



Exploring how lean tools
can improve risk management
in the construction industry

Master Thesis

Diana Akkerman
5707390

Graduation committee:

Chairperson Dr. ir. Marian Bosch-Rekvelde
Associate Professor of Project Management
Faculty of Civil Engineering and Geosciences
TU Delft

First Supervisor Dr. ir. Ranjith Kuttanarappel Soman
Assistant Professor of Digital Construction
Faculty of Civil Engineering and Geosciences
TU Delft

Second Supervisor Dr. Daniel Hall
Assistant Professor
Faculty of Architecture and the Built
Environment
TU Delft

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Diana Akkerman

Student number: 5707390

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Graduation committee

Chairperson	Dr. ir. Marian Bosch-Rekvelde Associate Professor of Project Management Faculty of Civil Engineering and Geosciences (CiTG) TU Delft
First Supervisor	Dr. Ir. Ranjith Kuttantherappel Soman Assistant professor in Digital Construction Faculty of Civil Engineering and Geosciences (CiTG) TU Delft
Second Supervisor	Dr. Daniel Hall Assistant Professor Faculty of Architecture and the Built Environment (BK) TU Delft

Colophon

Title

Exploring how lean tools can improve risk management in the construction industry

Date

24 September, 2024

Author

Name Diana Akkerman
Student Number 5707390

Graduation Thesis

University Delft University of Technology
Faculty Faculty of Civil Engineering and Geosciences (CiTG)
Stevinweg, 1
2628 CN, Delft
Master Program MSc. Construction Management and Engineering (CME)

Graduation committee

Chairperson Dr. ir. Marian Bosch-Rekvelde
Associate Professor of Project Management
Faculty of Civil Engineering and Geosciences (CiTG)
TU Delft
First Supervisor Dr. Ir. Ranjith Kuttanharappel Soman
Assistant professor in Digital Construction
Faculty of Civil Engineering and Geosciences (CiTG)
TU Delft
Second Supervisor Dr. Daniel Hall
Assistant Professor
Faculty of Architecture and the Built Environment (BK)
TU Delft

Abstract

The construction industry, known for its multifaceted operations and inherent complexities, has long sought ways to enhance efficiency, reduce waste and ensure timely project delivery. Risk management (RM) is crucial in preventing unexpected events and keeping projects on track, but current RM practices often fall short, leading to disruptions, inefficient resource use, safety issues, financial setbacks, and time overruns. These issues undermine the purpose of RM and jeopardize projects. Meanwhile, lean construction, grounded in lean thinking, offers a promising solution by identifying and minimizing constraints and inefficiencies. The goals of lean management, like waste reduction and value optimization, align well with RM, which focuses on identifying and mitigating threats to project success. Although there has been extensive research on lean management and RM as separate entities in construction and evidence of their integration in other sectors, there is a significant gap in the literature regarding their intersection in construction. This presents a research opportunity to explore how integrating lean management with RM strategies can improve project outcomes.

This research explores how lean tools can improve RM in the construction industry to enhance the ability of construction organizations to anticipate, mitigate, and respond to risks. It does so by analyzing the RM process to identify gaps and deficiencies in existing knowledge and practices. It then examines the nature and potential of lean tools to address these deficiencies.

The aim of this research is to understand the common issues in construction RM and highlight the potential for integrating lean tools into the RM process to achieve more resilient and efficient operations in the construction sector.

The result of the research is a conceptual lean RM framework, developed based on issues identified in the literature and supported by practical evidence, along with an analysis of lean construction tools and their potential to address chosen RM challenges. The framework spans the tender, planning, development, and construction phases. In addition to the framework, the approach to its application is outlined, including potential short-term and long-term benefits, inherent limitations, and potential integration challenges. The framework's potential application environment is conceptually explored, and recommendations are offered for construction companies, standard developers, prospective users of the framework and future research efforts.

Preface

I am pleased to present this report as the culmination of my master's studies. I embarked on this journey to address gaps in my management knowledge that I noticed while advancing in my career. Deciding to leave a stable job, move to another country, and return to academia was challenging, both daunting and exhilarating. Although I only partially achieved my goal of filling these knowledge gaps, I found that many of the issues I faced still need solutions, along with many new gaps I became aware of. This experience was truly eye-opening and psychologically demanding. Yet, I persevered and have grown from it.

I am deeply grateful to my graduation committee. Marian, Ranjith and Daniel, your guidance, support and the friendly atmosphere you fostered made this journey both rewarding and memorable. While our meetings were focused, we had some light, positive moments that helped ease the process and made them stand out. Your thoughtful questions pushed me to think more deeply (not just about the research, but also about myself) and that was truly inspiring. Even when I doubted my results, you always found a way to help me stay motivated and believe in the importance and value of my work. You are the best team I could have ever hoped for.

I want to thank my family and friends who were always there for me. Your presence brought joy and laughter into my life and played a key role in helping me navigate this journey smoothly. You provided encouragement when I needed it most. You have been my rock, my support system and my biggest fans, and I could not have reached this point without you.

This graduation project was certainly a challenge. Going through it felt like navigating uncharted waters. I dedicated twelve (or thirteen) straight months to this project, and it proved to be far more demanding than my previous master's project in Structural Engineering. While I anticipated technical and system-related challenges, I discovered that understanding and dealing with people is the most complex task. I thought I was quite adept at this, but it became clear that there is still much room for improvement. Although I cannot control the behavior and actions of others, I can influence my actions and define my ways of dealing with them. I am also aware that I can be difficult to deal with at times, but I am committed to learning and growing from this experience. This project has taught me lessons in patience, commitment and accountability, which will be invaluable as I continue to grow both personally and professionally.

As I look to the future, I feel both scared and excited about where I will end up. Through this journey, I have gained a deeper understanding of myself, my values, my desires, and my expectations. My perception of the construction industry has evolved, and I am ready to move forward into areas that align better with my interests and strengths. This experience has equipped me with the confidence and insight to pursue a path that truly resonates with me, and I am eager to embrace the opportunities that lie ahead.

