supervision of preliminary works. Collectively, these factors contributed to project delays, increased labour costs, and heightened concerns over quality. By mapping the actual ripple effects, the CLD highlights how different risks are interrelated during project process, with the potential to delay progress, disrupt parallel processes, and necessitate dynamic budget adjustments to maintain financial stability.

As illustrated in the diagram, the three core project objectives—time, quality, and cost—are closely related to key project resources, including materials, labour, and equipment. The text indicates specific events or states (e.g., Miscommunicate with design team). The arrows demonstrate how key risks eventually influence these three objectives. In a CLD, the causal relationships between variables are indicated by '+' and '–' symbols, representing positive and negative causal links respectively (Tip 2011). For instance, an increase in miscommunication with the design team may lead to a decline in their performance efficiency due to information overlooked. As shown in Figure 6.3, each feedback loops reflecting different ripple consequences and involving distinct project stakeholders, including design teams, contracting parties, overall project performance, and higher-level influences. The causal loop diagram consists of one reinforcing loop (R_1) and one balancing loop (B_1). The presence of the balancing loop introduces a stabilizing mechanism that counteracts the reinforcing dynamics. This aligns with Barbrook-Johnson and Penn (2022), who argue that systems containing negative feedback structures tend to reach a stable equilibrium when balancing processes dominate.

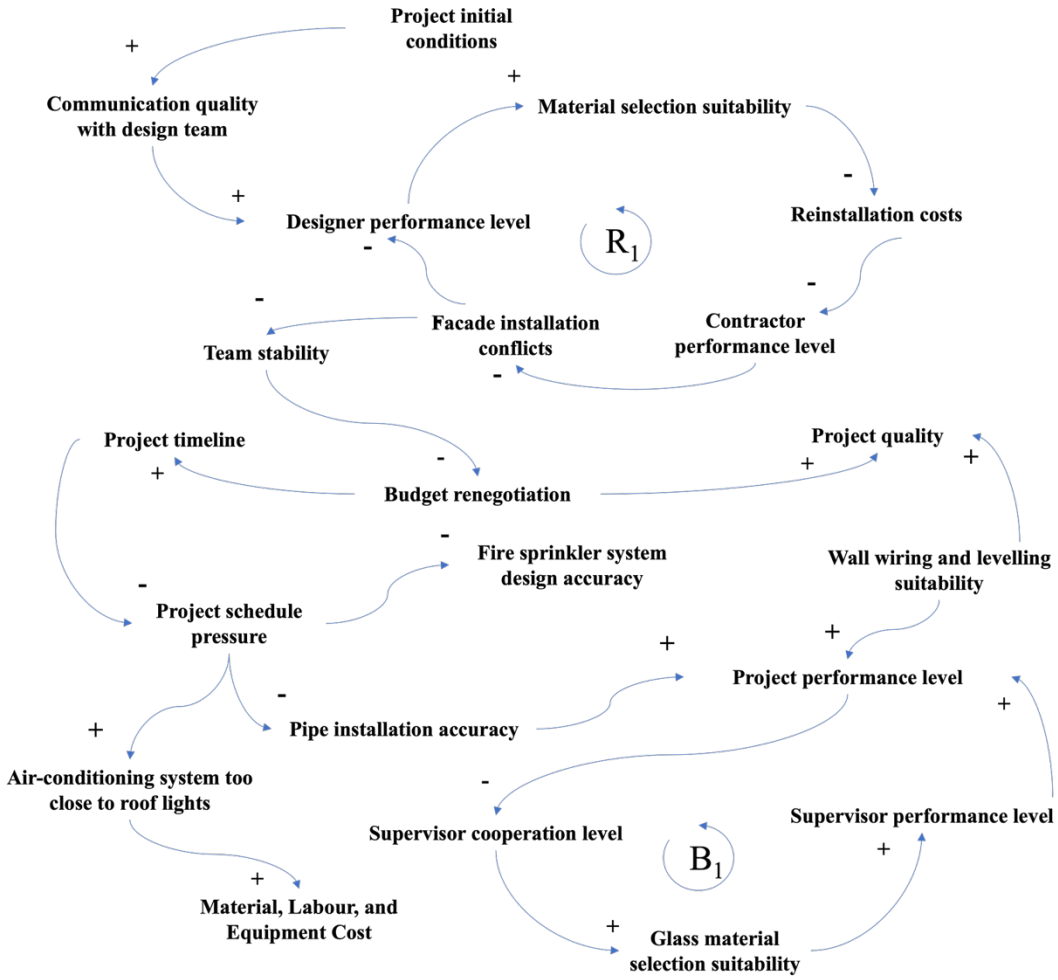


Figure 6.3: Causal loop diagram for case study ripple effect

Source: The author

From the CLD, miscommunication with the design team reduced designer performance, which subsequently triggered material changes and disputes over reinstallation costs. These disagreements lowered contractor performance, leading to façade installation conflicts, the replacement of construction teams, and budget renegotiations. Such repeated adjustments created disruptions that directly delayed the project timeline and compromised project quality, eventually causing difficulties with wall wiring and levelling.

On the other hand, the pressure of adhering to a tight project schedule resulted in errors such as fire sprinkler system design flaws and the accidental cutting of water pipes during underfloor heating installation. These mistakes required rework and coordination, thereby increasing material, labour, and equipment costs while further constraining project performance. Stronger supervisory performance was found to minimise such disruptions, for instance by addressing the improper placement of air-conditioning systems near roof lights and the incorrect selection of glass materials. Enhancing supervisory capacity thus contributed to improving the overall performance level of the project.

Building on the results presented in casual loop diagram, Figure 6.4 further evaluates the performance levels of different project stakeholders across various event scenarios. The stakeholders considered include the design firm, contractor, and supervisor. During the façade refurbishment process, the decline in the performance of the design company was manifested through ineffective communication with the contractor. The subsequent failure to reach an agreement led to the replacement of the construction team, which further contributed to a decline in the contractor's performance. The subsequent replacement of the contractor required renegotiation of the project budget and introduced adverse impacts on both the project timeline and quality, leading to a compressed project schedule and complications with wall wiring and levelling, ultimately reducing overall project performance. In contrast, drawing on the concept of maintaining a dynamic balance in project performance, the supervisor enhanced their role by assisting the client in selecting suitable glass materials, thereby helping to sustain overall project outcomes.

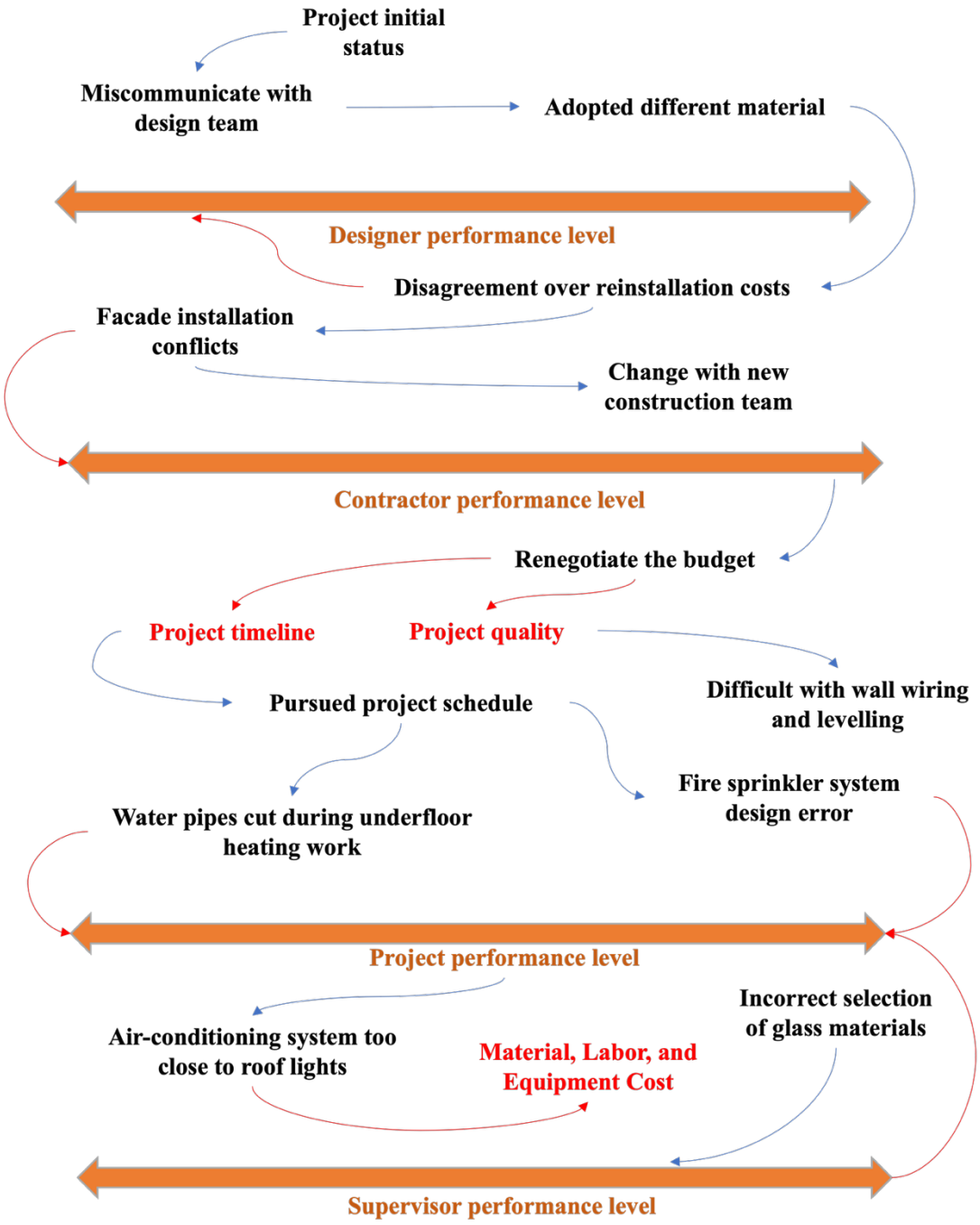


Figure 6.4: Performance diagram for case study ripple effect

Source: The author

6.5 Ripple effects impacts

Through interviews with SME practitioners in the construction industry and the development of the CLD, this section presents ripple effects as experienced and

described by industry professionals in real-world cases. By linking these ripple effects to the four common SCR categories identified earlier, the analysis illustrates how such events manifest in construction SME projects. Adopting a systems thinking perspective, this section examines the impacts of ripple effects, from 12 early warning to ripple effects cases including event timelines, schedule delays, direct financial losses, and quality-related issues. Furthermore, the analysis distinguishes between impacts arising from risks anticipated by stakeholders and those triggered by unforeseen events, as revealed through the interviews.

Figure 6.5 illustrates the primary ripple effect identified in the case study: The dispute over the installation of the exterior façade. The root cause was inadequate communication between the design team and the construction team, which resulted in the selection of façade materials that did not meet the required specifications. This triggered a chain of ripple effects across the project resources. From a cost perspective, the excessive quotation of construction team and the request for an additional RMB 20,000 for wall reinstallation inflated the budget, while the discovery that light-steel keel specified in the quotation had not been used further intensified financial disputes. From a timeline perspective, conflicts with the original contractor and subsequent renegotiation of contract terms prolonged decision-making, and the replacement of the construction team caused further delays. From a quality perspective, the newly selected wall materials required additional wiring and surface levelling, creating technical challenges that affected the quality of workmanship and reduced construction efficiency.

Importantly, some of these risks were anticipated by stakeholders, such as the need to renegotiate contracts or replace the construction team, while others were triggered by unforeseen events, including the material non-compliance discovered during quotation review and the technical complications caused by the new wall materials. As the project manager explained：

Although replacing the construction team avoided an additional RMB 20,000 expenditure for gypsum board installation, the dispute delayed the wall completion date from the originally scheduled 3 April to 14 April. Additionally, using concrete instead of the recommended material for the walls may compromise thermal insulation quality during winter.

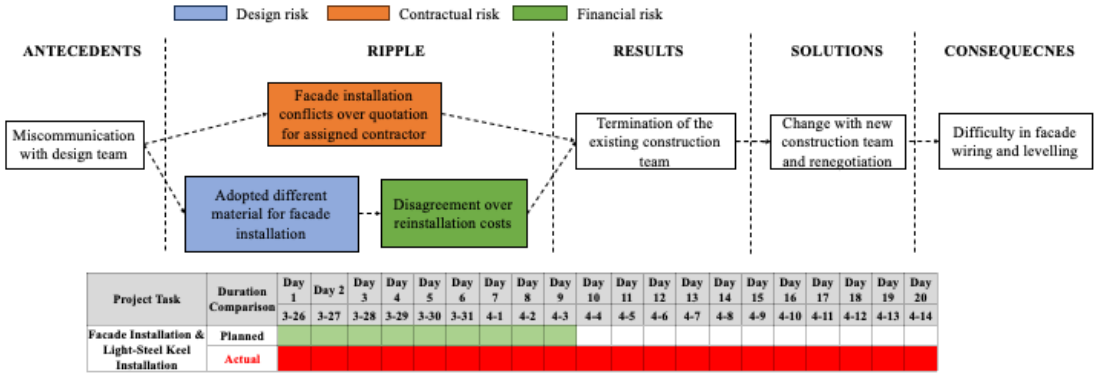


Figure 6.5: Facade installation ripples from case study

Source: The author

Figure 6.6 illustrates the ripple effects caused by design errors identified in the case study. Two critical issues emerged: Flaws in the fire sprinkler system design and the installation of air-conditioning vents positioned too close to lighting fixtures both not expected. The fire sprinkler defect was detected only at the closeout stage, when the system was found not to meet functional requirements, thereby requiring redesign, repositioning, and additional approval from the fire department. By contrast, the air-conditioning issue, although based on a correct capacity calculation, stemmed from poor layout decisions, with vents installed too close to roof lights, leading to condensation dripping and creating operational safety hazards.

Although both problems originated from design errors, their impacts varied according to the stage of identification. The fire sprinkler system error, uncovered late in the project, resulted in significant time delays due to the need for fire safety revalidation, as well as additional costs associated with system repositioning. The air-conditioning

layout error, while identified earlier, required additional material costs (3,060 Yuan) and reinstallation work, thus increasing both cost and labour inputs. From a quality perspective, both errors compromised system functionality and user safety. The contractor discussed the background of the fire sprinkler system design defect issue:

> *Fire sprinklers were included in the project design, but during the final stages of the project, we discovered that part of the design submitted to the fire department did not meet the requirements. Therefore, we needed to re-adjust the spacing between the sprinklers and apply to the fire department for a change.*

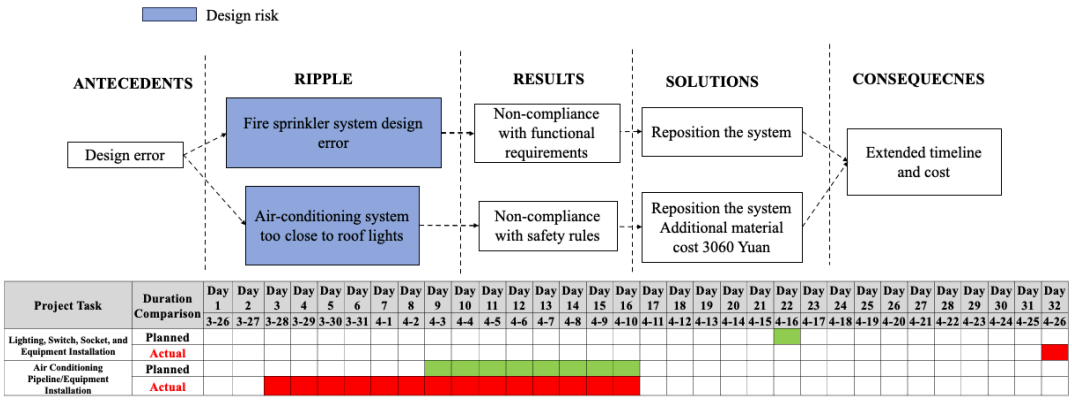


Figure 6.6: Design error ripples from case study

Source: The author

Figure 6.7 illustrates the ripple effects resulting from insufficient supervision during the pre-work stage. Two major issues emerged: the accidental cutting of water pipes during underfloor heating work and the incorrect selection of glass materials. The water pipe incident forced the suspension of subsequent construction activities until the leak was repaired, directly extending the project timeline. The repair required extra labour and materials, generating an additional cost of RMB 1,800 (including RMB 1,000 in labour costs). From a quality perspective, concerns were raised over the long-term reliability of the repaired system, as the potential for hidden leaks could compromise future performance.

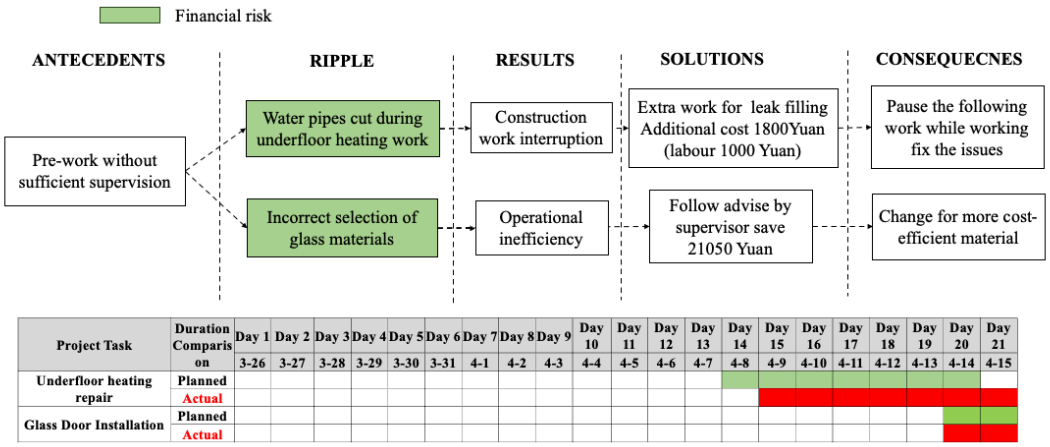


Figure 6.7: Lack supervision ripples from case study

Source: The author

The glass selection issue revealed a mismatch between the chosen glass type and the project requirements, which had not been fully anticipated at the outset. Although corrective advice from the supervisor saved RMB 2,1050 and the final choice reduced the total expenditure compared with the initial quotation, the incident still reflected deficiencies in supervision and risk control. While the short-term cost impact was favourable due to savings, the risk of quality defects remained, as inappropriate materials could shorten service life and reduce thermal performance. The project manager described the situation regarding glass selection as follows:

> *We were not well-informed about selecting glass doors, so we consulted the supervisor and learned that we could not use laminated glass. We had to use framed insulated glass to ensure better indoor warmth in winter and improve cooling efficiency in summer, as this design eliminates gaps.*

6.6 Discussion

The previous literature review identified a research gap, as there is limited empirical research on their impact in construction SMEs. To bridge this gap, this chapter answers RQ3 by designing an identification framework for ripple effects in construction SMEs. The process combines several methods: (i) comparison of financial budgets with actual

project costs across four categories of risk: financial, safety, design, and contractual (ii) observation of risk manifestations across the four project phases of design, beginning, process, and closeout; and (iii) semi-structured interviews with key stakeholders. These methods enable the identification of events, risks, and stakeholder responses, which were then summarised into 12 early warning events to illustrate different risks and their corresponding responses. For RQ4, the author analyses the warnings associated with ripple effects as perceived by interviewees, along with the related risk responses, and the mitigation strategies applied in practice. Stakeholder interviews also provide insights into the rationale behind their risk management decisions and the suggestion for future ripple effect mitigation.

For RQ 5, this chapter adopts a systems thinking approach to illustrate the series of ripples generated in the case study. The author developed a CLD based on interviews with project manager, supervisor, and brand representatives regarding the ripple events they experienced during the project. This was supported by the project Gantt chart, as well as collected images and videos shown in the Appendix D. The performance levels of different stakeholders under various events were also assessed. Based on the identified causes, the study categorises ripple effects into three types: miscommunication, design errors, and lack of supervision. For each category, an in-depth analysis was conducted to examine specific changes in project performance, including impacts on project timeline, quality, and material–labour–equipment costs.

The mitigation analysis identifies risk events that associated with ripple effects, revealing that most strategies focused on reducing the impact of risks rather than eliminating ripple effects entirely. Only a few cases, such as the resolution of wall disputes, successfully prevented ripple effects through risk avoidance by changing the construction team. Although the literature highlights multiple mechanisms through which ripple effects can develop, such as dependence, parallel, or series, only a dependence and parallel mechanisms were observed in practice within this case. This

is largely due to the small scale of the project, compressed timelines, and informal communication structures. Stakeholders emphasised the importance of supply chain resilience, particularly proactive feedback during the design stage (e.g., selecting appropriate glass materials) to prevent ripple effects. The role of an experienced supervisor also emerged as a critical factor in effective ripple effect mitigation, contributing not only to construction quality assurance but also to risk avoidance during the design phase. These findings underscore the value of experienced supervision in mitigating supply chain ripple effects in construction SMEs and highlight opportunities for future empirical research in this area.