Diana Akkerman
Delft, September 2024

Focusing on knowledge preservation and customization of internal guidelines are the opportunities which might be beneficial to explore.

Similarly, standard developers might explore ways to make their standards more adaptable and tailored to various contexts of organizations. Furthermore, given the difficulties in practical risk assessment, it could be beneficial to reevaluate qualitative risk assessment scales and clarify the conversion of qualitative assessments into monetary values to increase trust and reliability of RM outcomes.

The main users of the proposed framework, the operational level employees, may focus on options which might help them in getting the understanding of project context to support accurate judgments and informed decision-making.

As for further research, there is an opportunity to evaluate the proposed framework in real-world settings. Furthermore, the research might be continued to improve the understanding of project complexity in RM, manage stakeholder interconnectedness and its impact on project risks, improve RM during the Front-End Planning (FEP) and manage the information generated during project execution. The pull of lean construction tools potentially helpful in the defined RM deficiencies consists of 14 tools, while in-depth were studied only 5, meaning that there is an opportunity to dive deeper into lean construction tools left behind the scope of this research as well as to address the RM deficiencies identified but fell outside of the scope.

There is an opportunity to address the limitations of the proposed framework. For example, given the technical focus, it could be beneficial to explore how the human, organizational, environmental, political, financial, and legal elements of RM can be better recognized and integrated into lean RM. Furthermore, it can be beneficial to study different construction project types and sizes and contract types to understand the benefits and limitations of lean integration in RM.

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Abbreviations

CPA – Construction Process Analysis

FEP – Front-End Planning

LPS – Last Planner System

PM – Process Map

PJ – Professional Judgement

RM – Risk Management

WS – Work Structure

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1. Introduction

The construction industry, with its multifaceted operations and inherent complexities, has long been in search of methodologies that can enhance efficiency, reduce waste, and ensure timely project delivery. On that behalf, risk management (RM) has been recognized as a critical component in ensuring that construction projects are executed without unforeseen disruptions and within the project constraints. By starting the RM process at the very beginning, the productivity and overall performance of the construction project gain significant improvement (Alshibly, 2013; Alsaadi & Norhayatizakuan, 2021). Therefore, with growing sizes and complexities of construction projects, managing risks throughout the whole construction process has become a central element preventing unwanted consequences and ensuring project success.

Despite its significance, current tactics are not devoid of deficiencies. One notable shortcoming in many construction companies is reactive strategies, where risks are tackled only after they manifest (Banaitiene & Banaitis, 2012). Additionally, there is a concern for comprehensive evaluations given that uncommon risk events, which could severely undermine both the project's success and the company's standing, might be overlooked. Some risk components are not quantifiable and thus elude technological tools and may go unnoticed without human supervision. The static nature of some risk assessment approaches can also lead to the overlooking of evolving threats (Banaitiene & Banaitis, 2012). These and other deficiencies in RM can trigger operational disruptions, inefficient resource distribution, compromised safety, financial setbacks, missed chances, time overruns, and failed strategic and operational endeavors. These negative consequences in turn jeopardize the project itself and sabotage the purpose of using RM.

On the other hand, lean construction practices, rooted in the principles of lean thinking, have emerged as a promising approach to address project challenges. These practices focus on optimization of operations by identifying constraints and inefficiencies that endanger project performance, then minimizing their influence. Their orientation on streamlining processes, eliminating non-value-added activities, and optimizing resource utilization has demonstrated its effectiveness in enhancing safety on construction sites (Nahmens & Ikuma, 2009), improving production quality control (Ballard & Howell, 1997), and curtailing project costs and durations (Ballard, 1997; Issa, 2013). Lean tools have been shown to foster a proactive, adaptable mindset (Ballard, 2020), while also promoting collaboration and continual learning within construction projects (Ballard & Tommelein, 2012).

It seems that the objectives of lean management, such as waste reduction and value optimization, align with the goals of RM, which seeks to identify, assess, and mitigate potential threats to project success. For instance, within the supply chain domain, both lean management and RM work on the objective of ensuring supply chain reliability and efficiency. Konecka's study (2010) shows that multiple lean tools perform risk reduction functions, influencing the probability of flow disruption, losses caused by non-value-adding operations and quality problems. The potential of lean integration in RM and the evidence of their various adaptations are seen across other sectors. However, despite extensive research on lean management and RM as separate entities within the construction domain, there is a gap in literature specifically addressing the intersection of these two disciplines in construction. This suggests a research opportunity to explore the potential of effective combination of lean management principles and RM strategies in construction projects.

1.1. Research background

Within construction projects, RM stands as a cornerstone, ensuring project success and efficiency. To understand whether there is a potential to improve RM with lean principles, this synergy and why it is not yet developed in the construction industry should be explored based on the existing body of knowledge.

1.1.1. The Choice of Lean Management

Construction RM usually operates within a traditional predictive approach, where projects are developed through a linear sequential process covering planning, design, development, and testing. In this approach, all the requirements are determined upfront and remain unchanging. Each step in the sequence is executed once, with formal reviews and approvals required to proceed from one step to the next, accompanied by extensive documentation (Process Groups: A Practice Guide, 2022; Marnewick & Marnewick, 2023).

Given this context, the importance of RM in construction becomes evident. The sequential nature of construction projects means that each phase depends on the successful completion of the previous one. Any disruptions or risks in an early stage can cascade through subsequent phases, potentially causing delays and cost overruns. Due to the long-term nature of construction projects and the need for a high level of predictability and control, RM is important for managing uncertainty and maintaining the integrity of the project's linear progression. Even with the recent developments of hybrid methodologies for construction projects, the nature of construction projects remains closely tied with traditional methodologies.

On the other side, lean management, originally developed in the manufacturing context, has been widely adopted in various industries, including construction (Shah & Ward, 2003). The lean model is characterized by 'doing more with less' (Womack et al., 1990), requiring fewer inputs to create the same results as traditional systems while offering a wider range of values (Cruz et al., 2020). The scope in the lean model remains flexible, allowing for continuous learning and adjustment based on feedback. Although lean can follow a sequential process, but within the entire project planning, it employs multiple tools, like Last Planner System (LPS), to break down the general planning into manageable shorter durations, focusing on intermediate next steps (Ballard, 2000).

In the context of RM, lean does not explicitly outline traditional RM practices. Instead, it integrates RM within its practices through the concept of constraints and sometimes waste. Constraints in lean encompass factors that could endanger project performance, such as bottlenecks, inefficiencies, and resource shortages. Identifying and addressing these constraints are key steps to improving effectiveness and optimizing processes (Ballard, 1997; Ballard & Howell, 1997b).

Furthermore, according to Etges et al., (2012), a wide range of lean tools have been adapted for different processes in construction, demonstrating a strong fit for the construction project environment. Despite the radically different approach to project control, LPS has been successfully implemented in large, complex projects across various countries, positively impacting project performance in terms of cost and time (Formoso & Moura, 2009). Experience shows that lean tools can be effectively tailored to fit into the operational details of an existing control methodology (Koskenvesa & Koskela, 2005). These findings suggest that lean tools are potentially a viable choice for improving RM in construction, given their evident adaptability.

As another alternative, the iterative agile approach is characterized by constant changes in requirements, with small manageable iterations covering planning, design, development, testing and review. Each iteration produces a minimum viable product, allowing for adaptive planning based on feedback and new insights (Agile Alliance, 2017). In agile, RM is not widely adopted (Almeida, 2017). Instead, each iteration provides an opportunity to assess risks and adapt plans dynamically, limiting the need for extensive traditional RM.

Within the linear context of construction projects, agile loses its benefits. The iterative development does not align well with the sequential and fixed nature of construction projects: RM, as

a separate activity, may be done in iterations, improving risk register as new information emerges, but, as a part of the whole system, the construction environment with defined requirements and set prices limits this flexibility. Given the outcome of each iteration, partial completion in construction RM could not be functional and may lead to incorrect tender price calculations or an inability to handle assumed risks. Moreover, the agile's flexibility in changing requirements mid-project can introduce significant risks to the PM process and, consequently, to the construction project itself.

1.1.2. Lean RM in other sectors

Numerous studies across other sectors show that RM practices were successfully upgraded with lean principles and tools, resulting in enhanced RM performance. For instance, Essaber et al (2021) introduced a modified RM approach using Theory of Inventive Problem Solving (TRIZ) to address lean-related risks within the food industry's supply chain. This approach, grounded in a new risk classification tied to lean objectives, led to a more flexible and accurate risk evaluation. It also clarified decision-making problems and guided problem-solving, resulting in both time and cost savings. Similarly, Willumsen et al (2017) redefined RM by incorporating lean thinking principles within the realm of product development. Existing lean solutions were adapted to address the effectiveness and efficiency challenges inherent in RM, leading to better outcomes and streamlined operations. Crema & Verbano's (2015) study investigates Italian projects that combined lean management principles with clinical RM, aiming to improve efficiency, patient safety, and overall healthcare quality. Their findings indicate a growing trend in Italian healthcare sector to lean management and clinical RM methodologies to achieve better patient results and more efficient healthcare processes. In the chemical industry, Aqlan & Ali (2014) proposed a new framework that combines lean principles with fuzzy bow-tie analysis. Their study highlighted the potential benefits of this combined approach in improving safety measures, optimizing processes, and ensuring a more robust RM strategy. A review of these studies across diverse sectors suggests that the combination of lean methodologies and RM is not only viable but also highly beneficial. Furthermore, this synergy offers the capability to identify and address risks that might be overlooked using conventional methods. The positive cross-sector experience and expertise could be one of the compelling reasons to further investigate its potential for the construction sector.

1.1.3. Barriers to using lean in RM in construction industry

One of the barriers may lie behind the lean approach itself. Despite its proven benefits in various industries, lean is not as widespread in the construction sector as might be expected (Johansen & Walter, 2007; Sarhan & Fox, 2013b; Samari et al, 2013). Several studies have identified a range of barriers hindering the integration of lean principles within construction practices. For instance, Sarhan & Fox (2013a; 2013b) identified challenges like limited awareness and understanding of lean, insufficient knowledge and skills, a lack of commitment from top and middle management, technological constraints, poor implementation strategy and inefficient stakeholder relationship management. Along with barriers, potential solutions to address and overcome these challenges have also been explored. For example, integrated teams, which are recognized as a standard model of collaboration in the Netherlands (Chao-Duivis, 2012) and are becoming increasingly popular in the construction industry (Franz et al, 2017). These teams have been effective in managing stakeholder issues (Thomas & Thomas, 2005) and enhancing understanding of lean principles and design-construction dichotomy (Sarhan & Fox, 2013a). Another example is the development of a long-term company philosophy (Chauhan & Singh, 2012) and use of practices that encourage active employee participation (Losonci et al, 2011). Both solutions contribute to a trustful environment, which, in turn, helps to address change-related concerns and boosts employee motivation and commitment (Crute et al, 2003). Despite this, lean methodologies are still not widely adopted within the sector.

Another barrier may be rooted to the prevailing assumption that the existing RM practices are sufficiently robust. However, evidence from studies suggests that the current practices are, in fact, inadequate. This inadequacy is attributed to a deficiency in RM experience and knowledge among industry practitioners (Banaitiene & Banaitis, 2012; Bahamid et al, 2022). Traditional sources like historical data analysis, project documentation review, and expert consultancy have become less influential in risk decisions. Instead, there is a growing reliance on intuition and personal experience, which often leads to disorganized and chaotic RM (Banaitiene & Banaitis, 2012; Bahamid et al, 2022). Moreover, there is skepticism about the suitability of risk methodologies for construction projects (Bahamid et al, 2022) and reluctance to invest in RM (Keçi & Mustafaraj, 2013), causing it to be relegated to background positions. Regardless of the existing confidence in current RM practices in construction, the evidence mentioned suggests otherwise. That means that industry needs to address these challenges and inconsistencies to achieve better efficiency and results.