The study found that in construction SMEs, ripple effects often impact project timelines, quality, and material–labour–equipment costs. Findings from the case studies indicate that the identification of ripple effect risks at different project stages ultimately determines the severity of their impact, depending on the degree of redundancy available. For example, two ripple effects caused by design errors: incorrect positioning of fire sprinklers and of air conditioning units, had distinctly different consequences. The air conditioning issue arose during the construction phase, when sufficient time buffers were available, resulting in relatively minor impacts. In contrast, the fire sprinkler issue occurred in the close-out phase, necessitating a timeline extension and significantly affecting project performance. These comparisons reveal that risks arising in different project phases can have varying impacts even within the same risk category. Finally, the findings show that ripple effects can be mitigated through dynamic adjustments to maintain overall project performance. For instance, in cases where initial project investments are high and timelines are tight, collaboration between project personnel and supervisors in selecting suitable glass materials can reduce the impact of ripple effects and help ensure the successful completion of the project.

6.7 Chapter summary

Chapter 6 presented an in-depth case study to empirically validate the presence and behaviour of ripple effects within construction SME supply chains. Using a real shop renovation project, the chapter examined how risk events emerged and propagated across four project phases: design, beginning, process, and closeout, revealing 12 early warning signals associated with four risks. The findings demonstrated that ripple effects rarely occur in isolation; rather, they evolve through interconnected disruptions influenced by stakeholder interactions, timing of occurrence, and resource dependencies. A comparative review of mitigation strategies showed that SMEs predominantly adopt resilience-based approaches to contain disruptions, with fewer instances of robustness or complete ripple avoidance. Experienced supervision and proactive design-stage feedback emerged as critical enablers for minimising ripple intensity. A CLD and a performance diagram were developed to visualise how ripple effects spread across stakeholders and project objectives. One reinforcing loop illustrated escalation mechanisms fuelled by miscommunication and design errors, while a balancing loop highlighted the stabilising role of supervisory intervention.

Overall, this chapter provides one of the few empirical validations of ripple effects in construction SMEs. It highlights that the severity of ripple effects depends on the project phase in which they occur, with late-stage disruptions imposing the greatest performance burden. It also evidences that ripple effects can be mitigated through early detection, supervisory buffering, and design-stage intervention. These findings bridge a key gap in ripple effect research by illustrating how ripple mechanisms unfold in real construction projects, thereby offering practical insights to enhance SME resilience and informing the propositions developed in Chapter 7.

Chapter 7 Ripple effect in construction SMEs

7.1 Chapter overview

Chapter 7 integrates the core findings from the literature review and the three empirical chapters (Chapters 4, 5, and 6) to provide a consolidated understanding of how ripple effects emerge, propagate, and impact project performance within construction SME supply chains. Drawing on the sequential evidence from risk identification, prioritisation, and case-based validation, this chapter advances the thesis from empirical insights to theoretical development. It further develops a set of propositions that formalise the relationships between key ripple triggers and performance outcomes, demonstrating that miscommunication, design errors, and inadequate supervision act as primary drivers of cost escalation, schedule delay, and quality degradation. Therefore, Chapter 7 marks a transition from evidence generation to theory building and contributes a conceptual foundation for future scholarly inquiry and managerial strategies aimed at enhancing the resilience of construction SMEs to ripple effects.

7.2 Insights of research findings

The literature review highlighted that although the ripple effect has been widely examined in manufacturing supply chains, empirical evidence within the construction SME context remains limited. Existing studies predominantly rely on quantitative modelling or conceptual theorisation, with insufficient focus on real-world project environments, cross-stakeholder dynamics, and how ripple effects unfold across project stages. Furthermore, prior research has not adequately addressed how different risk types interact, nor has it explored the differentiated impacts of ripple effects on SMEs with varying roles across the supply chain. This gap justified the need for a holistic study that moves beyond conceptual understanding towards empirical identification, prioritisation, and validation of ripple effects within construction SMEs.

This thesis addresses the identified research gap. Chapter 4 responds to this gap by identifying four core ripple effect risk categories: financial, safety, contractual, and design, and mapping their sources, consequences, and interrelationships through thematic analysis and the development of an integrated supply chain risk map for construction SMEs. Chapter 5 advanced this analysis by establishing the relative importance of these risk factors across six construction SME types using AHP, revealing sector-specific differences in risk sensitivity and confirming that ripple effects are not uniform across SME types. The results show that financial and safety risks are considered the most important by construction SMEs. Building on this, Chapter 6 provided empirical validation through a real-world case study, demonstrating how risk events propagate across project phases, and ultimately influence project time, cost, quality, and labour–material–equipment performance. Evidence from the case showed that design-related miscommunication, lack of supervision, and design errors were critical triggers of ripple escalation, while experienced supervision and proactive design-stage intervention served as key mitigating mechanisms.

Figure 7.1 synthesises the key research insights generated across the three empirical chapters, illustrating how the study progressively builds an integrated understanding of ripple effects in construction SME supply chains. Collectively, these findings not only confirm the existence and characteristics of ripple effects in construction SMEs but also reveal the mechanisms through which risks propagate, the conditions under which they intensify, and the organisational responses that contain or magnify them. This integrated evidence base establishes a strong foundation for theorising how ripple effects emerge, interact, and influence performance, thereby enabling the development of four propositions that analysis ripple effects within construction SME supply chains.

Literature Review

- Ripple effect describes the impacts of how supply chain disruptions to some variables are rippling through the rest of the supply chain and influencing its performance (Ivanov et al. 2014c).
- Researchers focus on applying mathematical modelling and simulation such quantitative method to interpret the mechanisms of the ripple effect and explore potential mitigation strategies (Llaguno et al. 2022).
- When discussing mitigation strategies for the ripple effect, many scholars adopt a disruption-oriented perspective to minimise its impacts (Scheibe and Blackhurst 2018; Yang et al. 2021).
- Robustness refers to the capacity of a supply chain to withstand the adverse effects of disruptions while maintaining normal operations and minimizing the impact on performance (Ivanov and Sokolov 2013; Han and Shin 2016; Dolgui et al. 2020).
- Resilience focuses on the ability of a supply chain to recover and resume its normal operations after disruptions (Ivanov et al. 2014c; Dabhilkar et al. 2016; Ivanov 2018; Liu and Lee 2018).
- While construction SCR shares common characteristics with general supply chain risk, such as uncertainty, disruption, and vulnerability to external shocks, it also reflects the unique conditions of the construction environment (Shojaei and Haeri 2019).
- Tang (2006) categorizes SCR according to severity, distinguishing between operational risks, such as fluctuating demand and extended supply lead times, and disruption risks, including natural disasters, pandemics, and human-induced events.
- SCRM strategies refer to the systematic actions and processes undertaken by companies to identify, assess, and respond to risks in order to reduce their likelihood and potential adverse impact (Jüttner et al. 2003; Hallikas et al. 2004; Wagner and Bode 2006).
- SCR in construction can manifest in various ways, such as supply delays, poor product quality, and reduced demand (Stecke and Kumar 2009).
- There is a global consensus that SMEs tend to have less developed financial and technological capabilities compared to larger enterprises (Yang et al. 2020b; Caballero-Morales 2021).

Ripple effect factors

- A total of 13 ripple-effect risk factors were identified across four categories: Financial, Safety, Contractual, and Design risks, through thematic analysis of interviews (Table 4.1).
- A integrated supply chain risk (SCR) map was developed to illustrate key stakeholders and risk transmission pathways in construction SMEs (Figure 4.2).
- Financial risks emerged as the most frequently mentioned category (13/25 participants), driven by advanced payments, delayed or unclear payments, risk-shifting contracts, and external environmental pressures, often triggering project-level cash flow ripple effects (Figure 4.3).
- Safety risks, though less frequent, had high-severity ripple potential, caused by logistics unreliability, material/equipment quality issues, weak supervision, and inexperienced labour, often resulting in multi-stakeholder delays, rework, and regulatory interventions (Figure 4.4).
- Contractual risks acted as a major ripple transmission mechanism, with unclear terms, risk transfer, and non-performance cascading downstream, extending financial pressure across multiple supply chains (Figure 4.5).
- Design risks were commonly linked to drawing inaccuracies, poor communication with site teams, lack of secondary design checks, and unique client demands—frequently leading to rework, safety incidents, and dispute escalation (Figure 4.6).
- A three-layer consequence structure was identified (Figure 4.7 and Section 4.3.5): Direct include delays, rework, resource reallocations, and worker injury. Indirect include reduced productivity, stakeholder conflict, increased turnover, and regulatory delay. Long-term effects include legal/financial liabilities, reputational damage, and sustainability threat to SMEs.

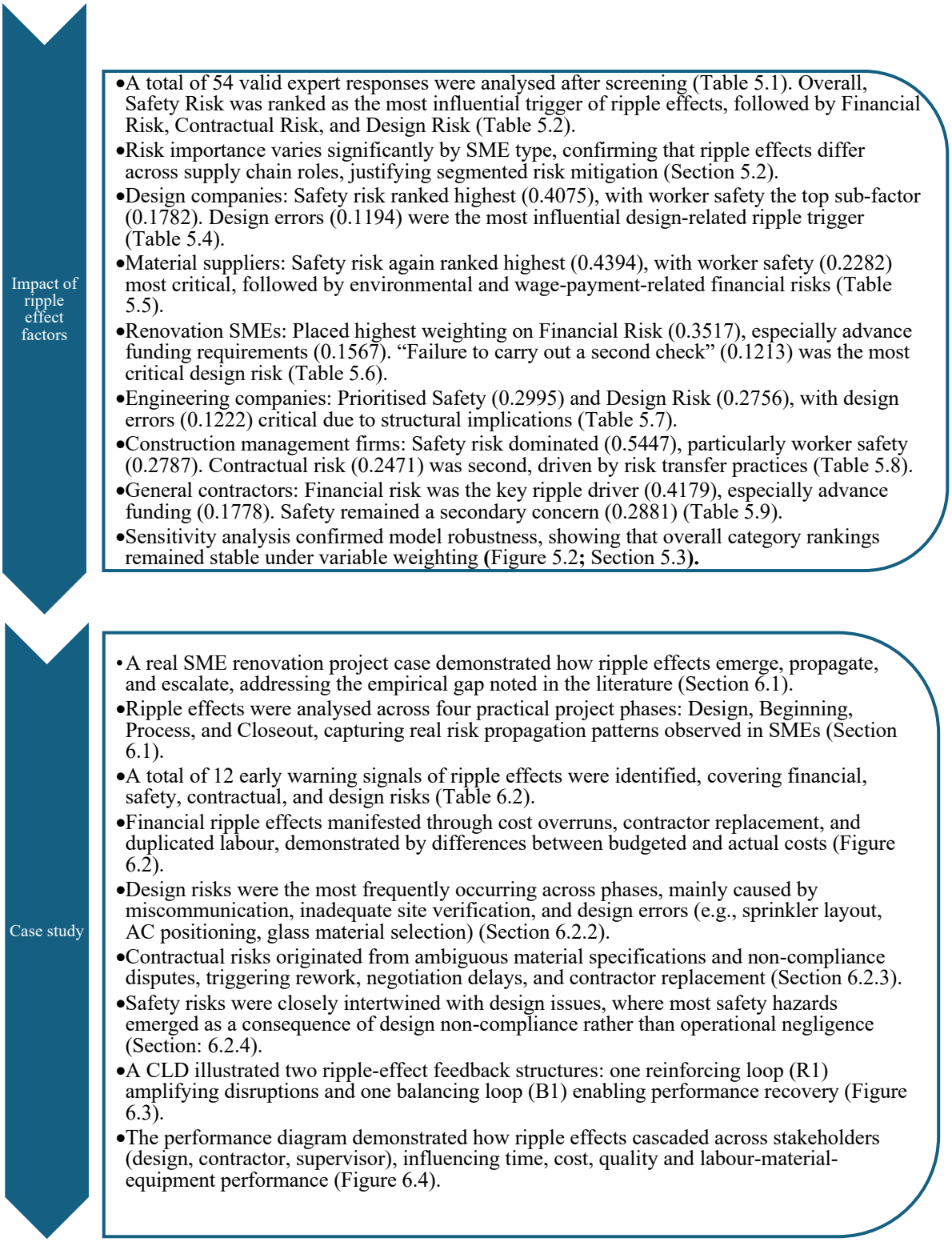


Figure 7.1: Research insights from chapters

Source: The author

7.3 Construction SMEs ripple effect propositions

The four propositions presented in this chapter are grounded in the cumulative evidence developed throughout this thesis and demonstrate how ripple effects emerge, propagate, and influence project performance within construction SME supply chains. The literature review established that, while the ripple effect has been widely modelled in supply chains, its characteristics remain empirically underexplored in the construction context. In response, Chapters 4, 5, and 6 progressively built a multi-layered evidence base: from risk identification, to prioritisation, to real-world manifestation, culminating in the four propositions below. This section discusses each proposition in relation to the thesis findings and its theoretical and practical implications.

Proposition 1: Ripple effects triggered by miscommunication, particularly with the design team, can disrupt project timelines and compromise project quality.

This proposition draws from Chapter 4, where design-related risks, especially communication failures between designers and site teams were identified as one of the most frequently cited ripple triggers among SME stakeholders. Chapter 5 further supported this by showing that design firms, contractors, and construction management companies all rated communication-driven safety and design issues as high-impact factors. The case study in Chapter 6 provided concrete evidence: Miscommunication between the design team and contractors led to improper façade construction, unclear specifications, and rework, which subsequently delayed completion. This supports the literature suggesting that information asymmetry accelerates ripple propagation. Furthermore, this thesis extends that understanding by showing that miscommunication is a primary factor trigger ripple effects in SMEs.

Proposition 2: Ripple effects triggered by design errors can increase project costs by affecting materials, labour, and equipment.

Chapter 4 identified design errors as a one of the ripple effect factors, often linked to inaccurate drawings, insufficient site verification, and lack of secondary checks.

Chapter 5 showed that design risk was consistently ranked as the second or third most critical risk across SME types, with “design errors” identified as one of the most sensitive factors in the AHP sensitivity analysis, showing large weight variation under different scenarios. Chapter 6 demonstrated how design errors resulted in additional labour, such as redesigning fire sprinklers, repositioning air-conditioning vents, and replacing inappropriate glass materials. These empirical findings reinforce that design errors create embedded downstream disruptions which translate directly into material–labour–equipment cost inflation.

Proposition 3: Ripple effects triggered by inadequate supervision can escalate project costs and disrupt project timelines.

Chapter 4 highlighted ineffective supervision as a critical safety-linked cause of ripple effects, while Chapter 5 showed that supervision-related risks were ranked relatively high by construction management company. The Chapter 6 case study evidenced that lack of supervisory oversight during early-stage construction activities enabled avoidable errors, such as cutting water pipes during underfloor heating works which resulted rework, additional labour, and subsequent project delays. This proposition contributes a new dimension to ripple effect theory: Supervision functions as a buffering or amplifying mechanism. Weak supervision fails to intercept early risks, allowing ripple effects to intensify, whereas strong supervision provides a stabilising buffer that prevents disruption propagation, consistent with the balancing loop (B1) in the CLD. This suggests that supervision is not merely an operational control mechanism but a containment capability.

Proposition 4: Ripple effects within construction SME supply chains ultimately lead to project performance degradation, manifesting in increased cost, extended timelines, and compromised quality.

This integrative proposition is derived from evidence that presented across the thesis. Chapter 4 established the interconnected nature of risks, Chapter 5 demonstrated that the most influential risks align with cost, time, and quality dimensions, and Chapter 6

empirically confirmed that once ripples are triggered, they accumulate across project phases and negatively affect performance. The CLD and performance diagram illustrated how reinforcing feedback loops magnify disruptions, while limited redundancy in SME projects constrains recovery capacity particularly during late-stage ripples. This final proposition therefore extending ripple effect impact by evidencing the SME-specific vulnerability condition: Low financial buffers, design errors, and fragmented communication channels intensify the long-term performance impact of ripples.

7.4 Chapter summary

Chapter 7 synthesised the empirical findings of this thesis and advanced the theoretical understanding of ripple effects within construction SME supply chains. Section 7.2 offered a holistic understanding of the mechanisms, conditions, and performance implications of ripple effects. It highlighted how communication patterns, design-related decisions, supervision capacity, and project-stage timing collectively shape the severity and trajectory of ripple effects, thereby extending current theories of supply chain disruption within the underexplored context of construction SMEs. Section 7.3 built upon these insights to develop propositions that conceptualise the relationships between key ripple triggers and performance outcomes, showing how miscommunication, design errors, and inadequate supervision act as primary drivers of ripple effects and how these ultimately degrade cost, time, and quality performance. Supported by a systems thinking approach, these propositions strengthen both the theoretical and practical contributions of this research. Collectively, the chapter moves the thesis from empirical findings to conceptual proposition-building, establishing a foundation for future model development manage strategies tailored to construction SMEs, and leading into the concluding chapter of the thesis.

Chapter 8 Conclusion

8.1 Chapter overview

Chapter 8 serves as a comprehensive summary of the thesis, synthesising its key findings and contributions. First, it reviews the main results of the study, outlining how each chapter contributes to the overall conclusions. Second, it directly addresses the five research questions, providing clear answers based on the evidence gathered. Third, the chapter highlights both the theoretical and practical contributions of the research, emphasising its significance for academia as well as for the construction industry. Given the empirical nature of the study, the chapter also discusses its limitations and acknowledges potential constraints in the methodology and findings. Finally, it outlines opportunities for future research, offering insights and directions for scholars interested in further advancing this field.

8.2 Summary of research findings

This thesis investigated the theory and practice of ripple effects in the construction supply chain from the perspective of SMEs. **Chapter 1** introduced the research motivations and highlighted the gap in the existing literature, noting that current studies on ripple effects in construction SME supply chains are fragmented and fail to consider both the unique characteristics of SMEs and the holistic nature of ripple effects. The chapter emphasised the vulnerability of construction SMEs to financial and operational risks due to their limited resources, with ripple effects often leading to cost overruns, project delays, and even project failure (Chen et al. 2025). Building on these factors, the research questions were formulated from five key motivations, which served as the foundation of this thesis.

The literature review in **Chapter 2** consisted of two parts. The first part reviewed foundational concepts related to SMEs, SCR, and ripple effects. It introduced the definitions of these concepts and the mitigation strategies discussed in current research,

and then turned to the construction industry, with a particular focus on construction SMEs. The second part conducted a structured literature review, analysing existing studies on supply chain ripple effects in construction SMEs. The descriptive analysis identified the types and methods adopted in the ripple effect literature, while the structured review further revealed the research tools applied to study ripple effects.

Chapter 3 presents the research paradigm and methodology adopted in this study, identifying critical realism as the philosophical foundation. Given the objective of linking ripple effect theory with practical applications, a multi-methods approach was selected. Qualitative methods, including interviews and a single case study, were applied in Chapters 4 and 6, while quantitative methods, particularly AHP analysis, were employed in Chapter 5. The detailed procedures and instructions are explained in this chapter, which also outlines the ethical considerations addressed throughout the research process.

Chapter 4 identified ripple effect factors in construction SME supply chains through semi-structured interviews with industry practitioners. The study developed integrated risk map for construction SMEs, explaining how risks and their antecedents emerge within specific stakeholders. An RCA of four major risks, along with a consequence map, was also presented to illustrate their underlying causes and resulting consequences. The findings reveal that risks trigger disruptions through complex antecedents that are amplified by the inherent vulnerabilities of SMEs. Furthermore, stakeholder interactions intensify these dynamics, ultimately leading to ripple effects in construction SME supply chains.

Chapter 5 identified key ripple effect factors affecting SMEs in the construction industry through AHP analysis based on surveys of construction project practitioners. The chapter ranked six types of construction SMEs: design companies, material suppliers, renovation firms, engineering companies, construction management firms, and general contractors, explaining their relative importance. The findings indicated that different types of construction SMEs face varying ripple effect risks. Specifically,

SMEs in the renovation and general contracting sectors considered financial risks to be the most significant, whereas SMEs in project design, material supply, engineering, and construction management prioritised safety risks. These findings emphasise the need for further segmentation to develop targeted risk mitigation strategies.

Chapter 6 employs a mobile phone store renovation project as a case study to analyse the propagation of 12 risk events across financial, safety, design, and contractual categories during the different phases of the project. The chapter also presents the management strategies adopted to mitigate ripple effects, along with suggestions for future practice. The findings reveal that risks arising in different project phases can have varying impacts even within the same risk category. In contrast, risks emerging during the closeout phase tend to result in higher costs and delays due to their late-stage occurrence. The management strategies revealing that most strategies focused on reducing the impact of risks rather than eliminating ripple effects entirely. A CLD was developed to demonstrate the dynamics of ripple effects, which was further integrated with the roles of the designer, contractor, and supervisor, as well as their influence on the project performance diagram. The chapter also examines the financial losses, project delays, and quality impacts associated with ripple effects.

Chapter 7 synthesises the literature review together with the findings from Chapters 4, 5, and 6 to provide consolidated insights into ripple effects within construction SMEs, with the accompanying diagram summarising the key concepts and conclusions. Building on this synthesis, the chapter advances the discussion by proposing four propositions that explain how ripple effects manifest through miscommunication, design errors, and inadequate supervision, and how these disruptions ultimately lead to project performance degradation.

Finally, **Chapter 8** concludes the thesis by answering the research questions, discussing both theoretical and practical contributions, and outlining the research limitations. The chapter also identifies future research opportunities and provides recommendations to advance the study of ripple effects in construction SME supply chains.

8.3 Research questions answered

This thesis explores both theoretical and practical developments in supply chain ripple effects within construction SMEs. While research on supply chain ripple effects has been gradually increasing, its integration with real-world industry practices remains limited (Ivanov et al. 2025). Therefore, this thesis bridges this gap by examining ripple effects from a practical perspective, aligning empirical findings with existing theories on construction SMEs and supply chain ripple effects. Building on the research gaps identified in Chapters 1 and 2, this thesis addresses five research questions. The overall structure of the thesis is illustrated in Figure 8.1.