1.1.4. Potential of lean in construction RM

To understand the possibility to establish connections between lean and RM in construction, the application of lean principles and their outcomes in this field should be examined. The first point of contact can be a key aspect of lean philosophy – the concept of "waste", which is defined as any activity that takes time without adding value (Liker, 2003). When decomposing and analyzing production processes, eight types of process waste are identified (Liker, 2004), with six being mostly recognized in construction settings (Arleroth & Kristensson, 2011). A common example of such waste is the delay in material delivery, which from a lean standpoint is seen as a constraint to productivity, leading to material shortages, project delays, and increased costs. This issue is compounded by uncertainties caused by weather conditions, slow decision-making, raw material shortages, logistics challenges, and inadequate planning (Rahman et al, 2017), categorizing it as a potential risk from RM perspective. Moreover, process waste like damages, losses, and defects, such as materials and equipment being damaged or stolen due to poor protection (Arleroth & Kristensson, 2011), are also identified as high-impact risk events (Husin et al., 2019). Such incidents exemplify the dual nature of waste and risk, showing the synergistic potential of lean and RM in identifying risks. The more meticulously a process is broken down, the greater the likelihood of uncovering waste, which in turn could reveal more events resembling risks.

Another point is related to the methodologies underlying both management areas. In construction, lean waste and risk events are evaluated in terms of time and cost, as these are key performance metrics (Lai & Lam, 2010). Scientific literature lacks clear explanations on the application of lean tools for waste measurement, although several case studies indicated their usage by practitioners. One notable example is Value Stream Mapping (VSM), which is recognized in lean construction as an effective quantifying tool (Arleroth & Kristensson, 2011). VSM graphically represents material and information flows, featuring quantitative data like time, cost, or material usage per unit produced, in the current and ideal production states (Lasa, Laburu & De Castro Vila, 2008). These diagrams are then analyzed using root cause analysis tools, such as the Ishikawa diagram, a technique prevalent in various management approaches, including RM (Ilie & Ciocoiu, 2010). Despite its qualitative nature, the Ishikawa diagram can be adapted to include quantitative aspects or be aligned with the Fault Tree Analysis (Batziar, 2012), another risk assessment method. The overlap in methodologies between lean management and RM highlights a significant potential for combination. By employing similar tools, both disciplines can benefit from a shared framework of analysis.

A further aspect demonstrating the potential of lean for RM is its use in other management areas like stakeholder management. Modern construction projects typically depend on a variety of parties, known to introduce significant uncertainties (Ward & Chapman, 2008). RM addresses these

uncertainties by concentrating on project processes and strategic planning to ensure efficiency and effectiveness (Chapman & Ward, 2003). Meanwhile, Lean Six Sigma (LSS), which merges six sigma and lean and aims to enhance operational performance through collaborative teamwork, is recognized as a vital element in managing stakeholders across various sectors (Sunder, 2016). Within this philosophy, the inform-involve-influence (3I) model was developed to support LSS in stakeholder management (Sunder, 2016). This approach demonstrates how involving stakeholders at various project stages aids in identifying and eliminating risks related to stakeholders. Additionally, lean tools like VSM and Building Information Modeling (BIM) technology have been highlighted as means for knowledge gathering, integration, and application (Bo et al, 2020), promoting stakeholder communication and cooperation. This, in turn, helps reduce risks and conflicts in construction projects, which often lead to delays and increased costs (Ebekozi et al, 2023). The interconnection of different project management areas highlights how lean and RM complement each other. Lean's collaborative side can enhance RM strategies, facilitating the identification, reduction, and prevention of risks related to project uncertainties and stakeholder dynamics. Their integration can be beneficial in navigating complex project environments more effectively.

1.2. Research Dimensions

1.2.1. Problem statement

Current practice shows that RM within the construction industry aims to enhance product value by dealing with reasons that potentially could decrease it (Bollinger, 2010). Even though it is a widely accepted and used approach, RM may not always be agile or efficient, leading to oversights, delays, or increased costs. Since there is no alternative methodology to handle threads, it is important to address the limitations of the present approach.

On the other hand, lean management pursues value creation through process optimization by dealing with non-value creating activities and other organizational wastes. In various settings, except construction, lean practices were successfully integrated with RM strategies to achieve better outcomes. Therefore, the integration of lean tools into RM within the construction domain is an emergent area of interest and a significant research gap.

The research gap centers around how the proactive, waste-reducing nature of lean management can enhance the ability of construction organizations to anticipate, mitigate, and respond to risks. Covering this gap could potentially redefine industry practices by showing how the integration of lean tools into RM can lead to more resilient, efficient, and cost-effective operations in the construction sector.

1.2.2. Research questions and research objective

From the research objective, the research question arises:

"How can lean construction tools improve risk management in construction projects?"

To answer the research question, the following sub questions should be addressed:

1. SQ1: Which risk management strategies are used in construction? What are their theoretical deficiencies?

First, the RM process, its purposes, advantages and shortcomings should be identified. This question will help to understand the various RM approaches and provides a baseline for evaluation of

its effectiveness; identify strength and weaknesses of the RM process, allocating the areas asking for solutions for a more robust and resilient RM framework.

2. SQ2: How is risk management done in practice? What works well and what requires improvements in current risk management practice?

While SQ1 addresses the theoretical aspects, SQ2 delves into practical applications of RM, bridging the gap between theory and practice. This question will help to understand the RM approaches used in the construction industry, identify what works well in current RM practices and what areas require improvement. Furthermore, the attitude of stakeholders and practitioners to current practice should be studied to incorporate their expectations, preferences and complaints into a new framework.

3. SQ3: What are the lean tools used in construction?

After the risk side of this research is studied, the side of potential solutions should be grounded in theory. Understanding the lean tools used in construction, their features and details will help to identify specific lean tools that may assist in enhancing the efficiency of overall RM and cover identified gaps and shortcomings.