Chapter 4 addresses RQ 1, identifying the risks that contribute to ripple effects. This is achieved through semi-structured interviews with industry practitioners and subsequent thematic analysis, which enables the systematic identification of risk factors based on empirical evidence. Chapter 5 explores RQ 2, analysing the relative importance of these risks. To accomplish this, a survey is conducted and analysed using the AHP method, allowing for the prioritisation and weighting of different ripple effect factors.

RQ 3 and 4 are examined in Chapter 6, focusing on how ripple effect risks are elevated in the case context and how manage strategies can be implemented. This investigation adopts a case study approach, providing an in-depth examination of ripple effects in real-world construction SME projects. Finally, Chapter 6 addresses RQ 5 by investigating how ripple effects can be visualised through a systems thinking approach. By developing CLD and performance diagrams, this chapter illustrates how initial disruptions evolve into broader disturbances and affect project performance dimensions such as cost, schedule, and quality.

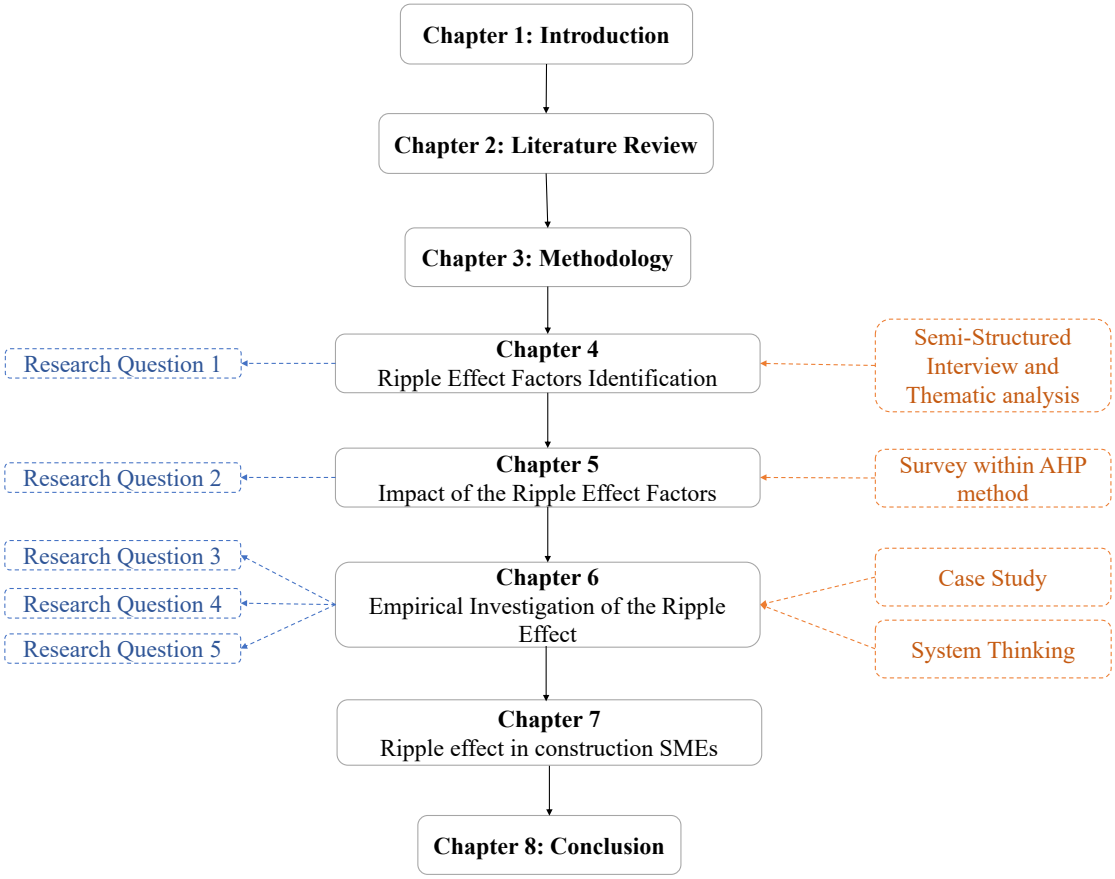


Figure 8.1: Thesis structure

Source: The author

The continuity among these questions is illustrated in Figure 8.2, which highlights their causal interrelationships. RQ 1 focused on identifying risk factors, while RQ 2 examined their hierarchical significance. Building on this, RQ 3 and 4 investigated case study and practical mitigation strategies to address the ripple effect problem more effectively. RQ 5 presented the visualisation of ripple effects and their impacts. The following paragraph summarises the answers to these five research questions.

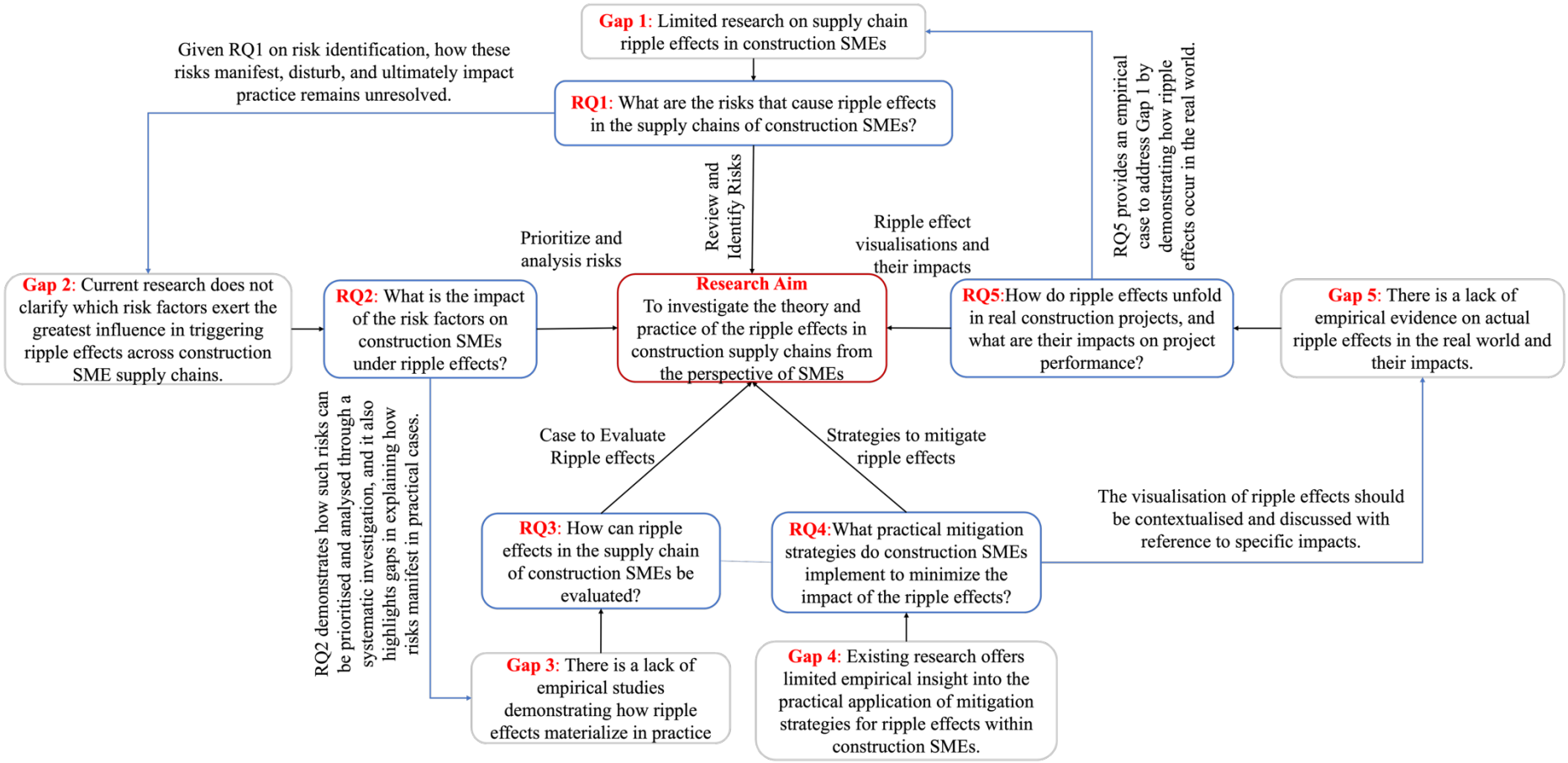


Figure 8.2: Research questions answered

Source: The author

RQ 1: *What are the risks that cause ripple effects in the supply chains of construction SMEs?*

To address RQ1, this study investigated ripple effects in construction SMEs through semi-structured interviews with industry practitioners. The research began with a structured literature review, which revealed a lack of empirical studies on supply chain ripple effects in construction SMEs (Duong et al. 2023). To bridge this gap, semi-structured interviews were conducted, aligning with methodologies suited to exploring theoretically underdeveloped areas (Alfnes et al. 2021). Using thematic analysis of the interview data, 13 risk factors were identified, which were grouped into four main categories: Financial, safety, design, and contractual risks. An integrated supply chain map was then developed to illustrate how these risks are distributed across different stakeholders and how they propagate through SME supply chains.

Furthermore, the RCA analysis results show that the deeper causes of these risks and their consequences are also presented in Chapter 4. Although these risk categories are not unique to SMEs, their manifestation and consequences differ significantly from those in large construction enterprises (Miklian and Hoelscher 2022). Larger firms typically possess more formalised project management systems, diversified supplier networks, and stronger contractual leverage, which can absorb or mitigate the initial shocks of disruption (Baghersad and Zobel 2021). By contrast, construction SMEs often operate with limited financial flexibility and weaker information systems, causing even minor disruptions to escalate rapidly through the supply chain (Omowole et al. 2024). This distinction reinforces the importance of examining ripple effects specifically from the construction SME perspective.

The analysis shows that these risks do not exist in isolation but emerge from complex antecedents and are amplified by the structural vulnerabilities of SMEs. For example, financial risks persist throughout the project lifecycle due to limited reserves and weak bargaining power, making SMEs more sensitive to cash flow disruptions. Safety risks are strongly linked to labour skills, material safety, and supervision mechanism,

primarily arising during the construction phase. Design risks originate from inadequate communication and insufficient design review at the early project stage, while contractual risks are rooted in vague contracts and disputes that emerge at project initiation. Moreover, the findings highlight that stakeholder interactions play a pivotal role in shaping ripple effects. Ineffective supervision and poor communication between contractors and design firms frequently triggered cascading disruptions, leading to project delays and cost escalation. This indicates that ripple effects are not only driven by individual risks but also by the ways in which stakeholders interact within the supply chain.

Table 8.1: Risk factors for the ripple effect in construction SMEs

Ripple effect Risks	Risk factors
Financial risks	Advance funds for the project
	Delay in wage payment
	Environmental issues
Safety risks	Worker safety issues
	Logistics reliability
	Low quality of equipment and materials
	Ineffectiveness of supervision mechanisms
Contractual risks	Failure to perform an obligation
	Contractual ambiguity
	Transfer unavoidable risks to other stakeholders
Design risks	Design errors
	Miscommunication for material size and features
	Failure to carry out a second check

Source: The author

RQ 2: *What is the impact of risk factors on construction SMEs under ripple effects?*

Before addressing RQ2, insights from the interviews revealed that construction SMEs are highly segmented. Drawing on both prior literature and survey data, this thesis categorised construction SMEs into six groups: Design companies, material suppliers, renovation firms, engineering companies, construction management, and general contractors. To systematically evaluate the importance of risks across these segments,

the study employed the AHP methodology, supported by questionnaire data collected from construction practitioners. The results indicate that financial risks and safety risks are the most critical triggers of ripple effects.

More specifically, financial risk was found to be most significant in the renovation industry and general contractors, reflecting the vulnerability of renovation SMEs to high upfront material and labour costs, stringent client contract terms, and environmental or regulatory compliance costs (Zhang et al. 2021). Safety risk, in contrast, was prioritised in design company, material suppliers, engineering company and construction management, with central concerns including worker safety, logistical reliability, equipment and material quality, and monitoring effectiveness. Among these factors, worker safety consistently emerged as the most critical issue.

The analysis also shows that contractual risks, including failure to fulfil obligations, contractual ambiguity, and risk transfer, remain a key driver of ripple effects. The most severe factor perceived in the renovation sector is the failure to fulfil obligations, often caused by weak enforcement mechanisms or misinterpretation of contract terms (Thomas and Wright 2020). In addition, design risks, such as design errors, miscommunication regarding material sizes and features, and the failure to carry out a second check, play a significant role. Among these, design errors were particularly critical in the renovation sector, where mistakes frequently resulted in financial losses, reconstruction requirements, and extended project timelines. For instance, miscommunication about material sizes and features often led to product specification inconsistencies, project rework, and delays. Together this underscores the need for tailored risk management strategies that account for both the type of SME and the project phase in which risks are most likely to manifest.

RQ 3: *How can ripple effects in the supply chains of construction SMEs be evaluated?*

RQ3 is addressed through a detailed case study that evaluates how ripple effects emerge and propagate in the supply chains of construction SMEs. The assessment process combined observation and stakeholder interviews to provide a multi-dimensional

understanding of disruption propagation. Financial analysis was used to compare budgeted versus actual project costs, thereby quantifying the impact of financial risks. Observational data and interviews with key stakeholders including branding representative, the supervisor, the project manager, and contractors to capture the manifestation of risks across four categories: financial, safety, design, and contractual.

The case of a phone shop renovation project demonstrated how disruptions escalated into ripple effects across different phases of the project lifecycle. In the design phase, miscommunication led to the use of different wall materials, disrupting the schedule. In the beginning phase, a dispute over wall construction resulted in the replacement of the construction team. During the process phase, difficulties in wiring and levelling, linked to earlier design errors, increased labour costs. Finally, in the closeout phase, errors in the sprinkler system design were discovered, necessitating rework that generated further delays and cost overruns. In summary, this case study illustrates that ripple effects in construction SMEs can be effectively evaluated by combining cost analysis, risk event tracking, and stakeholder perspectives.

RQ4: *What practical mitigation strategies do construction SMEs implement to minimize the impact of ripple effects ?*

Most existing mitigation strategies for ripple effects, as highlighted in the literature, focus on enhancing supply chain robustness and resilience (Özçelik et al. 2021; Katsaliaki et al. 2022). However, empirical studies examining their practical application in real-world contexts remain limited. To address RQ4, this study analysed seven ripple effect related events and their corresponding risk responses and conducted stakeholder interviews to evaluate the mitigation strategies employed in construction SMEs. These interviews also provided insights into the rationale behind mitigation decisions and offered suggestions for practical measures to manage future risk events.

The analysis revealed that most mitigation strategies adopted in practice seek to reduce the impact of risks rather than eliminate ripple effects entirely. For example, only in a few cases such as the resolution of wall construction disputes, was risk avoidance

effectively implemented to prevent ripple effects. In most events, mitigation focused on adaptation, containment, and minimisation of consequences once disruptions had already occurred.

The findings also underscore the importance of early-stage interventions in enhancing resilience. Proactive actions during the design stage, such as selecting appropriate materials for glass doors, successfully prevented ripple effects downstream. Moreover, the study highlighted the critical role of experienced supervisors, who not only ensured construction quality but also anticipated potential risks during the design phase. Their foresight and interventions reduced the likelihood of disruptions escalating into ripple effects, thereby strengthening both resilience and robustness in SME supply chains.

RQ 5: *How do ripple effects unfold in real construction projects, and what are their impacts on project performance?*

To address RQ5, Chapter 6 adopts a systems thinking approach, integrating CLD, performance diagram, and qualitative evidence from interviews, images, and videos to visualise ripple effects in construction SMEs. The CLD illustrates events that trigger ripple effects during the project lifecycle and traces their development pathways, thereby capturing the impacts. Drawing on interviews with the project manager, supervisor, and brand representatives, ripple effects were categorised into three principal types: miscommunications with design team, design errors, and inadequate supervision, each of which was visually mapped to demonstrate its distinct propagation pathway and its impacts on project performance.

The finding shows that ripple effects primarily affect project timeline, quality, and the costs of materials, labour, and equipment. Importantly, the findings reveal that the stage of disruption is critical in determining its consequences. Early-stage disruptions, such as incorrect air-conditioning layouts, could often be absorbed by available buffer mechanisms, producing relatively minor impacts. In contrast, late-stage disruptions, such as the incorrect installation of fire sprinkler systems, had more severe consequences, including rework, extended schedules, and higher costs, due to the

absence of redundancy and flexibility at this stage. Collectively, the findings highlight their value for understanding ripple effects: not only do they illustrate how risks propagate, but they also explain why their consequences differ depending on the type of disruption and its timing within the project lifecycle.

8.4 Theoretical contribution

This thesis explores the supply chain ripple effect from the perspective of construction SMEs, providing a comprehensive analysis of SCR, their interactions, and the resulting ripple effects. An empirical study was conducted based on real-world examples, and the theoretical contributions of this research are categorised as follows:

First, this study extends and operationalises established supply chain theories, particularly those relating to SCRM, ripple effects, robustness, and resilience, within the underexplored context of construction SMEs. While prior literature has extensively examined ripple effects in manufacturing and large-scale supply networks, these theoretical frameworks have rarely been systematically applied to construction SME supply chains. By integrating thematic analysis, AHP method, and systems thinking into a project-based construction environment, this research demonstrates how existing supply chain theories can be adapted, empirically validated, and refined. In doing so, it addresses a significant theoretical gap concerning the contextual applicability of ripple effect theory beyond manufacturing-dominated supply chain studies.

Second, this thesis provides empirical evidence that ripple effects operate differently within construction supply chains. Through the identification of 13 risk factors, segmentation of SME firm types, and case-based visualisation of disruption propagation, the study demonstrates that ripple effects in construction are shaped by project-based structures and stakeholder coordination dynamics. The findings confirm that ripple effects in construction SMEs follow identifiable propagation mechanisms, but with unique characteristics influenced by design changes, contractual arrangements, and project specific vulnerabilities. This contribution expands the theoretical boundary

of ripple effect research by establishing its relevance within construction supply chains and by highlighting construction industry specific mechanisms.

Third, this thesis contributes to ripple effect theory through a systems thinking interpretation of how interacting risks and stakeholder interdependencies shape disruption propagation in construction SMEs. By linking the causal loop diagram with project performance analysis, the study explains how miscommunication, design errors and inadequate supervision generate consequences across interconnected stakeholders and project activities. The case evidence further suggests that these consequences depend on disruption timing and the availability of buffers, helping explain why late-stage disruptions can produce greater cost and schedule impacts. This provides a contextual refinement of ripple effect theory by identifying stakeholder coordination and the capacity to absorb disruptions at different project stages as important conditions shaping propagation and project performance.

8.5 Practical contribution

The practical contribution of this study varies across different chapters, offering valuable insights for construction SMEs, policymakers, and industry practitioners. In Chapter 2, the structured literature review provided SMEs with a comprehensive framework for identifying and categorising risks associated with ripple effects in the construction industry. This framework enables SMEs to systematically assess risks at different project stages, thereby promoting more proactive risk management.

Chapter 4, which focuses on identifying risks in ripple effects, examines the supply chain structures of construction SMEs and provides industry practitioners with insights into how risks emerge and propagate. By mapping risks within real-world SME supply chains, the study contributes to the limited body of research on ripple effects in the construction industry. The integrated risk map can also guide policymakers in designing targeted policies to mitigate specific SCRs across stakeholders. For example, policymakers could develop contract templates tailored to the distinct risks faced by

different stakeholder groups. In addition, raising awareness of risk causes and consequences through RCA and consequences map can help industry stakeholders better understand and address financial, safety, design, and contractual risks.

In Chapter 5, the assessment of risk importance, along with the segmentation of construction SMEs, offers valuable insights for both industry practitioners and policymakers. The study highlights the need for detailed classifications and higher standards for worker safety protection. Beyond the construction sector, the segmentation approach using the AHP methodology has broader applications for supply chain management in other industries. It enables organizations to identify and prioritize key risk factors, ultimately improving safety and efficiency across various supply chains. Additionally, by considering the ripple effects of SMEs in the construction industry through extensive segmentation, this study introduces a new perspective that enriches both academic literature and practical risk management strategies.

Chapter 6 makes a practical contribution by providing specific guidance on how construction SMEs can recognise, evaluate, and mitigate ripple effects across different phases. By systematically identifying and analysing disruptive events, the chapter develops a practical framework for event management in construction projects, enabling SMEs to track how risks emerge and propagate through their supply chains. This framework allows firms to adopt preventive measures before disruptions escalate, thereby reducing the overall impact of ripple effects on cost, schedule, and quality. The findings also demonstrate that phase-specific vulnerabilities require differentiated responses: late-stage risks often impose the highest cost and time penalties. In practice, these insights offer construction SMEs actionable recommendations for strengthening their supply chain resilience and robustness.

Chapter 6 further investigates ripple effects in project processes from a practical perspective, focusing on their underlying causes, interactions with other factors, and resulting consequences. Drawing on project documentation and interviews with project stakeholders, a CLD and a project performance diagram were developed to demonstrate

the impact of ripple effects on stakeholder performance. In addition, three ripple effect impacts, identified through expert interviews in the construction industry, illustrate how different disruptive factors influence project cost, timeline, and quality. These findings provide practical insights for SME managers, highlighting how ripple effects manifest in real-world projects. Importantly, the case study results indicate that even under tight budgetary and time constraints, ripple effects can be effectively mitigated through collaborative practices and adaptive supervision, particularly in areas such as material selection.