4. SQ4: How can lean construction tools address the deficiencies in risk management?

After the information from the literature and practice is gathered, the RM baseline is established, the identified gaps and inefficiencies in the existing RM process are matched with lean tools as potential solutions, the new lean RM approach can be developed and described. These questions help to understand the framework's feasibility, potential benefits and barriers, implementation steps and expected impact on the RM effectiveness.

The research objective is to develop a framework for RM leveraging lean tools based on existing RM strategies to foster a proactive rather than reactive approach to RM, streamline processes, minimize unnecessary steps, stimulate continuous learning and improvement and achieve higher standards in construction practices.

1.2.3. *Research scope*

This study is limited to one construction company in the Netherlands, preferably acting as the main contractor, one of which specializations is RM for construction projects. The scope encompasses multiple interviews with risk managers of various levels within the company. These limitations provide a controlled environment to study the processes and allow for in-depth examination of the company's current RM strategies and the specific challenges it faces. Moreover, it facilitates the research of organizational factors that may influence the adoption of lean RM, such as company culture, employee skills, and project management practices. Furthermore, this research will focus on RM deficiencies and their resolution at the operational level, leaving root causes and solutions at the strategic level outside.

1.2.4. *The company selection and background research*

1.2.4.1. *Selection process*

The goal of company selection and background research is to identify the most suitable option that aligns with the objectives of this research. The selection process is based on specific criteria to ensure the chosen company meets the necessary requirements. The selection criteria are:

1. A company which has experience in the construction market with priority given to experience of doing RM systematically for its projects, should be selected.

2. A company which delivers a variety of services should be selected. Priority is given to a company performing as a main contractor on the market.
3. A company which can share information should be selected.

According to the first criteria, the company is likely to have well-established RM processes, therefore is likely to be able to provide deep and valuable insights based on their long-term experience. Selecting a main contractor is preferable because such companies are typically responsible for the overall coordination of construction projects. As a result, they should be directly involved in RM across various stages of a project, contributing to a broader perception and experience in RM. Regarding the third criteria, the information about RM is often closely tied to a company's strategy, finances and other sensitive areas, often considered confidential and restricted for external access. Therefore, the company should be cooperative and open enough to share meaningful data collection while respecting its policies.

After the companies satisfying all three criteria are selected, the process is continued with background research. The goal of this step is to gather information and understand the nature of selected companies, the environment in which they operate, the role of research subjects within the companies and their functionality. The information is sourced from open 'grey' sources e.g. companies' website, news articles, and from the companies' representatives in "off the record" communication. For data safety reasons, the names and specific terms used by the representatives would be anonymized, along with details that could identify the companies.

Once the background information has been gathered, the final selection of the company is made based on additional criteria designed to optimize the research process. These criteria are as follows:

1. A company which has more operational-level employees, managers and other relevant stakeholders available for interviews should be selected.
2. A company which has already gathered data or conducted internal studies related to the topic of this research should be selected.
3. A company which has already attempted to deal with the problem in this research should be selected.

These criteria are introduced to streamline the research process by avoiding the unnecessary duplication of already existing knowledge, so the study can concentrate on advancing the solution. Additionally, having more personnel available to participate in the research increases the likelihood of achieving data saturation and ensures that all relevant aspects of the topic are covered.

1.2.4.2. The selected company description

Out of the fifteen companies contacted, varying in size, project complexity and market experience, most did not meet the first selection criterion: having experience in doing RM systematically for their projects. This left only two companies with well-established RM processes. Both companies serve as main contractors in the Dutch market and offer a wide range of services. However, only one of the two agreed to participate and share information for the research. This eliminated the need to apply additional selection criteria intended to streamline the research process.

The selected company is a main contractor with a history on the market that designs, builds and maintains a variety of construction projects around the world. The company succeeded in delivering residential buildings, commercial development and infrastructure projects of different sizes. Since the company operates on the Dutch market and does public construction projects, the

procurement process is governed by the Public Procurement Act 2012 (Aanbestedingswet 2012), which incorporates elements that inherently require RM considerations.

A few years ago, the company introduced an internal guideline for RM to assist employees during the tender, contract awarding and execution phases. According to the company's information, this guideline was developed based on RM practices from the gas and oil industry, as well as the ISO 31000 Standard (ISO, 2018). Like many companies, risks are evaluated and quantified in monetary terms. The guideline primarily focuses on financial, technological and ecological risks. As part of the established RM process, the risk division identifies and analyzes potential issues for top management before a contract is awarded, enabling a go/no-go decision. Once the contract is secured, the risk shifts to an advisory role, as the responsibility for RM is transferred to the assigned project manager. While the project manager is not guaranteed a full-time risk manager on their team, they can seek assistance from the RM division as needed.

This setup presents an interesting research opportunity, highlighting the company's extensive experience and established standards that suggest a high level of expertise and accumulated knowledge. However, the large scale and long history may lead to management challenges and inefficient processes. Additionally, the advisory role of the RM department raises questions about the effectiveness of knowledge transfer and support, e.g., when responsibilities shift from the risk division to the project manager.

1.3. Research design

Figure 2 represents the overview of the research process and research outline. It shows how the selected methodology and the results of each research sub-question will be used to build up to answer the main research question and achieve the research objective.