For policymakers, the study highlights the importance of regulatory reforms, financial incentives, and educational programmes to better support construction SMEs. Specifically, simplifying and streamlining standard contract management procedures can help reduce administrative burdens. In addition, financial support measures such as low-interest loans and tax incentives can strengthen the resilience of SMEs against financial risks. Finally, raising awareness and enhancing the capacity of SMEs to apply advanced risk management tools can be achieved through targeted educational programmes and peer to peer exchanges, fostering collaboration and knowledge sharing across the industry.

8.6 Limitation of the research

This thesis adopts an exploratory research design, employing multiple methods including interviews, surveys, single case study, and system thinking. These methods were selected due to the limited existing literature on ripple effects in construction SMEs and the absence of a well-established theoretical foundation. While the findings provide valuable insights into the domain of supply chain ripple effects, a key limitation of the study lies in the uncertainty of their generalisability to large construction firms. Since the research primarily focused on SMEs, the risks identified may differ significantly from those encountered by larger firms. Future studies could therefore investigate how these risks manifest across the broader construction industry.

Moreover, in ranking risks within construction SME supply chains, the questionnaire targeted employees from different companies. However, risk perceptions may vary between departments within the same organisation. Future research could therefore benefit from collecting data across multiple internal departments to capture a more comprehensive perspective. In addition, despite efforts to expand the sample size, the final dataset remained relatively small, which may affect the generalisability of the results. Addressing these limitations in future research would strengthen the robustness and applicability of findings related to SCRs in construction SMEs.

The single case study approach, while valuable for providing in-depth analysis, also carries inherent limitations. Risk diffusion may vary across different project types, making it difficult to generalise the findings beyond the specific industry examined. Another limitation is the scarcity of empirical research specifically addressing ripple effects in construction SMEs, which may constrain the broader understanding of risk propagation in this sector. Geographical constraints further limit the study, as the interview sample was restricted to China. It is possible that SMEs in other regions face distinct risks due to differences in regulatory environments, market conditions, and cultural factors. Future research should therefore examine whether similar ripple effects occur in other geographical contexts to enhance the broader applicability of this study.

8.7 Opportunities for further research

Based on the literature review and research findings, this thesis outlines possible directions for future research on ripple effects in construction SME supply chains as identified throughout the research process. To guide further investigation, five key research questions are proposed in the following section.

8.7.1 Exploration drivers of ripple effect of SMEs in the construction industry between different countries

The research question concerns case studies on ripple effects within construction SMEs. Observing trends in scholarly work, most current research focuses on the methodology

and characteristics of ripple effects (Ivanov et al. 2025). Within the limited body of empirical research, scholars often employ case study analyses to validate their theoretical propositions. For construction SMEs, case studies are particularly valuable as they enable researchers to examine the gap between actual operations and theoretical modelling (Barratt et al. 2011). However, existing studies largely address the broader industry. For instance, Timotius et al. (2022) explored the factors and implications of disruption within the retail industry. This highlights the need for more detailed, SME-specific case studies across different countries to better understand ripple effects in the construction sector. The country of study for this thesis is China. Nevertheless, analysing the specific drivers of construction SMEs in other countries and comparing the underlying reasons can help academics understand how the ripple effects of risk vary under different policy and market environments. By examining how regulatory frameworks, economic conditions, and industry practices influence SCRs, future research can provide a more detailed understanding of how ripple effects manifest globally. Cross-country comparisons may also reveal best practices and policy recommendations for mitigating ripple effects in construction SMEs under diverse governance systems and market conditions.

8.7.2 How do forward and backward paths in the supply chain influence the ripple effect in other industry?

This research question addresses the conceptual nature of the ripple effect, focusing on the current lack of clarity regarding the forward and backward pathways of ripple effects in the construction supply chain. While Li et al. (2021) examined forward and backward networks in the context of disruption risk, research specific to the construction sector remains limited. Analysing these forward and backward pathways can help scholars quantify the impact of risk responses, thereby offering a structured approach to mitigating disruptions. Therefore, further research across different industries on forward and backward ripple effect paths is necessary.

A clearer understanding of forward and backward pathways is particularly valuable in industries characterised by structured and tiered supply chain levels, where disruptions can systematically spread between suppliers, manufacturers, and distributors. Developing well-defined models of risk propagation would not only strengthen theoretical insights into supply chain disruption dynamics but also provide practical guidance for organisations to design more targeted mitigation strategies, improve coordination across tiers, and enhance overall supply chain resilience.

8.7.3 To what extent are existing resilience and robustness frameworks applicable to construction SME supply chains?

This research question focuses on the theoretical study of robustness and resilience in construction SMEs. While El Baz and Ruel (2021) examined the role of SCRM in enhancing resilience and robustness during the COVID-19 pandemic, the literature remains limited in systematically exploring these concepts within construction SME supply chains.

The findings of this study indicate that risk impacts and propagation patterns vary significantly across different types of construction supply chain actors, highlighting structural difference within SME networks. This variability underscores the need for further research to examine how robustness and resilience function under the resource constraints and project-based characteristics of construction SMEs. At present, robustness and resilience are recognised as primary strategies for managing ripple effects in supply chains (Ivanov et al. 2014c). However, their practical application in SMEs remains at an early stage, requiring a deeper understanding of both their current state and their effectiveness (Bak et al. 2020). Future studies should therefore focus on developing tailored frameworks and methodologies to enhance these dimensions, enabling construction SMEs to better withstand and recover from disruptions.

8.7.4 How applicable are current supply chain research tools for construction SMEs?

This issue focuses on the application of research tools in studying ripple effects within construction supply chains. The structured literature review identified three primary research approaches for analysing ripple effects: Modelling, simulation, and empirical research. However, the effectiveness of modelling and simulation tools in the context of construction supply chains remains debatable, highlighting the need for further studies specifically targeting construction SMEs. A key challenge in applying mathematical modelling and simulation methods to SMEs is the development of theoretical models that accurately reflect their unique characteristics. Such models must be capable of assessing both the probability and impact of ripple effects, while also allowing for the testing of alternative mitigation strategies. Future research should therefore focus on refining these tools to enhance their applicability, ensuring that construction SMEs are better equipped to anticipate, manage, and mitigate ripple effects within their supply chains.

8.7.5 What are the possible mitigation strategies for the ripple effect in construction SMEs

This research question focuses on how to mitigate ripple effects in construction SMEs. Chapter 6 presents the current mitigation strategies employed in the construction and renovation sector, while the literature review highlights resilience and robustness as key approaches. Specifically, supply chain resilience and robustness can be further broken down into components such as flexibility, redundancy, visibility, and agility, all of which play a critical role in mitigating disruptions (Ali et al. 2017b).

However, an important consideration is whether these dominant mitigation strategies are equally effective for construction SMEs as they are for larger firms. Due to financial and knowledge constraints, SMEs often cannot address all potential risks and must instead prioritise only the most critical ones (Saad et al. 2021). This underscores the need for a tailored set of ripple effect mitigation strategies designed specifically for

construction SMEs. Future research should therefore examine whether different segments within construction SMEs require distinct mitigation approaches, ensuring that ripple effect mitigation strategies align with the unique challenges faced by smaller firms.

8.8 Chapter summary

The concluding chapter summarises the key findings of this thesis and provides detailed answers to the five research questions. It synthesises the insights generated throughout the research process and reflects on how the findings collectively contribute to a deeper understanding of ripple effects within construction supply chains, particularly in the context of construction SMEs. The chapter also systematically discusses the theoretical and practical contributions derived from the structured literature review and the main empirical chapters, highlighting how the study advances existing knowledge on ripple effects, risk propagation, and resilience in construction supply chains. Furthermore, the chapter highlights the limitations of the study, identifies gaps in the current understanding of ripple effects in construction SMEs, and outlines opportunities and recommendations for future research. These reflections provide a foundation for further scholarly inquiry and encourage the development of more robust theoretical frameworks and practical approaches for managing ripple effects in complex construction supply chains.

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Appendix A: Cardiff University Ethics Approval

Dear Shicheng Chen,

Research project title: The Impact of Ripple Effects on Supply Chain Disruption Risk Management in Construction SMEs
SREC reference: 2149

The School Research Ethics Committee (SREC) reviewed the above application via its proportionate review process.

Ethical Opinion
The Committee gave a favourable ethical opinion of the above application on the basis described in the application form, protocol and supporting documentation.

Additional approvals
This letter provides an ethical opinion only. You must not start your research project until all any other approvals required for your research project (where relevant) are in place.

Amendments
Any substantial amendments to documents previously reviewed by the Committee must be submitted to the Committee via CARBS-ResearchEthics@cardiff.ac.uk for consideration and cannot be implemented until the Committee has confirmed it is satisfied with the proposed amendments.

You are permitted to implement non-substantial amendments to the documents previously reviewed by the Committee but you must provide a copy of any updated documents to the Committee via CARBS-ResearchEthics@cardiff.ac.uk for its records.

Monitoring requirements
The Committee must be informed of any unexpected ethical issues or unexpected adverse events that arise during the research project.

The programme director would include your research in end of project report. The Committee must be informed when your research project has ended. This notification should be made to CARBS-researchethics@cardiff.ac.uk within three months of research project completion.

Documents reviewed by the Committee
The documents reviewed by the Committee were:
Application ID: 2149
Link to applications list, where you can access the reviewed version.
CARBS SREC ethics application form.docx
Consent Form.docx

Interview - Exploring Ripple Effect Factors in Construction SMEs.docx
Invitation Letters.docx
Participant Information Sheet.docx
Questionnaire - Supply chain ripple effect impact.docx
Research integrity and ethics training certificate.pdf
SREC-New feedback form for PhD (1).docx

Complaints/Appeals
If you are dissatisfied with the decision made by the Committee, please contact Dr Carmela Bosangit (BosangitC@cardiff.ac.uk) in the first instance to discuss your complaint. If this discussion does not resolve the issue, you are entitled to refer the matter to the Head of School for further consideration. The Head of School may refer the matter to the University Research Integrity and Ethics Committee (URIEC), where this is appropriate. Please be advised that URIEC will not normally interfere with a decision of the Committee and is concerned only with the general principles of natural justice, reasonableness and fairness of the decision.

Please use the Committee reference number on all future correspondence.

The Committee reminds you that it is your responsibility to conduct your research project to the highest ethical standards and to keep all ethical issues arising from your research project under regular review.

You are expected to comply with Cardiff University's policies, procedures and guidance at all times, including, but not limited to, its Policy on the Ethical Conduct of Research involving Human Participants, Human Material or Human Data and our Research Integrity and Governance Code of Practice .

Yours sincerely,

Dr Carmela Bosangit
Chair of School Research Ethics Committee

A.1 CARBS SREC ethics application form

CARBS RESEARCH ETHICS COMMITTEE

APPLICATION FOR ETHICAL REVIEW

For Office Use Only	
SREC Reference: [x]	Meeting/Review Date: [x]

SECTION 1. GENERAL INFORMATION	
Application Type:	☐ Staff ☐ PGR student ☐ PGT/Masters Student ☐ Undergraduate
Research Project Title:	The Impact of Ripple Effects on Supply Chain Disruption Risk Management in Construction SMEs
Short Title (where applicable):	
For Staff Projects	
Name of Chief/Principal Investigator:	
Contact details:	
Other members of research team:	
For Student Projects	
Name of Student:	Shicheng Chen
Contact details:	Chens111@cardiff.ac.uk
Name of Supervisor(s):	Daniel Eyers; Jonathan Gosling; Huang Yuan
Contact details:	eyersdr@cardiff.ac.uk; goslingj@cardiff.ac.uk; huangy66@cardiff.ac.uk
Other members of research team:	

SECTION 2. SCREENING QUESTIONS			
		Yes	No

2.1	Is the research project categorised as 'Research' (as defined in the Cardiff University Policy on the Ethical Conduct of Research involving Human Participants, Human Material or Human Data Ethics Policy)? If **no** (i.e. the research project is a Service Evaluation or Audit), the Committee is not required to conduct a review of the proposal but may choose to do so. **Please contact the Research Office** *Carbs-ResearchEthics@cardiff.ac.uk* **to seek advice before proceeding with this application.**	Yes	
2.2	Does the research project involve human participants, human material or human data (as defined in the Ethics Policy)? If **no**, you are not required to submit the research proposal to this Committee. **Please do not continue with this application.**	Yes	
2.3	Does the research project require review by an external ethics committee (refer to Appendix 1 of the Ethics Policy)? Please note that this includes all research projects involving participants who lack the capacity to consent. If **yes**, the research project should be submitted to the relevant external ethics committee for review and does not fall within the remit of this Committee. Please contact the *Research Governance Team* for further advice. **Please do not continue with this application.**		No
2.4	Has the research project been ethically reviewed by another university or research institution (for example, where the Chief/Principal Investigator for the research project is based at another institution)? If **yes,** please provide evidence of the review conducted (such as an outcome letter or communication) and the ethical review policy of the relevant institution or committee and send to CARBS-ResearchEthics@cardiff.ac.uk. **Please do not continue with this application.**		No
2.5	Is the research project exempt from ethical review under the University's framework for the 'Ethical Review of Research using Secondary Data and/or Publicly Available information only'? This framework allows certain research projects using only secondary data and/or publicly available information to proceed without ethical review by a SREC provided certain conditions are met. *If **yes***, **please register your research project with the Research Office via the** *AHSS CARBS ethics submission system***.** Please provide a summary of your research project and details on the information and its source.		No

2.6	Does the research project fall within the scope of the UK Policy Framework for Health and Social Care Research? This Framework broadly applies to research taking place within, or involving, the health and social care systems. If **yes**, you will need to apply to the *Research Governance Team* for Sponsorship using the Advanced Project Information Proforma (APIP) (available on the Cardiff University intranet). The Research Governance Team will advise you on the approvals that are required for the research project after it has conducted a review of the APIP and supporting documentation. **Please do not continue with this application until you have sought advice from the Research Governance Team.**		No
2.7	Does the research project involve the collection or use of Human Tissue (including, but not limited to, blood, saliva and bodily waste fluids)? If **yes**, the research project should be submitted to the *Human Tissue Act Compliance Team* (HTACT) prior to submission to an ethics committee. **Please do not continue with this application until you have sought advice from HTACT.** Please note that submission of a research protocol/proposal to HTACT is essential for all projects involving the collection or use of Human Tissue		No
2.8	Does the research project fall within the scope of the University's Security-sensitive Research Policy? This Policy broadly applies to research involving terrorism, extremism or radicalisation (or access to materials of such a nature). If **yes**, you must register the research in accordance with the Policy and comply with the IT and security arrangements contained in the Policy.		No
2.9	Has the research project received appropriate peer/scientific review? (For student research projects, review by the research project supervisor/module leader or course director is an acceptable form of scientific review) For staff, peer review is not essential but may improve the quality of the application and speed up the application process. Appropriate review depends on the circumstances, this may be: a) specific peer review by a major-grant giving body or similar organisation for funded projects; b)School scientific review panel or c) tow members of academic staff who have a good understanding of the field but independent to the research.	Yes	
2.10	Have you and all other Cardiff University co-applicants/ /Supervisors/Members of the research team (as listed in Section 1)	Yes	

	completed the University's Research Integrity Online Training Programme? If **no**, please complete the training before submitting the application to this Committee. If **Yes, please include evidence of successful completion with this application.**		

If the research project involves the use of animals, please contact the Cardiff University Biological Standards Office bso@cardiff.ac.uk to seek further advice.

SECTION 3. PROJECT SUMMARY

3.1	Summarise the research project (including the purpose and its methodology) using language that would be understood by a lay person.

This application is for both online interviews and questionnaire/survey. The aim of this study is to explore the impact of ripple effects on construction SMEs, rank the importance of the factors generating the ripple effect, and model the other significant factors using a case study approach. This paper intends to start by summarizing the influencing factors of the ripple effect from the literature review. It will then identify these factors through interviews and the distribution of questionnaires. The questionnaires will be designed using the Analytical Hierarchy Process (AHP) method to collect participants' opinions on the comparison of the risks, which will be used to compute the final ranking of the risks. In the discussion of the most important ripple effect factors, case studies and simulation will be used to select target organizations and simulate the ripple effect when it occurs.

3.2	State the research question(s).

RQ1: What are the main disruption risk factors faced by construction SMEs under the ripple effect?
RQ2: What is the impact of the identified risk factors of disruption in construction SMEs in the context of ripple effects?
RQ3: How can the ripple effect of supply chain disruption in construction SMEs be measured and assessed?
RQ4: What are the effective mitigation strategies that construction SMEs can adopt to minimize the impact of the ripple effect?

3.3	Estimated start date.

06 November 2023

3.4	Estimated end date (usually the end of data collection).

30 Sep 2026			
3.5	Is the research project funded? If **yes**, please name the funding body.		
No			
3.6	Are there any potential conflicts of interest? If **yes**, please confirm the action you propose to take to address such conflicts. *Information and guidance on conflicts of interest is contained in the Research Integrity Online Training Programme and the Research Integrity and Governance Code of Practice.*		
No			
SECTION 4. FULL REVIEW CRITERIA			
Your answers to the questions in this Section 4 will help the Committee determine whether your project requires full or proportionate review. If all 'No' boxes apply, your project may be considered for proportionate review. If a 'Yes' box applies, your project will proceed to full review unless the School has approved a Ethics Protocol for that particular criterion. Where an Ethics Protocol applies, this is confirmed below. If you have complied with the Ethics Protocol, your project may be considered for proportionate review.			
		Yes	No
4.1	Will the research project be performed without the participants' prior consent? If you have answered YES to 4.1 have you complied with the CARBS ethics protocol for Research performed without participants' prior consent? This can be found here. You are expected to explain this in Section 6.1.		No
4.2	Does the research design include an element of deception, including covert research? If you have answered YES to 4.2 have you complied with the CARBS ethics protocol? This can be found here. You are expected to explain this in Section 6.1.		No
4.3	Will the research project involve children under the age of 18 or 'at risk' (vulnerable) adults or groups?		No

	The Cardiff University Safeguarding Children and Adults at Risk: Policy and Guidance sets out examples of 'at risk' or 'vulnerable' adults.		
4.4	Does the research project include topics which may be considered highly sensitive for participants? This includes sexual behaviour, illegal activities, political, religious or spiritual beliefs, race or ethnicity, experience of violence, abuse or exploitation, and mental health. If you have answered YES to 4.4 have you complied with the CARBS ethics protocol? This can be found here.		No
4.5	Does the research project require access to records of a sensitive or confidential nature, including Special Category Data or criminal offence data? Special Category Data is defined in data protection legislation and currently includes information about an individual's: racial or ethnic origin; political opinions; religious beliefs; trade union membership; physical or mental health; sexual life or orientation;genetic data; and biometric data where this is used to identify an individual. If you have answered YES to 4.5 have you complied with the CARBS ethics protocol? This can be found here.		No
4.6	Is permission of a gatekeeper required for initial or continued access to participants? This includes participants in custody and care settings, or research in communities where access to research participants is not possible without the permission of another adult, such as another family member or a community leader. If you have answered YES to 4.6 have you complied with the CARBS ethics protocol? This can be found here.		No
4.7	Does the research project involve intrusive or invasive procedures? This includes the administration of substances, vigorous physical exercise, procedures involving pain or more than mild discomfort to participants (including the risk of psychological distress, discomfort or anxiety to participants).		No

4.8	Does the research project involve visual or audio recordings where participants? may be identified? If you have answered 'yes' to 4.8, have you complied with the School's ethics protocols on audio and/ or visual recordings a) AUDIO b) VISUAL If you have answered YES to 4.8 have you complied with the CARBS ethics protocol? This can be found here.	Yes	
4.9	Does the research project involve the collection or use of human tissue?		No
4.10	Does the research project involve more than a minimal risk of harm to the safety and wellbeing of participants and/or the Researchers? Please answer this question based on your assessment of the risks involved in this project. Further information about possible harm or potential risks to participants/researchers must be provided in Section 7 of this form. If you have answered YES to 4.10 have you complied with the CARBS ethics protocol? This can be found here.		No

If you have answered YES to any of the above, please use this space to provide details on how you will address these points in an ethically sensitive way.

Interviews with participants will be audio-recorded to ensure that their points are fully documented. Prior to any audio recording, informed consent for recording will be obtained from the participants through a consent form. Participants will be provided with details regarding the purpose of data collection, who will have access to the data, and how the data will be anonymized.

Once the recording is complete, the data will be uploaded to a password-protected computer at the University. Each respondent will be assigned a code or pseudonym to anonymize the data and any personal information will be stored separately.

SECTION 5. PARTICIPATION AND RECRUITMENT	
5.1	How will you identify and recruit participants to the research project?