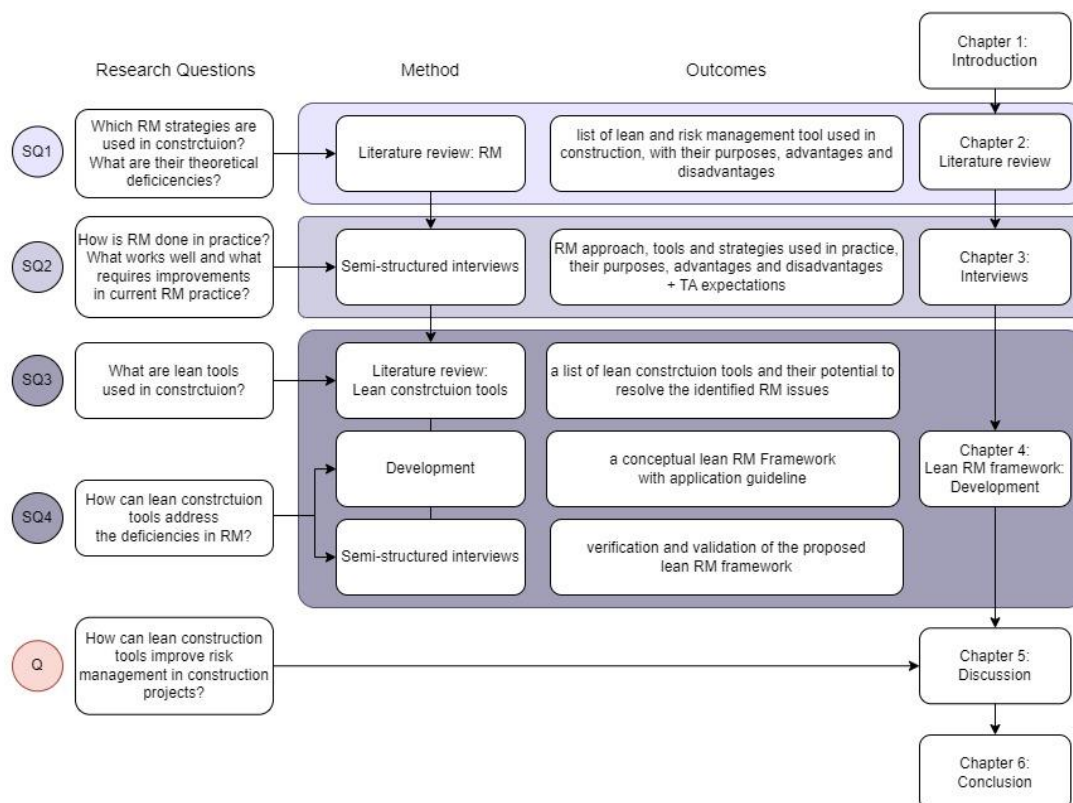


Figure 2 - Research Design

The chosen methodology includes literature reviews, semi-structured interviews for data gathering, development of the framework and semi-structured interviews for verification and validation. This approach allows for a problem-oriented study utilizing the solid foundation of existing knowledge on the topic, validating the theoretical findings and expanding on them by providing contemporary and context-specific insights. As semi-structured interviews require a prior understanding of the research area (Wengraf, 2001) to formulate interview questions, a literature review is conducted to assess prior research (Krauss et al., 2009). Consequently, this prior knowledge forms the conceptual basis for the interviews (Åstedt-Kurki & Heikkinen, 1994).

Before the main research starts, the preliminary research in the form of literature review is done. The main purpose is to define the research background by describing previous research in the area of interest, evaluating the state of knowledge on the topic, identifying and motivating the research gap. Based on the preliminary study, the surface-level information is obtained and substantiates the following stages.

The following main chapters in this research present the results of methodology used.

1.3.1. Literature Review

The goal of the literature review is to investigate the collective evidence in the research focus area and gather the basic information to map the framework building process. Since this stage is dedicated to answering the SQ1 and SQ3, a suitable technique will be a structured literature review, which is used when the question targets well-defined concepts and specific areas (Snyder, 2019). The methodology allows for coverage of a wide range of literature sources within the focus area, which makes it possible to minimize biases and conduct objective comparison (Snyder, 2019).

The literature research will be done with research engines like Google Scholars, Scopus, ScienceDirect, ResearchGate and TU Delft online library. The relevance of the literature to the research will be based on the key words used like “lean tools in construction” and “risk management strategies”. The range of issue years is not limited since some principles, models and findings can still be in use, but priority will be given to more recent sources. The takeaways from the selected papers will be recorded. The information will be examined to define patterns, advantages and shortcomings, limitations. Unnecessary data will be removed. Unclear points will be studied more or removed from the database of this research. Selected findings will be sorted based on the weight of each finding derived from the number of times the point was mentioned in the literature, the range of noticed applications, the magnitude of the influence the finding has.

The literature review will be concluded when the information saturation is reached (the information is felt as being enough to move further). However, the literature review can be repetitive during the research process, if a novel and relevant information gap is found.

1.3.2. Multiple Semi-Structured Interviews

The semi-structured interviews aim to collect practical knowledge regarding the environment of the identified problem, which contributes to the formulation of the framework’s requirements and its acceptance criteria. Interviews widely used within different domains because it poses flexibility enabling follow-up questions to be improvised based on participant’s responses and giving space to provide a meaningful answer in a comfortable manner for the participant (Kallio, 2016).

The primary objective of data gathering interviews is to confirm the relevance of the identified theoretical deficiencies and pinpoint the exact aspects through which these shortcomings can be effectively addressed. Additionally, the process seeks to uncover any new gaps and inefficiencies that may exist within the realm of practical RM. This approach ensures that the theoretical insights gained are not only grounded in real-world experiences but also contribute to refining and enhancing practical RM strategies.

In the first stage, to address the objective of SQ2, the plan is to gather interview participants from a single company. This approach minimizes the impact of variables such as organizational culture and policies, thereby avoiding the confounding effects that may arise from differing organizational contexts. However, since the focus is limited to a single construction company, the number of participants will depend on the company's available resources, while ensuring that the requirement for data saturation is met. The participants should satisfy the following criteria:

1. Participants should have expertise in RM, to ensure they can provide informed perspective.
2. Participants should have distinct roles related to RM, to capture a range of opinions and experiences.
3. Participants should have experience with various RM methodologies, to compare their effectiveness.
4. Participants should be directly involved or affected by the RM process and the potential change in it.

While the focus of this research is on the operational RM, the target audience for the interviews may extend beyond just operational-level managers. By including both operational and strategic-level managers, the research might be able to capture a broader view of how RM is applied within the company and how strategic decisions shape operational practices.

The main set of questions is defined based on the gaps identified with the analysis of data gathered during the literature review. Before the start, the Human Research Ethics Committee (HREC) approval is required to ensure that the research is conducted responsibly, ethically, and in a manner that respects and protects the individuals involved. All interviews will be recorded and transcribed with the available software like MS Teams, organized and coded with tools like ATLAS.ti. Since this step is required to provide practical knowledge and evaluate the existing processes, a combination of inductive and deductive coding will be used. Initially, codes will be identified based on research objectives, literature review and the interviews themselves. These identified codes will then be applied to identify and analyze the excerpts.

The interviews will be concluded when the responses start to become repetitive, indicating that no new information is being provided and the data saturation is reached, and when the information sufficiently covers the research objectives of SQ2 and stated the framework's requirements and acceptance criteria.

1.3.3. Framework Development

The development starts with the framework's requirements to allocate what exactly should be addressed with the framework and how it can be addressed. This is done based on the research objectives and the information gathered during the literature review and interviews. Then, based on the requirements and inputs, the framework is worked out in detail. The key point of the development

step is ensuring compatibility and ease of adoption within existing systems and processes within an organization. For this purpose, the creation of specific supportive tools can be required. They may include templates, software tools, checklists or guidelines.

1.3.4. Verification & Validation

Then the developed framework will go through verification and validation. Verification states for the compliance of the developer framework to its specifications that were established in advance (Lucko & Rojas, 2010). Validation goes beyond the set requirements and is used to support the generalizability of results and ensure the credibility, accuracy, and applicability of findings (Leedy & Ormrod, 2001). Verification and validation will be done with the expert review, using an evaluation form and semi-structured interviews.

The expert team must possess in-depth knowledge of both RM and lean construction to ensure the verification's and validation's accuracy. The number of participants is set to be at least three, as this stage is not expected to yield much new information or substantial changes, meaning a small group should be sufficient to capture the robustness of the findings. However, attention is still paid to meeting the requirement for data saturation. Due to the use of an evaluation form, having an odd number of participants is preferable to reduce the likelihood of tied votes in cases of disagreements or differing opinions.

The selected experts for the verification and validation stage are three industry professionals with diverse yet complementary expertise: one with profound expertise in lean construction, another with experience in RM, and a third expert from the initially selected company who possesses expertise in both RM and lean. This combination of diverse expertise provides a verification & validation process with insights from both the RM and lean perspectives. Moreover, having an expert from the same company involved in the data-gathering stage offers a deeper understanding of the company's specific context, needs and challenges. This insider knowledge enables the expert to provide tailored ideas for customizing the framework to fit seamlessly into existing processes and to suggest adaptive recommendations that align with the company's long-term goals and current operational realities.

Experts are tasked with the following objectives:

- Evaluate Accuracy and Relevance: assess the framework's accuracy in achieving its intended goals and its relevance to the construction industry. This involves examining how well the framework aligns with the set requirements.
- Identify Strengths and Weaknesses: analyze the framework to pinpoint its benefits and potential areas for improvements with improvements ideas if these are present.
- Ensure Full Coverage: confirm that the framework encompasses all necessary aspects of its intended application. This includes verifying that critical elements and scenarios within the RM process are addressed.
- Assess Potential Usability and Practicality: evaluate the potential usability and practicality of the framework, ensuring that it can be integrated into existing processes and systems within the company.
- Identify Opportunities for Improvement: identify opportunities for continuous improvement and adaptation. This involves suggesting modifications that can enhance the framework, its adaptability and responsiveness to changing industry dynamics and organizational needs.

Prior to the validation meeting, a file containing the framework development, evaluation form, and interview questions will be shared with the expert team. This ensures that the experts are familiar with the requirements, objectives and content of the upcoming validation session. The evaluation form is used to collect a qualitative assessment of how well the developed framework aligns with the intended results and input requirements. Interviews are conducted to update the assessments in the evaluation form, provide detailed elaborations, and gather insights on barriers and potential solutions for enhancing the framework's applicability.

The last step involves sharing the results of the research. The developed framework will be discussed to define the theoretical contribution, practical relevance and limitations of the research. The main findings will be summarized, giving recommendations for the proposed solution and for future research.

1.3.5. The intended result

The intended result is a conceptual framework for lean RM designed for operational-level employees in construction companies. It is expected to address the tender phase, planning and development, as well as the construction phase. It will include the framework's limitations, benefits and a set of recommendations for its implementation and practical use. As this framework is not mandatory, it will be accompanied by theoretical insights, thereby enriching the current body of knowledge in the field.

2. Literature review

This chapter is focused on the literature analysis of the environment of the research problem to accumulate the theoretical knowledge that supports the research and set the initial requirements within the selected research methodology. This chapter answers sub-question 1:

SQ1: Which risk management strategies are applicable in construction? What are their theoretical deficiencies?

The analysis is limited to the threat side of RM and does not take opportunities into account, as the primary focus is on dealing with risks that could negatively impact the project. Addressing opportunities would require a distinct set of inputs and a broader scope that is beyond the aims of this research.

2.1. RM strategies used in construction

To understand how construction companies deal with inherent uncertainties and multifaceted nature of construction projects, this chapter will start with a theoretical overview of the standards for RM. It aims to gather recommendations and best practices for RM within the context of construction project management, analyze the findings and pinpoint potential inefficiencies. The focus on formal standards over other potentially relevant sources was chosen because of their widespread acceptance and authority in the practical field, comprehensiveness, structure, use of proven collective expertise and systematic development process in the layout.

One of the selected standards is “ISO 31000: Risk Management Guidelines” (ISO, 2018). The standard offers principles, framework and process for managing risks within organizations of any size, type or industry. The key goal is to integrate RM into overall organizational governance, strategy and planning, emphasizing the continuous and proactive nature of their approach. ISO 31010: Risk Assessment Techniques supports ISO 31000 by focusing on selecting and applying specific methodologies to the process of risk assessment. Together these standards offer a universally adaptable approach to RM.