In term of recruitment method, survey/questionnaire and interviews are share same method. To identify potential participants for the study, we will leverage various ways, including student networks and industry associations. The recruitment process will consist of the following steps:

Utilize social media platforms, such as LinkedIn and research forums, to identify and reach out to individuals who have expertise or experience in construction-related research or are involved in managing construction SMEs. Attend conferences, workshops, or seminars related to construction and supply chain risk management to network with potential participants and distribute study information. Engage with industry associations, such as construction and building associations, chambers of commerce, or small business organizations. These associations can help connect with professionals working in construction SMEs or those with relevant experience and knowledge. By utilizing these various channels and strategies, we aim to reach a diverse pool of potential participants with relevant expertise and experience in the construction industry.	
5.2	How many participants are you aiming to recruit? If applicable, please include a breakdown of participants by type and number.
we plan to recruit 5 participants for inital interview, which 2 of them from academia experts and 3 of them from construction SMEs professional. In the process of questionnaire, a small number of participants (less than 50) will be expect. It is worth mean that interviees and participants for questionnaire are different people.	
5.3	What are the inclusion and exclusion criteria for participants?
The main criterion for academics is whether their profession is related to the construction industry and whether they are aware of the situation of SMEs. For small business owners the criterion is whether they understand some of the supply chain risks in the construction industry.	
5.4	Will the research project involve participants that are Cardiff University staff or students or clients of the University (or the place in which you may otherwise work)? *If applicable, please provide details.*
No.	
SECTION 6. CONSENT PROCEDURES	
6.1	Will informed consent be obtained from participants? If so, how? Please include who will be taking consent, how consent will be recorded, when participants will be provided with information about the research project, and how long potential participants will be given to decide whether to take part.
For both interview and survey/ questionnaire. The research project will ensure that participant consent is obtained by providing each participant with an informed consent form, which will be recorded by the collector. Additionally, the project will provide information about the research project to each participant prior to collection, and participants will have time to decide whether or not they wish to participate.	

6.2	Will participants be offered any incentives to take part in the research project? If you have answered YES to 6.2 have you complied with the CARBS ethics protocol? This can be found here.
No	
6.3	If a questionnaire is to be used, will you give participants the option of omitting questions they do not wish to answer?
Yes	
6.4	Will participants be informed that their participation is voluntary and that they may withdraw at any time and for any reason?
Yes	
SECTION 7. POSSIBLE HARM TO PARTICIPANTS/RESEARCHERS	
7.1	Is there is a risk of the participants experiencing physical, emotional or psychological harm or distress? If yes, please provide details of how ethical issues will be handled and how any risks will be minimised. Please consider whether the research project includes topics which could be considered as highly sensitive for participants.
No	
7.2	Is there a risk of the Researcher(s) experiencing physical, emotional or psychological harm or distress? If yes, please provide details of how ethical issues will be handled and how any risks will be minimised.
No	
SECTION 8. DATA MANAGEMENT, CONFIDENTIALITY AND DATA PROTECTION	
8.1	How, and by whom, will data be collected?
For this study, the method of data collection was through questionnaires/survey, interivew and case study, which were administered primarily by investigate team.	
8.2	Will you be accessing or collecting Personal Data (identifiable personal information) as part of the research project? Note: If your project involves Personal Data, you are advised to review the University's *GDPR Guidance for Researchers* and to check whether your project requires, or would benefit from, the completion of a *Data Protection Impact Assessment* (DPIA). The

	University's *DPIA Screening Assessment page* will help with this. It is not the role of the SREC to review or advise on DPIA's, but if you have completed one, please confirm this below. For further advice, please refer to the 'DPIA' intranet page or contact *complianceandrisk@cardiff.ac.uk* **If yes, briefly describe below what Personal Data will be accessed and/or collected.** Remember to consider the information being captured through any consent process, alongside information captured during the research activity itself.
Yes, the collection of personal data for this study will be limited to the name and contact details of the respondents. Participants for both interview and survey/questionnaire will be informed about this in the Participant Information Sheet and Consent Form, and they will be given the choice to participate or decline.	
8.3	How long will you retain the Personal Data collected in connection with the research project? Please also explain any data deletion arrangements. Note: Research records and data must be retained for the period specified in Section 2.9 ('Research Project Conduct') of the University's Research Records Retention Schedule. If identifiable information is being collected, researchers must ensure that this is limited to the information necessary to achieve the relevant purpose (data minimisation). The University expects raw data containing identifiable information (questionnaires and audio tapes for example) to be retained for the full retention period unless: (1) the identifiable information is not required to support the research or to demonstrate good research conduct; and (2) stringent measures have been taken to verify and ensure the integrity of any anonymised or pseudonymised records/data produced from the raw data. Where (1) and (2) apply, the researcher must take the necessary steps to remove the personal data. Consent Forms must be retained for the full retention period. Please note that where UG and PGT projects do not contribute to a publication or wider research project, research records and data may be held for a shorter period. Please refer to the guidance notes in Section 2.9 of the University's Research Records Retention Schedule for further detail.
This research will retain for a minimum period of 5 years after publication of any findings based upon the data. The data, including emails and the name of the respondent, will be deleted at the end of the retention period.	
8.4	What efforts will be made to anonymise the data collected (where possible)?
For both interview and survey/questionnaire, to further ensure anonymity, any identifying information will be removed from the data once it has been collected. This includes any personal identifiers such as names or contact details. Data will be identified by a unique code or number, and any potentially identifying information will be replaced with generic descriptions. For example, instead of listing the name of a specific company, a generic description such as	

"Construction SME 1" will be used. This will help to ensure that the data collected is completely anonymous and cannot be traced back to individual respondents.			
8.5	Are you proposing to utilise 'public task' as the lawful basis for processing Personal Data for the purposes of the research project (by the University)? **If no**, please explain why and what alternative lawful basis you propose to use.	Yes	No
Yes			
8.6	Have you utilised/incorporated into your Participant Information Sheet the following sections from the University's template Participant Information Sheet: *'What will happen to my Personal Data'* and *'What happens to the data at the end of the research project?'* If **no**, please explain why this content has not been used and/or how you have otherwise ensured that the relevant data protection/privacy information has been provided to participants.	Yes	No
Yes			
8.7	For how long will the collected anonymised data be retained? Please also explain any data deletion arrangements. Note: Anonymised research data must be retained for the period specified in Section 2.9 ('Research Project Conduct') of the University's Research Records Retention Schedule. Please note that where UG and PGT projects **do not** contribute to a publication or wider research project, research records and data may be held for a shorter period. Please refer to the guidance notes in Section 2.9 of the University's Research Records Retention Schedule for further detail.		
The anonymous data collected will be securely stored for a period of 5 years following publication. After this time, all data, including email messages and consent forms related to the study, will be deleted to maintain participants' privacy and confidentiality.			
8.8	Who will have access to the data?		
Only investigator team			
8.9	Will the data be shared in any way, for example through deposit in a data repository, with third parties, or a transcription service?	Yes	No

	If yes, please confirm what steps will be taken to ensure that the data is treated with an appropriate level of care (particularly if it involves any data capable of identifying a participant) e.g. contracts/data processing agreements, a de-identification process, informing the participants about the data sharing etc.		

No

SECTION 9. OTHER ETHICAL CONSIDERATIONS

Please outline any other ethical considerations raised by the research project and how you intend to address these. You are obliged to bring to the attention of the SREC any ethical issues not covered in this Ethics Review Application Proforma.

SECTION 10. SUPPORTING DOCUMENTS

I have attached the following documents in support of this application.

		Yes	No	**Version no.** (where applicable)
1	Research Project Protocol/Proposal		No	
2	Recruitment Adverts/Invitation Letters	Yes		
3	Participant Information Sheet	Yes		
4	Consent Form	Yes		
5	Data Collection Tool(s) (e.g. questionnaire(s)) [**or** a detailed description of the proposed tool which provides the SREC with clear information about the parameters of the tool i.e. what themes/areas will be covered and what will be excluded].	Yes		
6	Other participant communications (e.g. debrief sheets)		No	
7	Evidence of Research Integrity training completion	Yes		
8	Applicant to list any additional documents provided to the SREC, particularly any additional documents relevant to recruitment, consent and participation		No	

If you have selected 'No' for any of the documents listed above, please confirm why these have not been provided. If a listed document is not relevant to your project, please confirm this below.

Since this research have not start yet, the debrief sheets are not available currently. Also please noted that there have no additional documents at this time.
SECTION 11. SIGNATURES AND DECLARATIONS
Applicant declaration I confirm that: The information in this form is accurate to the best of my knowledge and belief and I take full responsibility for it. I have the necessary skills, training and or/expertise to conduct the research project as proposed. I am familiar with the University's health and safety requirements and policies and that all relevant health and safety measures have been taken into account for the research project. I am familiar with, and will comply with, the University's Policy on the Ethical Conduct of Research involving Human Participants, Human Material or Human Data and the University's Research Integrity and Governance Code of Practice. The relevant equality and diversity considerations have been taken into account when designing the research project. If the research project is approved, I undertake to adhere to the research project protocol, the terms of the full application as approved and any conditions set out by the Committee and any other body required to review and/or approve the research project. I will notify the Committee and all other review bodies of substantial amendments to the protocol or the terms of the approved application, and to seek a favourable opinion from the Committee before implementing the amendment.
Signed: Shicheng Chen
Print name: Shicheng Chen
Date: 31 October, 2023
SUPERVISOR DECLARATION (FOR STUDENT PROJECTS)
I confirm that: I am familiar with the University's Policy on the Ethical Conduct of Research involving Human Participants, Human Material or Human Data and the University's Research Integrity and Governance Code of Practice. I have reviewed this application, and all supporting documents, and I am satisfied that the project as proposed meets the University's ethical standards. I have the necessary skills, training and or/expertise to offer appropriate supervision and support to the student researcher/applicant. I will encourage the student to discuss with me, and reflect on, any ethical issues that arise during or after the project and, where relevant, I will ensure such issues are notified to the SREC.
Signed: D Eyers
Print name: Dr Daniel Eyers

Date: 31 October, 2023

Please submit the completed application and supporting documents to the CARBS Research Office via the *AHSS CARBS ethics submission system***.**

Your electronic submission should contain wet-ink or electronic signatures of all relevant parties. Please note that if any information is missing, the application may be returned to you.

A.2 Consent Form



CONSENT FORM

Title of research project: The Impact of Ripple Effects on Supply Chain Disruption Risk Management in Construction SMEs

SREC reference and committee: CARBS SREC reference number: 2149

Name of Chief/Principal Investigator: Shicheng Chen

	Please initial box
I confirm that I have read the information sheet dated 27 October 2023 version 1.0 for the above research project.	
I confirm that I have understood the information sheet dated 27 October 2023 version1.0 for the above research project and that I have had the opportunity to ask questions and that these have been answered satisfactorily.	
I confirm that audio recording will be conducted during the interview.	
I understand that my participation is voluntary, and I am free to withdraw at any time without giving a reason and without any adverse consequences (e.g. to medical care or legal rights, if relevant). I understand that if I withdraw, information about me that has already been obtained may be kept by Cardiff University.	
I understand that data collected during the research project may be looked at by individuals from Cardiff University or from regulatory authorities, where it is relevant to my taking part in	

the research project. I give permission for these individuals to have access to my data.	
I consent to the processing of my personal information name contract information for the purposes explained to me. I understand that such information will be held in accordance with all applicable data protection legislation and in strict confidence, unless disclosure is required by law or professional obligation.	
I understand who access to personal information will have provided, how the data will be stored and what will happen to the data at the end of the research project.	
I understand that anonymised excerpts and/or verbatim quotes from my questionnaire may be used as part of the research publication.	
I understand how the findings and results of the research project will be written up and published.	
I agree to take part in this research project.	

Name of participant (print) Date Signature

Name of person taking consent Date Signature

(print)

_____

Role of person taking consent

(print)

THANK YOU FOR PARTICIPATING IN OUR RESEARCH

YOU WILL BE GIVEN A COPY OF THIS CONSENT FORM TO KEEP

A.3 Invitation Letters

The Impact of Ripple Effects on Supply Chain Disruption Risk Management in Construction SMEs

I hope this letter finds you well. We are conducting a research study on the impact of ripple effect in construction SMEs, and we believe your expertise in the field would be invaluable to our study. We would greatly appreciate your participation in our study by participant online questionnaire/interview we have prepared. Thank you in advance for your contribution to our research.

The aim of this study is to explore the impact of ripple effects on construction SMEs, rank the importance of the factors generating the ripple effect, and model the other significant factors using a case study approach. Your valuable insights will contribute significantly to our research and help us to better understand the challenges that SMEs in the construction industry encounter.

Participation in this study will require you to complete a brief online questionnaire or interview, which is estimated to take approximately 15-40 minutes. Rest assured that your responses will be treated with utmost confidentiality and anonymity and will be exclusively utilized for research purposes. Throughout the interview phase, your responses will be recorded to ensure we capture the complete content of our conversation for summary purposes.

We would greatly appreciate your participation in our study. Your input is invaluable and will help to advance my knowledge in this important field.

If you have any questions or concerns, please do not hesitate to contact us at Chens111@cardiff.ac.uk. Thank you in advance for your time and consideration.

Sincerely,

Shicheng Chen

PhD Student

Cardiff Business School

Chens111@cardiff.ac.uk

20 September 2023

A.4 Participants Information



PARTICIPANT INFORMATION SHEET

Title: The Impact of Ripple Effects on Supply Chain Disruption Risk Management in Construction SMEs

You are being invited to take part in a research project. Before you decide whether or not to take part, it is important for you to understand why the research is being undertaken and what it will involve. Please take time to read the following information carefully and discuss it with others, if you wish.

Thank you for reading this.

1. What is the purpose of this research project?

The aim of this study is to explore the impact of ripple effects on construction SMEs, rank the importance of the factors generating the ripple effect, and model the other significant factors using a case study approach.

2. Why have I been invited to take part?

You have been invited because you are experts in the field of construction, or individuals actively involved in the operations of small and medium-sized enterprises (SMEs) within the industry.

3. Do I have to take part?

No, your participation in this research project is entirely voluntary and it is up to you to decide whether or not to take part. If you decide to take part, we will discuss the research

project with you and ask you to sign a consent form. If you decide not to take part, you do not have to explain your reasons and it will not affect your legal rights.

You are free to withdraw your consent to participate in the research project at any time, without giving a reason, even after signing the consent form.

4. What will taking part involve?

Participation in this study will require to complete a brief online questionnaire or interview, which is estimated to take approximately 45-60 minutes for online interview and 15-40 minutes for questionnaire. Voice will be record during the interview. Rest assured that your responses will be treated with utmost confidentiality and anonymity and will be exclusively utilized for research purposes. Throughout the interview phase, your responses will be recorded to ensure we capture the complete content of our conversation for summary purposes.

5. Will I be paid for taking part?

No. You should understand that any questionnaire/interview you give will be as a gift and you will not benefit financially in the future should this research project lead to the development of a new treatment/method/test/assessment.

6. What are the possible benefits of taking part?

There will be no direct advantages or benefits to you from taking part, but your contribution will help us understand the impact of ripple effect of SMEs in the construction industry. This valuable knowledge will enable us to develop and propose targeted solutions that can benefit the companies involved, promoting more resilient and sustainable supply chain practices.

7. What are the possible risks of taking part?

Please note that this questionnaire will not have foreseeable discomforts, risks or disadvantages.

8. Will my taking part in this research project be kept confidential?

All information collected from (or about) you during the research project will be kept confidential and any personal information you provide will be managed in accordance with data protection legislation. Please see 'What will happen to my Personal Data?' (below) for further information.

9. What will happen to my Personal Data?

Cardiff University is the Data Controller and is committed to respecting and protecting your personal data in accordance with your expectations and Data Protection legislation. Further information about Data Protection, including:

- your rights
- the legal basis under which Cardiff University processes your personal data for research
- Cardiff University's Data Protection Policy
- how to contact the Cardiff University Data Protection Officer
- how to contact the Information Commissioner's Office

may be found at https://www.cardiff.ac.uk/public-information/policies-and-procedures/data-protection

To further ensure anonymity, any identifying information will be removed once the data has been collected. This includes any personally identifiable information such as name or contact details. The data will be uploaded to a password-protected computer at the University. Each respondent will be assigned a code or pseudonym to anonymize the data and any personal information will be stored separately.

After collection, the research team will anonymise all the personal data it has collected from, or about, you in connection with this research project, with the exception of your consent form. Your consent form will be retained for minimum period of 5 years

after publication of any findings based upon the data and may be accessed by members of the research team and, where necessary, by members of the University's governance and audit teams or by regulatory authorities. Anonymised information will be kept for a minimum of 5 years but may be published in support of the research project and/or retained indefinitely, where it is likely to have continuing value for research purposes.

If a participant chooses to withdraw their participation from the study, any identifiable data and samples collected from them will be destroyed unless they give explicit permission for their data to be used. However, it is important to note that it may not be possible to withdraw any anonymized data that has already been published or where identifiers are irreversibly removed during the course of the research project.

Interviews with participants will be audio-recorded to ensure that their points are fully documented. Prior to any audio recording, informed consent for recording will be obtained from the participants through a consent form. Participants will be provided with details regarding the purpose of data collection, who will have access to the data, and how the data will be anonymized.

10. What happens to the data at the end of the research project?

Any personal data and samples collected up until the point of participant withdrawal from the research project will be securely stored and will only be accessible to lead investigator involved in the project.

11. What will happen to the results of the research project?

It is our intention to publish the results of this research project in academic journals and present findings at conferences. Participants will not be identified in any report, publication or presentation.

12. What if there is a problem?

If you wish to complain or have grounds for concerns about any aspect of the manner in which you have been approached or treated during the course of this research, please

contact Shicheng Chen. If your complaint is not managed to your satisfaction, please contact the Chair of the School Research Ethics, Dr Carmela Bosangit (bosangitC@cardiff.ac.uk)

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone's negligence, you may have grounds for legal action, but you may have to pay for it.

13. Who is organising and funding this research project?

The research is organised by Shicheng Chen and supervisor teams: Daniel Eyers; Jonathan Gosling; Huang Yuan in Cardiff University

14. Who has reviewed this research project?

This research project has been reviewed and given a favourable opinion by the CARBS Student Research Ethics Committee, Cardiff University.

15. Further information and contact details

Should you have any questions relating to this research project, you may contact us during normal working hours:

Shicheng Chen

PhD Student

Cardiff Business School

Chens111@cardiff.ac.uk

Thank you for considering to take part in this research project. If you decide to participate, you will be given a copy of the Participant Information Sheet and a signed consent form to keep for your records.

A.5 Research integrity and ethics training certificate

Research and Innovation Services

This is to certify that

Shicheng Chen

has successfully completed

Completion of Research Integrity Training (Student) / Cwblhau Rhaglen Hyfforddiant Ar-lein Gonestrwydd Ymchwil (Myfyriwr)

on

23 August 2022

Appendix B: Interview

Exploring Ripple Effect Factors in Construction SMEs: A Semi-structure Interview

Introduction:

Hello, and thank you for participating in this interview. My name is Shicheng Chen, a second-year PhD student at Cardiff University. My research focuses on supply chain risk management, today's interview topic is examining the impact of ripple effects on SMEs in the construction industry I will explain the concept later.

Please be assured that the information you provide will remain anonymous. Your name and personal details will be changed, and only the research team will have access to this information. May I ask if it's alright to record our conversation to ensure accuracy? The recording will be stored on the University's secure drive, not on my personal device.

Section 1: Background Information

1. Can you please introduce yourself and your role?
2. If you are the owner of company how long has the company been operational, and what types of projects do you typically undertake?
3. Can you please brief introduce the organization structure?

Section 2: Understanding the Ripple Effect

Tell the interviewee example here to explain Ripple effect. Imagine you are a project manager overseeing the construction of a new office building. In the initial planning stages, a design change is proposed to replace a specified construction material with a more sustainable alternative, such as eco-friendly insulation material. This change has

implications throughout the construction supply chain example material suppliers, logistics, warehouse, project timelines and waste management.

4. What risks/problems are passed from suppliers, customers, site teams?
5. Ask the interviewee if they have encountered situations like this and what risks/problems are passed from suppliers, customers, site teams?

Section 3: Factors Contributing to the Ripple Effect

6. Based on your experience, what factors do you think that contribute to the ripple effect in construction projects?
7. Do you think compared to SMEs; large construction company have more flexibility dealing with ripple effect? And why?
8. In the following risks do you agree they can trigger ripple effect or if you think other types of risk:

Supply risk (e.g., Supplier opportunism, Unstable quality of inputs, Price fluctuations, Inflexibility of suppliers, Supplier bankruptcy, Suppliers dependency)

Operational risk (e.g., Design changes, Poor planning and scheduling, Technological change, Dissatisfaction with work, Accident, Inflexibility in layout for free flow of materials, Labor disputes/strikes, Lack of experience or training)

Demand risk (e.g., Demand variability, Deficient or missing customer relation management function, Customer bankruptcy, Customer dependency, High competition in the market, Customer fragmentation)

Human-made risk (e.g., Economic downturns, Social and cultural grievances, External legal issues, War and terrorism, Political instability)

Natural risk (e.g., Epidemics, Earthquakes, Natural catastrophes, Tsunami)

Section 4: Mitigation Strategies

9. Discuss how they managed the ripple effect and what strategies or approaches were used to minimize the impact of risk propagation.
10. Do you think construction SMEs are less control ripple effect compared to large construction company? If yes, what factors do you think that will be?
11. For large construction company, can you think the difference for strategies they have to mitigate ripple effect.

Section 5: Future Considerations

12. In your opinion, how might the landscape of construction project management evolve in relation to managing ripple effects?
13. Are there emerging technologies or methodologies that you believe could be particularly useful in this context?

Closing:

That brings us to the end of the interview. Thank you for sharing your invaluable insights. I will go over the information to ensure accuracy. Is there anything else you would like to add? Once again, thank you for your time and valuable input.

Table B.1: Chapter 4 NVivo word frequency

Word	Length	Count	Weighted Percentage (%)	Similar Words
construction	12	6635	0.45	building, buildings, builds, concept, concepts, construct, constructed, constructing, construction, express, making, manufacturer, manufacturers, reconstruction, structural, structure
project	7	5749	0.39	design, designate, designated, designation, designed, designer, designers, designers', designing, designs, external, figure, figured, laborer, laborers, picture, pictures, planned, planning, project, projects, proposal, proposed, seeing, undertake
change	6	4327	0.36	change, changed, changes, changing, convert, converted, deepen, deepening, exchange, exchanged, exchanges, interchangeable, modification, modifications, modify, shifts, switch, switching, transfer, transferred, varies, varieties, variety
material	8	3882	0.32	corporate, corporation, corporations, happen, happened, happening, happens, material, materials, physical, physics, substantial
example	7	3208	0.28	example, examples, exercising, modeling, represent, representative
situation	9	3609	0.26	deposit, located, location, office, officer, officers, placed, places, placing, position, positioned, positioning, positions, positive, positively, situation, situations
people	6	2464	0.22	people
understand	10	3053	0.22	agreement, clearly, comprehensive, comprehensively, realisation, realise, realize, reason, reasonable, reasons, seeing, understand,

				understandable, understanding, understands
reaction	8	2669	0.21	reaction, reactions, response, responsibilities, responsibility, responsible
particularly	12	3086	0.20	detail, detailed, details, especially, except, exceptionally, particular, particularly, peculiar, special, specialization, specialize, specialized, specializes, specializing, specific, specifically, specification, specifications, specifics, specified, specify
company	7	2352	0.20	accompanied, accompany, accompanying, companies, company, parties, society
process	7	3423	0.19	action, advance, advanced, advances, advancing, litigation, operate, operated, operates, operating, operation, operational, operations, operator, operators, procedure, procedures, process, processed, processes, processing, progress, refine, rising, served, serves, worked, working
customer	8	2118	0.19	client, clients, custom, customer, customers, customization, customize, customized, customizing, tradition, traditional, traditionally
supply	6	2355	0.18	catering, furnishing, furnishings, issued, issues, issuing, provide, provided, provides, provision, provisions, rendering, supplied, supplies, supply, supplying
workers	7	1891	0.17	worker, workers, workers'
contract	8	2489	0.17	catching, compact, compress, compressing, compression, concentrated, contract, contracted, contracting, contracts, cutting, declared, getting, narrow, pressed, reduce, reduced, reducers, reducing, shorten, shortened, shrink,

				shrinking, signed, signing, squeeze, taking, undertake
demand	6	2707	0.16	asking, demand, demanded, demanding, exactly, involve, involved, involves, involving, needed, require, required, requirement, requirements, requires, requiring, taking
including	9	1710	0.15	include, included, includes, including
original	8	2671	0.15	arises, arising, beginning, develop, developed, developer, developers, developing, development, earlier, foundation, founded, founding, inception, initial, initiative, institute, institutes, institution, institutional, institutions, introduction, master, masters, original, originally, originated, rising, source, started, starting, starts, stocking
problem	7	1636	0.14	problem, problems, trouble



Figure B.1: Chapter 4 NVivo word clouds

Appendix C: Questionnaire

Dear Participants,

This research is conducted by Shicheng Chen, a PhD student at Cardiff Business School, Cardiff University, under the supervision of Dr. Daniel Eyers, Professor Jonathan Gosling, and Dr. Yuan Huang. The aim is to explore the factors influencing the ripple effect in the construction supply chain. The results of the study will be used as part of a PhD thesis. All information provided in the questionnaire will be anonymised to ensure that responses and comments cannot be traced back to individuals. No personally identifiable data will be shared in this study.

Respondents' Rights: Participation in the study is entirely voluntary, and participants may withdraw from the study at any time without providing a reason.

How Information Will Be Stored: All information provided in the questionnaire will be stored anonymously, making it impossible to trace the provider of the information or comments. Information will be held in compliance with the current Data Protection Act. The data collected will only be used for purposes related to teaching, scholarly presentations, and publications.

Your expertise is vital to our PhD research. By exploring the ripple effects in the supply chain of construction SMEs, we aim to update academics on the types of elements and possible pathways to ripple effects. Participants are welcome to ask questions and discuss any concerns with the researchers (Chens111@cardiff.ac.uk) or the mentors listed above. Thank you for your participation and valuable contribution.

Best regards,
Shicheng Chen
Cardiff Business School
Cardiff University
Chens111@cardiff.ac.uk

○ I agree with the statement and decide to participate in this reserach

Your occupation:
eg: Building materials supplier; Decoration; Housing building.

Your role of department:
eg: Marketing; Finance; Production

How many years of experience do you have in this field?

What is the current size of your business in terms of employees?

The purpose of this survey questionnaire is to determine the relative weights of the influencing factors in 'ripple effect of construction SMEs'. The questionnaire is designed based on the Analytical Hierarchy Process (AHP) format. This method involves pairwise comparisons of the importance of influencing factors at the same level. The measurement scale is divided into 9 levels, where the values 9, 7, 5, 3, and 1 correspond to absolutely important, very important, relatively important, slightly important, and equally important, respectively. The values 8, 6, 4, and 2 indicate the importance level is between two adjacent levels. The left side of the grading cell indicates that the left column factor is more important than the right column factor, and the right side of the grading cell indicates that the right column factor is more important than the left column factor.

Example: When purchasing a car, do you consider safety or price to be more important? If you believe that safety is significantly more important than price (7), please change the color of the cell on the left (7, very important).

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Safety VS Price	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

The table summarises all supply chain risks explored in the survey

Objective	Criteria	Sub-Criteria
Explore the most significant impacts of ripple effects on construction SMEs.	Finanial risks	Advance funds for the project
		Delay in wage payment
		Environmental issues
	Safety risks	Worker safety issues
		Logistics reliability
		Low quality of equipment and materials
		Ineffectiveness of supervision mechanisms
	Contractual risks	Failure to perform an obligation
		Contractual ambiguity
		Transfer unavoidable risks to other stakeholders
	Design risks	Design errors
		Miscommunication for material size and features
		Failure to carry out a second check

Assessing the relative importance of Financial risks, Safety risks, Contractual risks, and Design risks

Explanation:
Financial risks: Refers to potential risks related to the financial condition of the enterprise. This includes issues such as insufficient funds, liquidity problems, increased cost of funds, etc. In the construction industry, financial risks may arise from poor financial management, cost

overruns in projects, payment delays, or client defaults.

Safety risks: Refers to potential dangers that may threaten workplace safety or cause harm to employees. In the construction industry, safety risks may involve poor site safety management, improper worker operations, quality issues with construction materials, etc.

Contractual risks: Refers to potential risks associated with contracts, including unclear contract terms, ambiguous contract interpretations, contract breaches, etc. In the construction industry, contractual risks may arise from unclear contract terms with clients, disputes arising from project changes, uncertainty in payment terms, etc.

Design risks: Refers to potential issues in the design aspect, including design errors, designs not meeting standards, design changes, etc. In the construction industry, design risks may lead to project delays, additional costs, quality issues, etc.

Please compare the following risks (Importance).

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Financial risks VS Safety risks	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Financial risks VS Contractual risks	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Financial risks VS Design risks	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Safety risks VS Contractual risks	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Safety risks VS Design risks	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Contractual risks VS Design risks	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Assessing the relative importance of Advance funds for the project, Delay in wage payment, and Environmental issues.

Explanation:
Advance funds for the project refer to providing financial resources upfront to support the initiation or progress of a construction project.

Delay in wage payment indicates a situation where workers or employees in the construction project are not paid their salaries or wages on time, leading to dissatisfaction, financial strain, and potential legal issues.

Environmental issues encompass a range of concerns related to the impact of construction activities on the environment, such as pollution, habitat destruction, resource depletion, and compliance with environmental regulations and standards.

Please compare the following risks (Importance).

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Advance funds for the project VS Delay in wage payment	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Advance funds for the project VS Environmental issues	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Delay in wage payment VS Environmental issues	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Assessing the relative importance of Worker safety issues, Logistics reliability, Low quality of equipment and materials, and Ineffectiveness of supervision mechanisms.

Explanation:
Worker safety issues pertain to concerns and risks associated with the health and safety of workers on construction sites, including accidents, injuries, exposure to hazardous materials, and compliance with safety regulations.

Logistics reliability refers to the dependability and consistency of logistical operations in the construction process, including the timely delivery of materials, equipment, and resources to the construction site.

Low quality of equipment and materials highlights the risk of using substandard or inferior quality equipment, tools, and materials in construction projects, which can lead to inefficiencies, rework, safety hazards, and compromised structural integrity.

Ineffectiveness of supervision mechanisms relates to challenges or deficiencies in the oversight and management of construction activities, including inadequate monitoring, lack of accountability, and failure to enforce safety protocols and quality standards.

Please compare the following risks (Importance).

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Worker safety issues VS Logistics reliability	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Worker safety issues VS Low quality of equipment and materials	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Worker safety issues VS Ineffectiveness of supervision mechanisms	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Logistics reliability VS Low quality of equipment and materials	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Logistics reliability VS Ineffectiveness of supervision mechanisms	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Low quality of equipment and materials VS Ineffectiveness of supervision mechanisms	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Assessing the relative importance of Failure to perform an obligation, Contractual ambiguity, and Transfer unavoidable risks to other stakeholders.

Explanation:
Failure to perform an obligation refers to situations where parties involved in a contract fail to fulfill their contractual duties or obligations, leading to breaches of contract and potential legal consequences.

Contractual ambiguity refers to uncertainties or vagueness in the terms and conditions of a contract, which can lead to misunderstandings, disputes, and difficulties in enforcing contractual rights and obligations.

Transfer unavoidable risks to other stakeholders involves the practice of shifting risks and liabilities inherent in a project to other parties, such as subcontractors or suppliers, which may result in disputes, increased costs, and project delays.

Please compare the following risks (Importance).

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Failure to perform an obligation VS Contractual ambiguity	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Failure to perform an obligation VS Transfer unavoidable risks to other stakeholders	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Contractual ambiguity VS Transfer unavoidable risks to other stakeholders	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Assessing the relative importance of Design errors, Miscommunication for material size and features, and Failure to carry out a second check.

Explanation:

Design errors entail mistakes or inaccuracies in the planning, design, or engineering of a construction project, which can lead to structural flaws, safety hazards, rework, and cost overruns.

Miscommunication for material size and features refers to misunderstandings or discrepancies in communicating the specifications, dimensions, or characteristics of construction materials, which can result in procurement errors, delays, and quality issues.

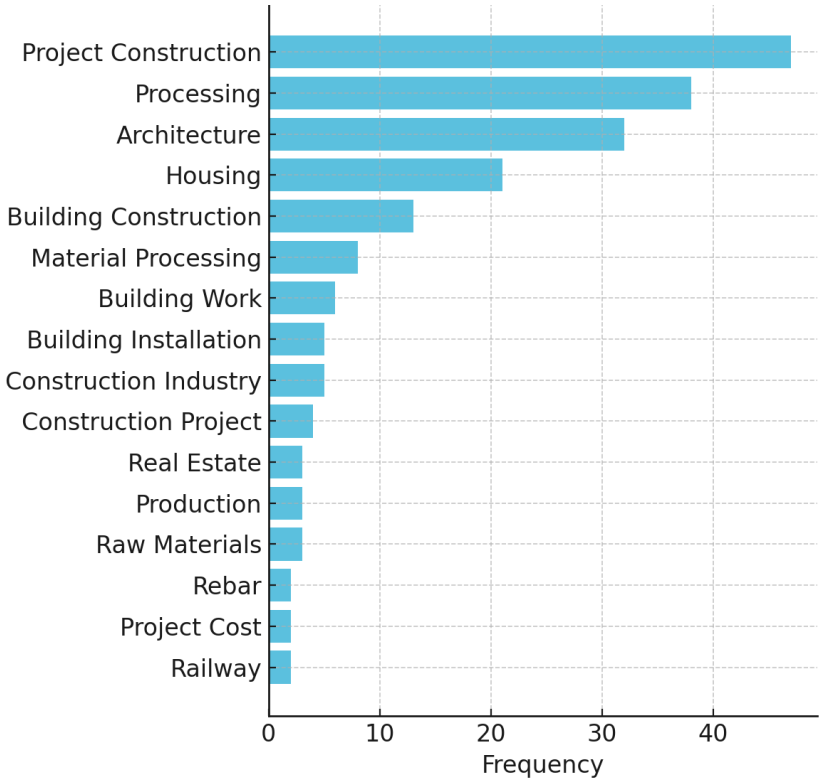
Failure to carry out a second check involves neglecting to conduct a thorough review or verification process to ensure the accuracy, completeness, and quality of construction work, materials, or documentation, which can lead to errors, omissions, and quality deficiencies.

Please compare the following risks (Importance).

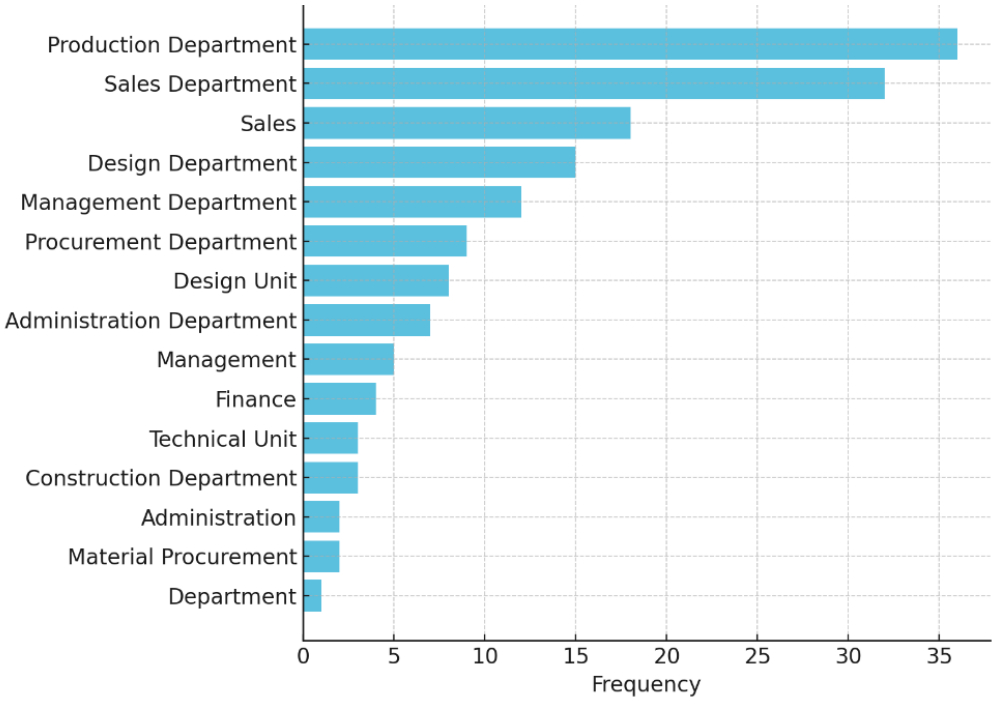
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Design errors VS Miscommunication for material size and features	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Design errors VS Failure to carry out a second check	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Miscommunication for material size and features VS Failure to carry out a second check	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Factors Influencing Chain Reaction Risk in Construction SMEs - Practitioner Scoring Scale

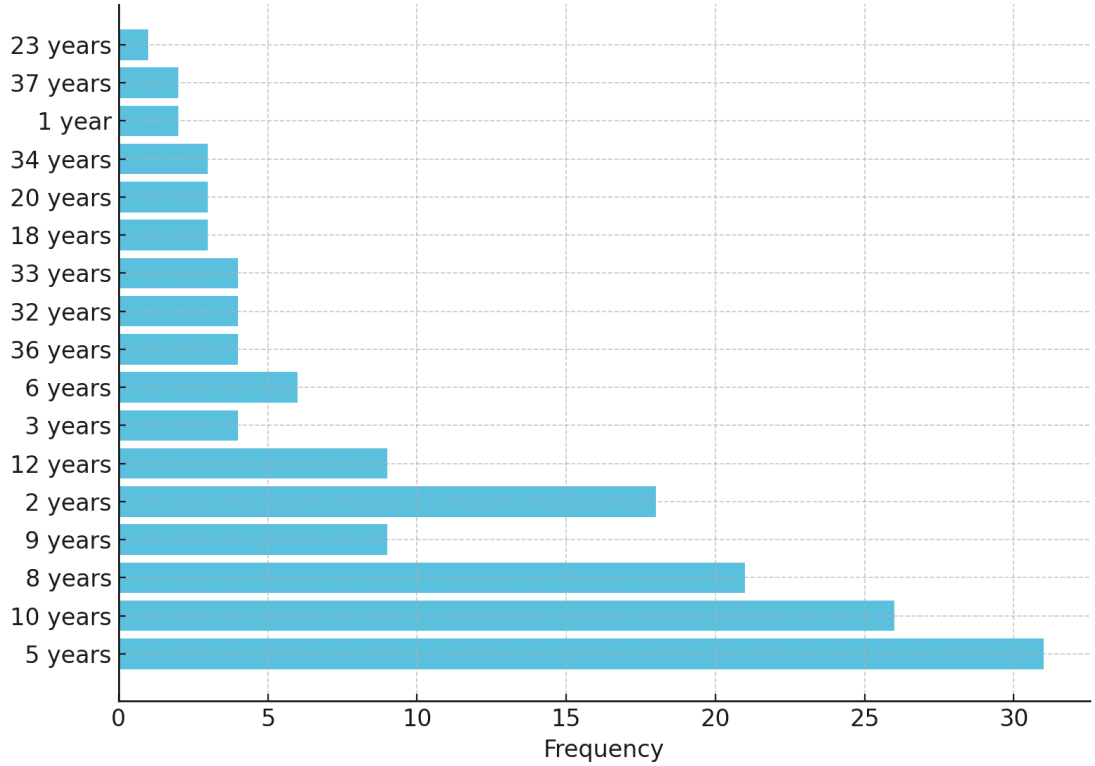
1. Your occupation:



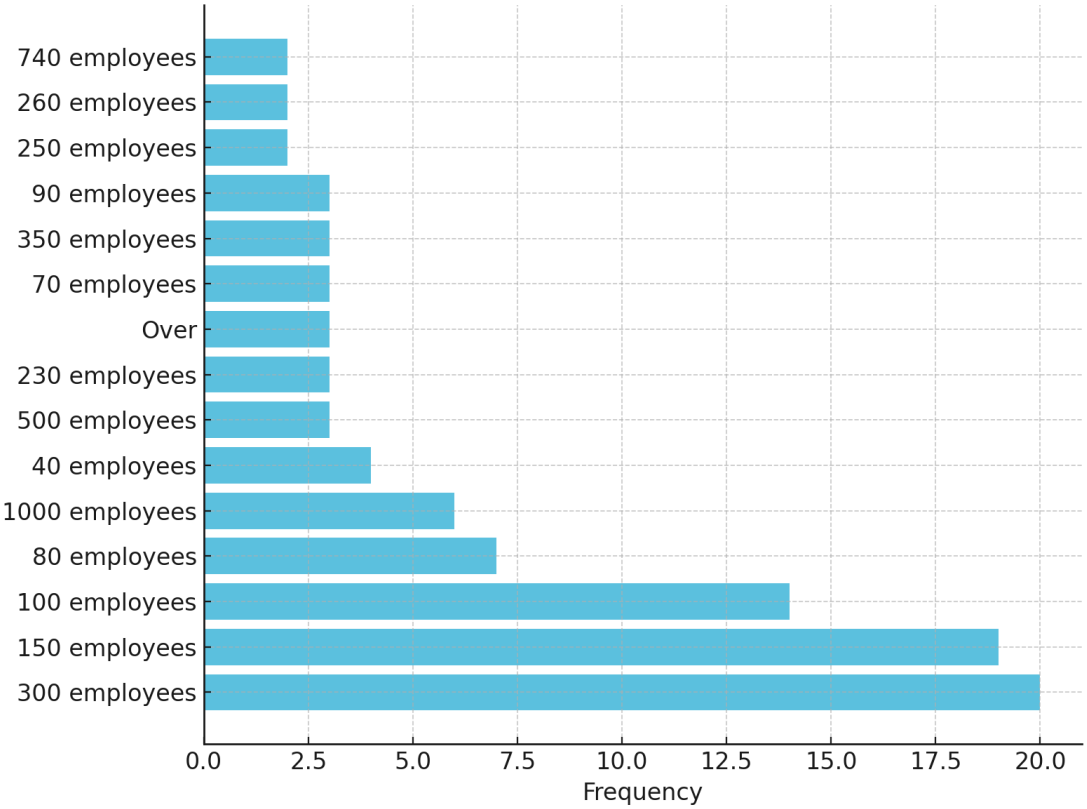
2. Your role of department:



3. How many years of experience do you have in this field?



4. What is the current size of your business in terms of employees?



Assessing the relative importance of financial risks, Safety risks, Contractual risks, and Design risks

Financial risks: Refers to potential risks related to the financial condition of the enterprise. This includes issues such as insufficient funds, liquidity problems, increased cost of funds, etc. In the construction industry, financial risks may arise from poor financial management, cost overruns in projects, payment delays, or client defaults.

Safety risks: Refers to potential dangers that may threaten workplace safety or cause harm to employees. In the construction industry, safety risks may involve poor site safety management, improper worker operations, quality issues with construction materials, etc.

Contractual risks: Refers to potential risks associated with contracts, including unclear contract terms, ambiguous contract interpretations, contract breaches, etc. In the construction industry, contractual risks may arise from unclear contract terms with clients, disputes arising from project changes, uncertainty in payment terms, etc.

Design risks: Refers to potential issues in the design aspect, including design errors, designs not meeting standards, design changes, etc. In the construction industry, design risks may lead to project delays, additional costs, quality issues, etc.

5. Financial risks——Safety risks

Options	Importance	Amount
9	18(7.5%)	18(7.5%)
8	13(5.42%)	13(5.42%)
7	22(9.17%)	22(9.17%)
6	11(4.58%)	11(4.58%)
5	7(2.92%)	7(2.92%)
4	9(3.75%)	9(3.75%)
3	7(2.92%)	7(2.92%)
2	9(3.75%)	9(3.75%)
1	17(7.08%)	17(7.08%)
2*	10(4.17%)	10(4.17%)

3*	10(4.17%)	10(4.17%)
4*	18(7.5%)	18(7.5%)
5*	23(9.58%)	23(9.58%)
6*	12(5%)	12(5%)
7*	20(8.33%)	20(8.33%)
8*	15(6.25%)	15(6.25%)
9*	19(7.92%)	19(7.92%)
Mean	5.64	5.64

6. Financial risks—Contractual risks

Options	Importance	Amount
9	21(8.75%)	21(8.75%)
8	27(11.25%)	27(11.25%)
7	28(11.67%)	28(11.67%)
6	21(8.75%)	21(8.75%)
5	16(6.67%)	16(6.67%)
4	8(3.33%)	8(3.33%)
3	3(1.25%)	3(1.25%)
2	8(3.33%)	8(3.33%)
1	16(6.67%)	16(6.67%)
2*	14(5.83%)	14(5.83%)
3*	11(4.58%)	11(4.58%)
4*	15(6.25%)	15(6.25%)
5*	12(5%)	12(5%)
6*	10(4.17%)	10(4.17%)
7*	10(4.17%)	10(4.17%)
8*	9(3.75%)	9(3.75%)
9*	11(4.58%)	11(4.58%)
Mean	5.68	5.68

7. Financial risks——Design risk

Options	Importance	Amount
9	15(6.25%)	15(6.25%)

8	28(11.67%)	28(11.67%)
7	25(10.42%)	25(10.42%)
6	28(11.67%)	28(11.67%)
5	22(9.17%)	22(9.17%)
4	12(5%)	12(5%)
3	11(4.58%)	11(4.58%)
2	5(2.08%)	5(2.08%)
1	10(4.17%)	10(4.17%)
2*	10(4.17%)	10(4.17%)
3*	18(7.5%)	18(7.5%)
4*	12(5%)	12(5%)
5*	9(3.75%)	9(3.75%)
6*	7(2.92%)	7(2.92%)
7*	10(4.17%)	10(4.17%)
8*	9(3.75%)	9(3.75%)
9*	9(3.75%)	9(3.75%)
Mean	5.6	5.6

8. Safety risks——Contractual risks

Options	Importance	Amount
9	36(15%)	36(15%)
8	38(15.83%)	38(15.83%)
7	20(8.33%)	20(8.33%)
6	23(9.58%)	23(9.58%)
5	13(5.42%)	13(5.42%)
4	11(4.58%)	11(4.58%)
3	7(2.92%)	7(2.92%)
2	8(3.33%)	8(3.33%)
1	13(5.42%)	13(5.42%)
2*	7(2.92%)	7(2.92%)
3*	6(2.5%)	6(2.5%)
4*	17(7.08%)	17(7.08%)
5*	11(4.58%)	11(4.58%)
6*	5(2.08%)	5(2.08%)
7*	7(2.92%)	7(2.92%)

8*	10(4.17%)	10(4.17%)
9*	8(3.33%)	8(3.33%)
Mean	6.05	6.05

9. Safety risks——Design risk

Options	Importance	Amount
9	39(16.25%)	39(16.25%)
8	33(13.75%)	33(13.75%)
7	32(13.33%)	32(13.33%)
6	16(6.67%)	16(6.67%)
5	21(8.75%)	21(8.75%)
4	12(5%)	12(5%)
3	14(5.83%)	14(5.83%)
2	5(2.08%)	5(2.08%)
1	8(3.33%)	8(3.33%)
2*	4(1.67%)	4(1.67%)
3*	12(5%)	12(5%)
4*	4(1.67%)	4(1.67%)
5*	13(5.42%)	13(5.42%)
6*	7(2.92%)	7(2.92%)
7*	6(2.5%)	6(2.5%)
8*	6(2.5%)	6(2.5%)
9*	8(3.33%)	8(3.33%)
Mean	6.15	6.15

10. Contractual risks——Design risk

Options	Importance	Amount
9	17(7.08%)	17(7.08%)
8	21(8.75%)	21(8.75%)
7	30(12.5%)	30(12.5%)
6	20(8.33%)	20(8.33%)
5	20(8.33%)	20(8.33%)
4	8(3.33%)	8(3.33%)

3	9(3.75%)	9(3.75%)
2	7(2.92%)	7(2.92%)
1	15(6.25%)	15(6.25%)
2*	10(4.17%)	10(4.17%)
3*	14(5.83%)	14(5.83%)
4*	14(5.83%)	14(5.83%)
5*	19(7.92%)	19(7.92%)
6*	7(2.92%)	7(2.92%)
7*	12(5%)	12(5%)
8*	7(2.92%)	7(2.92%)
9*	10(4.17%)	10(4.17%)
Mean	5.52	5.52

Assessing the relative importance of Advance funds for the project, Delay in wage payment, and Environmental issues.

Explanation:

Advance funds for the project refer to providing financial resources upfront to support the initiation or progress of a construction project.

Delay in wage payment indicates a situation where workers or employees in the construction project are not paid their salaries or wages on time, leading to dissatisfaction, financial strain, and potential legal issues.

Environmental issues encompass a range of concerns related to the impact of construction activities on the environment, such as pollution, habitat destruction, resource depletion, and compliance with environmental regulations and standards.

11. Advance funds for the project——Delay in wage payment

Options	Importance	Amount
9	23(9.58%)	23(9.58%)
8	21(8.75%)	21(8.75%)
7	30(12.5%)	30(12.5%)
6	11(4.58%)	11(4.58%)
5	14(5.83%)	14(5.83%)
4	7(2.92%)	7(2.92%)
3	8(3.33%)	8(3.33%)
2	12(5%)	12(5%)
1	14(5.83%)	14(5.83%)
2*	7(2.92%)	7(2.92%)
3*	13(5.42%)	13(5.42%)
4*	18(7.5%)	18(7.5%)
5*	14(5.83%)	14(5.83%)
6*	8(3.33%)	8(3.33%)
7*	15(6.25%)	15(6.25%)
8*	13(5.42%)	13(5.42%)
9*	12(5%)	12(5%)
Mean	5.71	5.71

12. Advance funds for the project——Environmental issues

Options	Importance	Amount
9	16(6.67%)	16(6.67%)
8	25(10.42%)	25(10.42%)
7	29(12.08%)	29(12.08%)
6	16(6.67%)	16(6.67%)
5	14(5.83%)	14(5.83%)
4	19(7.92%)	19(7.92%)
3	6(2.5%)	6(2.5%)
2	7(2.92%)	7(2.92%)
1	10(4.17%)	10(4.17%)
2*	7(2.92%)	7(2.92%)
3*	16(6.67%)	16(6.67%)

4*	17(7.08%)	17(7.08%)
5*	18(7.5%)	18(7.5%)
6*	16(6.67%)	16(6.67%)
7*	9(3.75%)	9(3.75%)
8*	10(4.17%)	10(4.17%)
9*	5(2.08%)	5(2.08%)
Mean	5.56	5.56

13. Delay in wage payment——Environmental issues

Options	Importance	Amount
9	20(8.33%)	20(8.33%)
8	27(11.25%)	27(11.25%)
7	20(8.33%)	20(8.33%)
6	20(8.33%)	20(8.33%)
5	13(5.42%)	13(5.42%)
4	9(3.75%)	9(3.75%)
3	13(5.42%)	13(5.42%)
2	10(4.17%)	10(4.17%)
1	16(6.67%)	16(6.67%)
2*	12(5%)	12(5%)
3*	10(4.17%)	10(4.17%)
4*	17(7.08%)	17(7.08%)
5*	18(7.5%)	18(7.5%)
6*	5(2.08%)	5(2.08%)
7*	12(5%)	12(5%)
8*	9(3.75%)	9(3.75%)
9*	9(3.75%)	9(3.75%)
Mean	5.46	5.46

Assessing the relative importance of Worker safety issues, Logistics reliability, Low quality of equipment and materials, and Ineffectiveness of supervision mechanisms.

Explanation:

Worker safety issues pertain to concerns and risks associated with the health and safety of workers on construction sites, including accidents, injuries, exposure to hazardous materials, and compliance with safety regulations.

Logistics reliability refers to the dependability and consistency of logistical operations in the construction process, including the timely delivery of materials, equipment, and resources to the construction site.

Low quality of equipment and materials highlights the risk of using substandard or inferior quality equipment, tools, and materials in construction projects, which can lead to inefficiencies, rework, safety hazards, and compromised structural integrity.

Ineffectiveness of supervision mechanisms relates to challenges or deficiencies in the oversight and management of construction activities, including inadequate monitoring, lack of accountability, and failure to enforce safety protocols and quality standards.

14. Worker safety issues——Logistics reliability

Options	Importance	Amount
9	41(17.08%)	41(17.08%)
8	34(14.17%)	34(14.17%)
7	43(17.92%)	43(17.92%)
6	21(8.75%)	21(8.75%)
5	20(8.33%)	20(8.33%)
4	5(2.08%)	5(2.08%)
3	11(4.58%)	11(4.58%)
2	4(1.67%)	4(1.67%)
1	8(3.33%)	8(3.33%)
2*	10(4.17%)	10(4.17%)
3*	7(2.92%)	7(2.92%)
4*	10(4.17%)	10(4.17%)
5*	6(2.5%)	6(2.5%)
6*	10(4.17%)	10(4.17%)

7*	4(1.67%)	4(1.67%)
8*	2(0.83%)	2(0.83%)
9*	4(1.67%)	4(1.67%)
Mean	6.2	6.2

15. Worker safety issues——Low quality of equipment and materials

Options	Importance	Amount
9	42(17.5%)	42(17.5%)
8	31(12.92%)	31(12.92%)
7	27(11.25%)	27(11.25%)
6	22(9.17%)	22(9.17%)
5	12(5%)	12(5%)
4	12(5%)	12(5%)
3	4(1.67%)	4(1.67%)
2	10(4.17%)	10(4.17%)
1	14(5.83%)	14(5.83%)
2*	5(2.08%)	5(2.08%)
3*	7(2.92%)	7(2.92%)
4*	12(5%)	12(5%)
5*	12(5%)	12(5%)
6*	6(2.5%)	6(2.5%)
7*	7(2.92%)	7(2.92%)
8*	9(3.75%)	9(3.75%)
9*	8(3.33%)	8(3.33%)
Mean	6.12	6.12

16. Worker safety issues——Ineffectiveness of supervision mechanisms

Options	Importance	Amount
9	29(12.08%)	29(12.08%)
8	29(12.08%)	29(12.08%)
7	33(13.75%)	33(13.75%)
6	29(12.08%)	29(12.08%)
5	20(8.33%)	20(8.33%)

4	9(3.75%)	9(3.75%)
3	7(2.92%)	7(2.92%)
2	6(2.5%)	6(2.5%)
1	13(5.42%)	13(5.42%)
2*	7(2.92%)	7(2.92%)
3*	10(4.17%)	10(4.17%)
4*	11(4.58%)	11(4.58%)
5*	12(5%)	12(5%)
6*	8(3.33%)	8(3.33%)
7*	8(3.33%)	8(3.33%)
8*	6(2.5%)	6(2.5%)
9*	3(1.25%)	3(1.25%)
Mean	5.86	5.86

17. Logistics reliability——Low quality of equipment and materials

Options	Importance	Amount
9	11(4.58%)	11(4.58%)
8	12(5%)	12(5%)
7	15(6.25%)	15(6.25%)
6	12(5%)	12(5%)
5	15(6.25%)	15(6.25%)
4	7(2.92%)	7(2.92%)
3	6(2.5%)	6(2.5%)
2	10(4.17%)	10(4.17%)
1	12(5%)	12(5%)
2*	8(3.33%)	8(3.33%)
3*	20(8.33%)	20(8.33%)
4*	25(10.42%)	25(10.42%)
5*	29(12.08%)	29(12.08%)
6*	16(6.67%)	16(6.67%)
7*	10(4.17%)	10(4.17%)
8*	16(6.67%)	16(6.67%)
9*	16(6.67%)	16(6.67%)
Mean	5.35	5.35

18. Logistics reliability——Ineffectiveness of supervision mechanisms

Options	Importance	Amount
9	7(2.92%)	7(2.92%)
8	16(6.67%)	16(6.67%)
7	19(7.92%)	19(7.92%)
6	14(5.83%)	14(5.83%)
5	16(6.67%)	16(6.67%)
4	12(5%)	12(5%)
3	10(4.17%)	10(4.17%)
2	2(0.83%)	2(0.83%)
1	13(5.42%)	13(5.42%)
2*	12(5%)	12(5%)
3*	22(9.17%)	22(9.17%)
4*	23(9.58%)	23(9.58%)
5*	24(10%)	24(10%)
6*	16(6.67%)	16(6.67%)
7*	14(5.83%)	14(5.83%)
8*	7(2.92%)	7(2.92%)
9*	13(5.42%)	13(5.42%)
Mean	5.22	5.22

19. Low quality of equipment and materials——Ineffectiveness of supervision mechanisms

Options	Importance	Amount
9	16(6.67%)	16(6.67%)
8	23(9.58%)	23(9.58%)
7	23(9.58%)	23(9.58%)
6	32(13.33%)	32(13.33%)
5	15(6.25%)	15(6.25%)
4	10(4.17%)	10(4.17%)

3	6(2.5%)	6(2.5%)
2	5(2.08%)	5(2.08%)
1	19(7.92%)	19(7.92%)
2*	11(4.58%)	11(4.58%)
3*	14(5.83%)	14(5.83%)
4*	16(6.67%)	16(6.67%)
5*	13(5.42%)	13(5.42%)
6*	16(6.67%)	16(6.67%)
7*	10(4.17%)	10(4.17%)
8*	4(1.67%)	4(1.67%)
9*	7(2.92%)	7(2.92%)
Mean	5.4	5.4

Assessing the relative importance of Failure to perform an obligation, Contractual ambiguity, and Transfer unavoidable risks to other stakeholders.

Explanation:

Failure to perform an obligation refers to situations where parties involved in a contract fail to fulfill their contractual duties or obligations, leading to breaches of contract and potential legal consequences.

Contractual ambiguity refers to uncertainties or vagueness in the terms and conditions of a contract, which can lead to misunderstandings, disputes, and difficulties in enforcing contractual rights and obligations.

Transfer unavoidable risks to other stakeholders involves the practice of shifting risks and liabilities inherent in a project to other parties, such as subcontractors or suppliers, which may result in disputes, increased costs, and project delays.

20. Failure to perform an obligation——Contractual ambiguity

Options	Importance	Amount
9	21(8.75%)	21(8.75%)

8	20(8.33%)	20(8.33%)
7	21(8.75%)	21(8.75%)
6	22(9.17%)	22(9.17%)
5	11(4.58%)	11(4.58%)
4	14(5.83%)	14(5.83%)
3	11(4.58%)	11(4.58%)
2	9(3.75%)	9(3.75%)
1	22(9.17%)	22(9.17%)
2*	8(3.33%)	8(3.33%)
3*	12(5%)	12(5%)
4*	10(4.17%)	10(4.17%)
5*	16(6.67%)	16(6.67%)
6*	7(2.92%)	7(2.92%)
7*	15(6.25%)	15(6.25%)
8*	11(4.58%)	11(4.58%)
9*	10(4.17%)	10(4.17%)
Mean	5.45	5.45

21. Failure to perform an obligation——Transfer unavoidable risks to other stakeholders

Options	Importance	Amount
9	13(5.42%)	13(5.42%)
8	18(7.5%)	18(7.5%)
7	31(12.92%)	31(12.92%)
6	9(3.75%)	9(3.75%)
5	13(5.42%)	13(5.42%)
4	13(5.42%)	13(5.42%)
3	12(5%)	12(5%)
2	8(3.33%)	8(3.33%)
1	18(7.5%)	18(7.5%)
2*	12(5%)	12(5%)
3*	8(3.33%)	8(3.33%)
4*	19(7.92%)	19(7.92%)
5*	23(9.58%)	23(9.58%)

6*	12(5%)	12(5%)
7*	7(2.92%)	7(2.92%)
8*	12(5%)	12(5%)
9*	12(5%)	12(5%)
Mean	5.35	5.35

22. Contractual ambiguity——Transfer unavoidable risks to other stakeholders

Options	Importance	Amount
9	20(8.33%)	20(8.33%)
8	23(9.58%)	23(9.58%)
7	14(5.83%)	14(5.83%)
6	14(5.83%)	14(5.83%)
5	12(5%)	12(5%)
4	10(4.17%)	10(4.17%)
3	15(6.25%)	15(6.25%)
2	5(2.08%)	5(2.08%)
1	23(9.58%)	23(9.58%)
2*	14(5.83%)	14(5.83%)
3*	15(6.25%)	15(6.25%)
4*	17(7.08%)	17(7.08%)
5*	24(10%)	24(10%)
6*	11(4.58%)	11(4.58%)
7*	10(4.17%)	10(4.17%)
8*	4(1.67%)	4(1.67%)
9*	9(3.75%)	9(3.75%)
Mean	5.14	5.14

Assessing the relative importance of Design errors, Miscommunication for material size and features, and Failure to carry out a second check.

Explanation:

Design errors entail mistakes or inaccuracies in the planning, design, or engineering of a construction project, which can lead to structural flaws, safety hazards, rework, and cost overruns.

Miscommunication for material size and features refers to misunderstandings or discrepancies in communicating the specifications, dimensions, or characteristics of construction materials, which can result in procurement errors, delays, and quality issues.

Failure to carry out a second check involves neglecting to conduct a thorough review or verification process to ensure the accuracy, completeness, and quality of construction work, materials, or documentation, which can lead to errors, omissions, and quality deficiencies.

23. Design errors——Miscommunication for material size and features

Options	Importance	Amount
9	26(10.83%)	26(10.83%)
8	22(9.17%)	22(9.17%)
7	26(10.83%)	26(10.83%)
6	24(10%)	24(10%)
5	18(7.5%)	18(7.5%)
4	11(4.58%)	11(4.58%)
3	4(1.67%)	4(1.67%)
2	2(0.83%)	2(0.83%)
1	17(7.08%)	17(7.08%)
2*	6(2.5%)	6(2.5%)
3*	21(8.75%)	21(8.75%)
4*	14(5.83%)	14(5.83%)
5*	13(5.42%)	13(5.42%)
6*	12(5%)	12(5%)
7*	8(3.33%)	8(3.33%)
8*	8(3.33%)	8(3.33%)
9*	8(3.33%)	8(3.33%)
Mean	5.68	5.68

24. Design errors——Failure to carry out a second check

Options	Importance	Amount
9	18(7.5%)	18(7.5%)
8	26(10.83%)	26(10.83%)
7	27(11.25%)	27(11.25%)
6	15(6.25%)	15(6.25%)
5	14(5.83%)	14(5.83%)
4	10(4.17%)	10(4.17%)
3	16(6.67%)	16(6.67%)
2	9(3.75%)	9(3.75%)
1	12(5%)	12(5%)
2*	6(2.5%)	6(2.5%)
3*	16(6.67%)	16(6.67%)
4*	13(5.42%)	13(5.42%)
5*	22(9.17%)	22(9.17%)
6*	12(5%)	12(5%)
7*	12(5%)	12(5%)
8*	5(2.08%)	5(2.08%)
9*	7(2.92%)	7(2.92%)
Mean	5.49	5.49

25. Miscommunication for material size and features——Failure to carry out a second check

Options	Importance	Amount
9	14(5.83%)	14(5.83%)
8	17(7.08%)	17(7.08%)
7	24(10%)	24(10%)
6	16(6.67%)	16(6.67%)
5	16(6.67%)	16(6.67%)
4	10(4.17%)	10(4.17%)
3	12(5%)	12(5%)
2	12(5%)	12(5%)
1	10(4.17%)	10(4.17%)
2*	19(7.92%)	19(7.92%)

3*	13(5.42%)	13(5.42%)
4*	19(7.92%)	19(7.92%)
5*	18(7.5%)	18(7.5%)
6*	9(3.75%)	9(3.75%)
7*	8(3.33%)	8(3.33%)
8*	14(5.83%)	14(5.83%)
9*	9(3.75%)	9(3.75%)
Mean	5.26	5.26

Appendix D: Case Study Interview

Part 1: Basic Information

1. What is your role in this project?
2. When did you get involved in this project?

☐ Project initiation stage (e.g., contract signing, initial design)

☐ Construction preparation stage (e.g., material procurement, labor allocation)

☐ Project implementation stage (e.g., construction progress, quality management)

☐ Project closing stage (e.g., inspection, delivery)

Part 2: Risk Identification

3. What are the major risk events you encountered during the mobile store renovation project? (Select all that apply)

☐ Project delays

☐ Cost overruns

☐ Insufficient or delayed material supply

☐ Technical issues (e.g., design changes or construction quality problems)

☐ Policy or regulatory changes

☐ Shortage of human resources

☐ Changes in client requirements

☐ Other (please specify): _____

4. What do you think are the main causes of these risks, and what consequences did they lead to?

Part 3: Risk Occurrence Stage

5. At which stage of the project are risks most likely to occur? (Select all that apply)

☐ Project initiation stage (e.g., contract signing, initial design)

☐ Construction preparation stage (e.g., material procurement, labor allocation)

☐ Project implementation stage (e.g., construction progress, quality management)

☐ Project closing stage (e.g., inspection, delivery)

6. Could you describe a specific risk event and indicate the stage at which it occurred?
    - Risk event: _____
    - Project stage: _____

Part 4: Stakeholder Communication

7. Which stakeholders were involved in the risk event? (Select all that apply)

☐ Brand owner

☐ Material supplier

☐ Project supervisor

☐ Contractors

☐ Other (please specify): _____

8. How did you communicate with the stakeholders to address this risk?
9. Did the risk cause a ripple effect affecting other project activities, such as delays, cancellations, or rework?

☐ Yes

☐ No

If yes, please describe the specific impact: _____

Part 5: Mitigation Measures and Strategies

10. What measures did you take after the risk occurred? (Select all that apply)

☐ Emergency resource adjustments (e.g., adding manpower or materials)

☐ Modifying construction plans or technical solutions

☐ Re-negotiating with stakeholders

☐ Seeking external support (e.g., loans or policy assistance)

☐ Other (please specify): _____

11. What strategies do you think can help reduce the occurrence of similar risks in the future?

Suggestions: _____

D.1 Chapter 6 NVivo word frequency and clouds

Table D.1: Chapter 6 NVivo word frequency

Word	Length	Count	Weighted Percentage (%)	Similar Words
light	5	824	2.64	bright, brightness, cleaning, clear, fire, illumination, light, lighting, lights, loose, short, soft, trip, tripping, weak
wall	4	368	1.52	wall, walls
side	4	378	1.49	face, facing, side, sides
requirements	12	409	1.48	ask, asked, demand, demanding, involve, involved, mandatory, necessary, need, needed, needs, prerequisite, require, required, requirement, requirements, requires, take, takes, want
design	6	384	1.34	deliberately, design, designated, designed, designers, designing, name, plan, plans, project, show
brand	5	384	1.27	brand, branding, brands, make, post, posting, steel
construction	12	399	1.23	build, building, constructed, constructing, construction, expression, make, manufacturer, manufacturers, structure
floor	5	353	1.23	based, floor, floors, level, levelled, levelling

heating	7	285	1.16	heat, heating, hot, warm
original	8	385	1.12	beginning, begins, found, foundation, grow, grows, line, lines, original, originally, sourced, start, started, starting, starts
air	3	394	1.10	aerated, air, beams, line, lines, public, send, sending, sends, spreading, vent, vents
time	4	271	1.02	clock, meters, metre, metres, time
wire	4	271	1.01	cable, cables, wire, wired, wires, wiring
give	4	391	1.00	applying, big, break, dedicated, establish, give, gives, hand, handed, hold, holding, leave, make, open, opened, opening, pay, paying, pays, reach, returned
people	6	231	0.95	people
back	4	250	0.83	back, cover, covered, second, support
finished	8	264	0.82	closely, coated, coating, end, ended, final, finally, finish, finished, finishing, last, stop
umm	3	197	0.81	umm
make	4	555	0.81	cause, caused, causing, clear, drawing, drawings, establish, fix, fixed, formed, hit, hitting, make, name, preparation, prepare, qualification, reach,

				ready, take, takes, work, working, works
change	6	188	0.73	change, changed, changes, changing, modification, modifications, switch, switched, variety

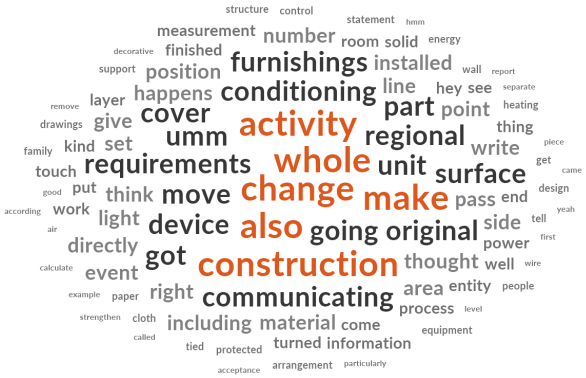


Figure D.1: Chapter 6 NVivo word clouds

D.2 Original budget of the project

Size: 235 sqm

	Project Name	Construction Method
Exterior		
1	Glass Door	8+8mm thick SGP laminated tempered ultra-clear glass
2	Showcase Window	8+8mm thick SGP laminated tempered ultra-clear glass, connected with glass ribs (only within the first-floor construction area)
3	Tempered Glass Bumper	Bumper
Power Room, Storage Room		
1	Gypsum Board Partition Wall	Fireproof gypsum board base, light steel frame, filled with 60KG/m³ rock wool, reinforced with 15mm fireproof board
2	Wall Base	Gap filling with joint plaster, reinforced with tape, wall interface agent reinforcement
3	Wall Plastering	Local leveling with plastering gypsum, two coats of putty, sanded
4	Latex Paint	Two coats of rolling
Lobby		
1	Overall Gypsum Board Ceiling	Light steel frame, filled with 60KG/m³ rock wool, reinforced with 15mm fireproof board, fireproof gypsum board base
2	Soft Film Light Frame	Soft film light frame and labor
3	Soft Film Light Ceiling	Alloy slot, soft film surface including labor
4	Custom Aluminum Panel for Equipment Trough	Custom
5	Curtain Box	Fireproof board frame, fireproof gypsum board base
6	Wall Base	Gap filling with joint plaster, reinforced with tape, wall interface agent reinforcement

	7	Wall Plastering	Local leveling with plastering gypsum, two coats of putty, sanded
	8	Latex Paint	Two coats of rolling
	9	Class A Fireproof Single Door	Class A Fireproof Door
	10	Fire Hydrant Concealed Paint Door	Paint Door
	11	Paint Door	Paint Door
	12	Column Wrapping	Labor and auxiliary materials
	13	Floor Tile Laying	800*800 anti-slip floor tile laying, including main materials, tiles, sand, and auxiliary materials
	14	Tile Grouting	Labor and main materials
	15	Overall Alloy Skirting Board	Alloy skirting board including labor and auxiliary materials
Others			
	1	Access Control	Finished product installation
	2	Ceiling Reverse Support	Labor and auxiliary materials
	3	Downlight/Spotlight	Custom finished product
	4	Socket	Custom finished product
	5	Floor Socket	Custom finished product
	6	600*1200 Explosion-proof Light	Custom finished product
	7	Safety Exit Sign	Custom finished product
	8	Double-headed Emergency Light	Custom finished product
	9	Floor Protection	Custom finished product

	10	Dust Mat	Custom finished product
	11	Electrical Modification	WDZB wire, KGB conduit
	12	Electrical Box	According to drawing standards
	13	Weak Current	Labor cost, auxiliary materials, and wires
	14	Lighting and Hardware Installation	Labor cost
	15	Garbage Removal Fee	Labor cost
	16	Material Handling Fee	Material handling by construction team
	17	Enclosure	Setup and dismantling
Total Project Cost		1650 RMB/sqm	This quotation does not include tax (this project is 235 sqm)

Expense Details

Date	Expense Type	Description	Amount (¥)
		Opening Balance	
2024/4/3	Materials	Payment for electrical materials (see details)	8,980
2024/4/4	Materials	Additional electrical materials (see details)	1,250
2024/4/4	Materials	Payment for materials (see details)	56,000
2024/4/7	Labor	Partial labor payment (transferred via WeChat to Xiao Chai)	10,000
2024/4/8	Other	Courier fee for sending documents to supervisor (Cui Xue)	12
2024/4/8	Equipment	Purchase of distribution box (see details)	4,300
2024/4/8	Materials	Tile transportation fee (2,920) + handling fee (252)	3,172
2024/4/8	Equipment	Purchase of floor socket	211
2024/4/8	Equipment	Purchase of surveillance system (see details)	17,827
2024/4/8	Equipment	Purchase of smart passenger flow system (see details)	4,840
2024/4/9	Materials	Purchase of sand (2 trucks × 380 = 760), cement (80 bags × 20 = 1,600), handling fee (640)	3,000
2024/4/10	Equipment	Purchase of cameras (see details)	10,004
2024/4/10	Equipment	Purchase of 42U 600×800 server cabinet (excl. shipping & installation), incl. 3 trays + 2 PDUs	3,450
2024/4/12	Labor	Payment for electrician labor	5,000
2024/4/12	Materials	Purchase of sand (8 cubic meters × 1,400), cement (70 bags × 1,400), handling fee (620)	3,420
2024/4/12	Equipment	Purchase of clamps (4 sets × 150 = 600), specific parts (4 sets × 750), H8184 (4 × 260 = 1,040)	2,390

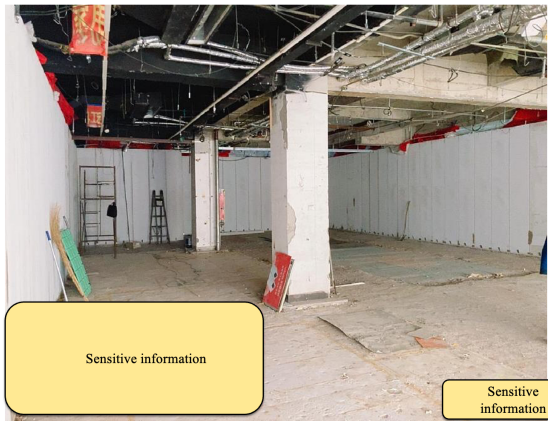
D.3 Actual cost of the project

2024/4/12	Equipment	Purchase of door handles (218 × 4 = 872), deposit paid (400), balance (472)	400
2024/4/13	Equipment	Purchase of top light, left door, right door (see details), 20% advance (34,500 × 20% = 6,900)	6,900
2024/4/13	Materials	Purchase of lumber (see details)	6,000
2024/4/14	Labor	Partial payment for tiling labor	7,500
2024/4/14	Materials	Purchase of clips	110
2024/4/15	Materials	Purchase of lumber (see details: 21,550) + shipping (350)	21,900
2024/4/15	Materials	Purchase of square tubes (4×6, 40 × 135)	5,400
2024/4/15	Labor	Payment for carpentry labor	20,000
2024/4/15	Other	Shipping fee for square tubes	180
2024/4/16	Labor	Payment for floor heating repair	1,000
2024/4/16	Equipment	Purchase of bumper stickers	646
2024/4/17	Equipment	Purchase of gypsum board (38 × 25.5 = 969) + shipping (110)	1,079
2024/4/19	Labor	Final payment for electrician (incl. shipping 260)	5,485
2024/4/19	Equipment	Purchase of aluminum alloy floor mat (0.9×1.8×2)	1,550
2024/4/19	Equipment	Purchase of large cutter (1 × 550)	550
2024/4/20	Materials	Shipping fee for baseboard	110
2024/4/20	Materials	Purchase of nuts + shipping fee	296.01
2024/4/22	Materials	Purchase of square tubes (1,080) + shipping (150)	1,230
2024/4/22	Materials	Purchase of welding rods (see details)	66
2024/4/22	Materials	Final payment for door handles	472

2024/4/23	Materials	Purchase of screws (see details)	32
2024/4/23	Materials	Purchase of anti-static flooring (42 pieces, incl. installation)	3,500
2024/4/25	Materials	Additional tiles (5 pieces)	465
2024/4/25	Materials	Purchase of lumber (see details)	2,490
2024/4/25	Other	Shipping fee for delivery	5
2024/4/25	Equipment	Final payment for glass (incl. shipping 1,500)	29,100
2024/4/25	Labor	Payment for welding labor	9,600
2024/4/27	Materials	Purchase of ultra-thin sheets (3 × 25)	75
2024/4/27	Labor	Payment for labor + materials	10,000
2024/4/27	Materials	Purchase of network cable (345), plastic hose (2 × 15 = 30), shipping (60)	435
2024/4/27	Equipment	Purchase of glass door accessories (see details)	645.82
2024/4/27	Materials	Purchase of fireproof boards (see details)	2,040
2024/4/28	Other	Additional shipping fee for tiles	200
2024/4/28	Materials	Purchase of glue gun (1 × 20 = 20) + glue sticks (20 × 1)	40
2024/4/28	Equipment	Purchase of eco-boards (see details)	699
2024/4/30	Equipment	Purchase of stainless steel + grooving (see details)	1,400
2024/4/30	Equipment	Purchase of 8 inspection ports	640
2024/5/3	Equipment	Purchase of white sleeves, emergency lights (see details)	3,245
2024/5/3	Labor	Partial payment for painting labor	8,000
2024/5/3	Materials	Purchase of gypsum boards + fireproof boards (see details)	3,240

2024/5/3	Materials	Purchase of spray paint (5 × 7 = 35), tape (1 × 4), waterproofing agent (1 × 5)	44
2024/5/4	Other	Courier fee for sending bumper stickers (Cui Xue)	13
2024/5/4	Labor	Payment for grouting labor + materials	3,740
2024/5/9	Labor	Purchase of soft film + installation, bumper stickers labor	8,200
2024/5/9	Labor	Final payment for electrician + vehicle fee + weak current cabinet + installation	8,080
2024/5/9	Other	Fuel fee for Cui Xue's two trips to the site	200
2024/5/9	Labor	Final payment for tiles (3,000), tile repair (300), grouting (100)	3,400
2024/5/11	Labor	Final payment for carpentry labor	10,450
2024/5/12	Labor	Final payment for painting labor	8,000
2024/5/12	Labor	Final payment for labour	4,560
		Total	337268

D.3: Pictures of the case study

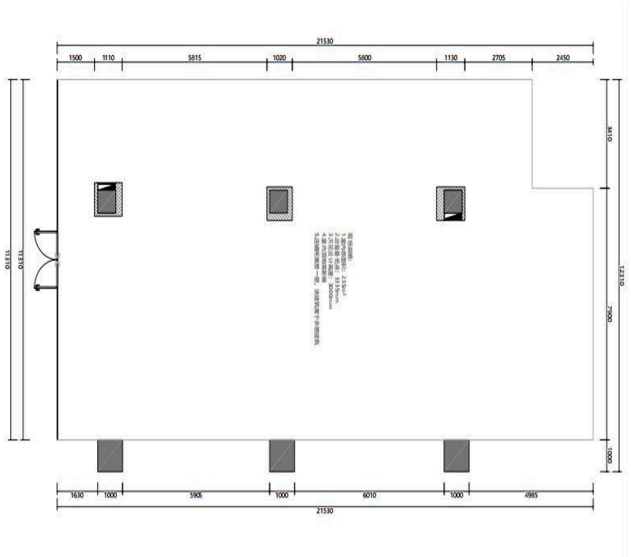
Number	Stage	Early Warning/Event	Picture
1	Design	Exterior wall installation	

2	Design	Air-conditioning system was designed too close to the roof lights.	
3	Design	Glass material selection	

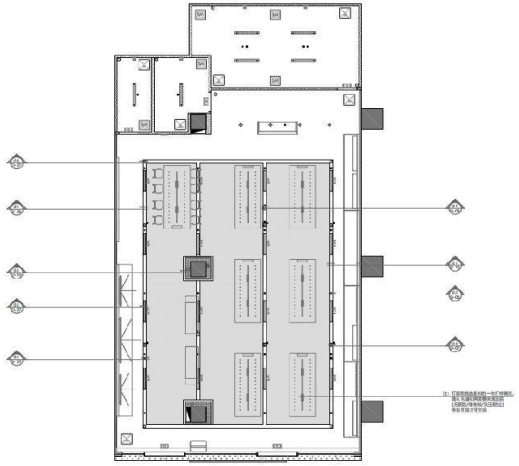
Entrance glass door and interior partitions (excluding drilling)	8+1.52SGP+8
Glass ribs (excluding drilling)	12mm+1.52SGP+12mm+1.52SGP+12mm
	15mm+1.52SGP+15mm+1.52SGP+15mm
Glass curtain wall – standard laminated (excluding drilling)	8mm+1.52SGP+8mm
	10mm+1.52SGP+10mm
	12mm+1.52SGP+12mm
	15mm+1.52SGP+15mm
	8mm+1.52SGP+8mm+16A+8mm+1.52SGP+8mm
	10mm+1.52SGP+10mm+16A+8mm+1.52SGP+8mm
	12mm+1.52SGP+12mm+16A+10mm+1.52SGP+10mm
	8mm+1.52SGP+8mm+16A+8mm+1.52SGP+8mm (LOWE)
	10mm+1.52SGP+10mm+16A+8mm+1.52SGP+8mm (LOWE)
	12mm+1.52SGP+12mm+16A+10mm+1.52SGP+10mm (LOWE)
Curved glass curtain wall – standard laminated (excluding drilling)	8mm+1.52SGP+8mm (Radius≥1500mm)
	10mm+1.52SGP+10mm (Radius≥1800mm)
	12mm+1.52SGP+12mm (Radius≥2000mm)
	15mm+1.52SGP+15mm (Radius≥3000mm)
	8mm+1.52SGP+8mm+16A+8mm+1.52SGP+8mm (Radius≥1500mm)
	10mm+1.52SGP+10mm+16A+8mm+1.52SGP+8mm (Radius≥1800mm)
	12mm+1.52SGP+12mm+16A+10mm+1.52SGP+10mm (Radius≥2000mm)
	8mm+1.52SGP+8mm+16A+8mm+1.52SGP+8mm (LOWE) (Radius≥1500mm)
	10mm+1.52SGP+10mm+16A+8mm+1.52SGP+8mm (LOWE) (Radius≥1800mm)
	12mm+1.52SGP+12mm+16A+10mm+1.52SGP+10mm (LOWE) (半径≥2000mm)

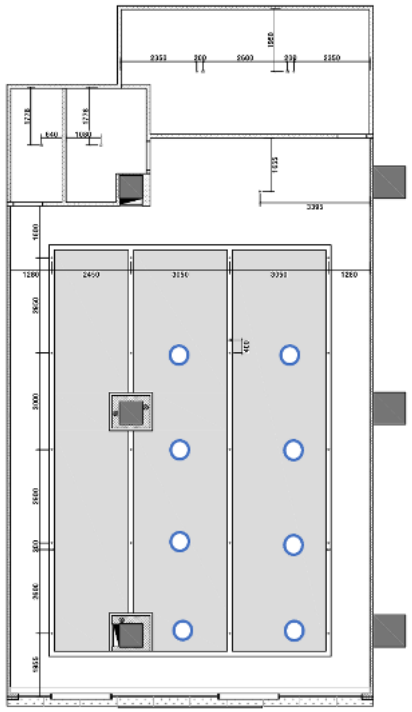
5	Process	Water pipes cut during underfloor heating work	

6	Process	Floor tile reworked; levels do not reach to the standard	

8	Process	Pillar not wide enough to accommodate fire valve and hydronic heating controller	

9	Process	Wall wiring and levelling	

11	Process	Observation holes added to ceiling for wiring observation and maintenance	

12	Closeout	Fire sprinkler system design error	

Appendix E: Further interview for case study

Further **Interview: Investigating Ripple Effects in Renovation Projects (Mobile Phone Store Case)**

Scenario	Ripple
1	Facade installation conflicts over quotation for assigned contractor
	Adopted different material for facade installation
	Disagreement over reinstallation costs
2	Fire sprinkler system design error
	Air-conditioning system too close to roof lights
3	Water pipes cut during underfloor heating work
	Incorrect selection of glass materials

Section I: Background Information

1.What is your role in this project? (e.g., Project manager, construction team member, design team member, etc.

2.At which stage(s) did you participate in the project?

Section II: Scenario 1 – Facade Installation Conflict

3. What do you believe caused the inconsistency in façade material selection?

4.Was there a formal design change communication process? If yes, how did it fail?

5.How was the conflict over the façade installation quotation discovered?

6.Why was the decision made to replace the construction team?

7.Were any new risks or delays introduced during after the replacement?

8.What were the ripple effects on subsequent trades (e.g., electrical, interior works)?

Section III: Scenario 2 – Fire Sprinkler and AC System Design Conflict

9.Was the design issue caused by technical oversight or communication failure?

10.Did the design team fully consider on-site spatial constraints?

11. How did the design conflict affect the installation process?

12.Were there any ripples with other systems (e.g., lighting, structure)?

13.How would you evaluate the efficiency and cost control of this solution?

14.Were these costs covered by the original budget? If not, how do you manage in the follow-up activity.

Section IV: Scenario 3 – Underfloor Heating Leak and Glass Material Error

15.Was the incorrect material choice due to design, procurement, or on-site decision-making?

16.Did the material mistake affect logistics or storage plans?

17.Did this event lead to any policy or procedure updates?

18.Was there ripple when the repair work causes other tasks paused? If not, how you manage it?

19.Did the switch to cost-efficient materials impact final quality or client satisfaction?

Section V: Cross-Case Reflection Questions

20. Which type of risk do you think is most underestimated but causes significant ripple effects?

21. How would you evaluate your team’s overall response capacity to ripple effects?

22. During the project, did you experience any ripple effects that were not anticipated at the time?

23. Please describe the unforeseen ripple effect other than three above: What triggered it? What were the resulting consequences? Why was it not anticipated?

24. What kind of impact did it have? (Timeline, Quality, or Fund)