Another standard is a specialized Project Management Institute's (PMI) “Standard for risk management across portfolios, programs and projects” (PMI, 2022). This standard extends beyond the RM guidance found in the "A Guide to the Project Management Body of Knowledge" (PMBOK® Guide), offering a more focused and detailed approach to managing risk in a diverse range of project management contexts. It provides a framework that, although not exclusive to construction, is highly relevant due to its project-focused RM processes.

The third standard is based on the project management methodology PRINCE2 (Projects IN Controlled Environments) - PRINCE2® 7 Managing Successful Projects (PeopleCert, 2023). While both PRINCE2 and PMI standards are focused on project management, PRINCE2 provides a more prescriptive step-by-step guidance for managing projects. In contrast, PMI's standard offers a framework and best practices focusing more on what should be done rather than how to do it. Covering both project-based standards with different priorities, strengths, principles and approaches will help to broaden and deepen the understanding of the recommendations for RM practices.

2.1.1. General framework and process flow

The overviewed standards share a similar overarching framework for RM that includes steps like initiation, risk identification, risk analysis, risk mitigation, monitoring and control (Fig. 3). This

common structure suggests a universal recognition of the fundamental steps necessary for effective RM.

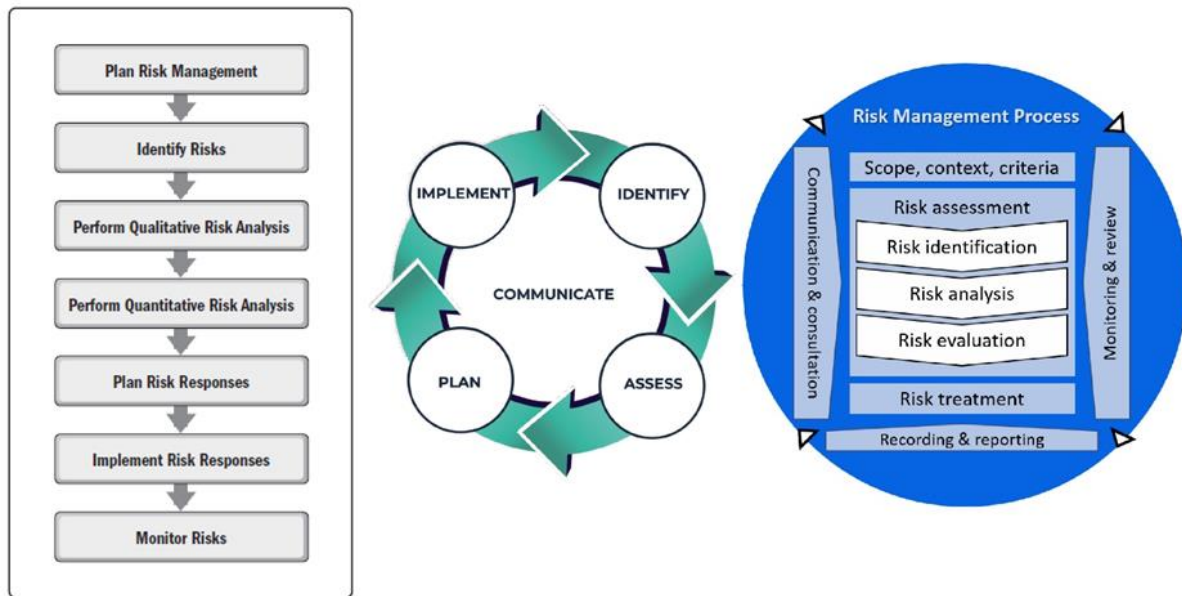


Figure 3 - RM Process in overviewed standards and guidelines.
 From the left to the right: PMI (2022), PRINCE2 (PeopleCert, 2023), ISO 31000 (ISO, 2018)

The terminology used to describe these steps varies among the standards, illustrating the priorities of each framework. For instance, what ISO refers to as "evaluation" aligns with PMI's "plan response strategies," and ISO's "treatment" phase encompasses both the PMI's planning and implementation of response. While PMI treats "monitoring and control" as a distinct phase, PRINCE2 integrates these activities across activities "planning," "implementation" and "communication." ISO, on the other hand, views risk monitoring and control as a pervasive process, spreading it through all phases. Both ISO and PRINCE2 place a strong emphasis on "communication" within the RM process to grasp the evolving nature of identified risks or define a new risk. This emphasis on communication also aligns with part of what PMI outlines in its "monitoring and control" phase.

Diving deeper, ISO perceives risk treatment in a more generic way so it can be adapted to the need of the situation to which it is applied. Conversely, PMI and PRINCE2 provide more detailed and focused guidance on RM, reflecting their concentration on project-specific risks.

2.1.2. Tools & Techniques

There is only limited overlap in the tools and techniques recommended by different standards. In total all standards recommended eighty tools, among which **only 3** were recommended by all standards and **17** by at least two standards. This variation could reflect the diverse origins and applications of the standards, as some are more general (e.g. ISO 31000) while others are tailored to industries or project types. The choice of tools and techniques might also be influenced by the project's specific needs, complexity and the stakeholders involved. The overview of recommended tools and techniques is presented in Appendix A.

2.1.3. Iterative nature

Another common theme is the recommendation that the RM process should be periodic. This acknowledges the dynamic nature of risks, which can change in significance or nature over the course of a project. Yet, despite the agreement on the need for a periodic approach, standards do not specify

how often these reviews should occur. This omission of specific intervals or the factors that can influence their identification may be due to the understanding that the appropriate timing is influenced by various project-specific elements such as its nature, environment, phase, stakeholders involved, milestones, critical decision points or external events. This absence of concrete guidance or criteria for establishing review timelines can leave practitioners seeking more direction or relying on their judgment and experience.

2.1.4. Limited “how” focus

Overviewed RM standards focus more on the "what" rather than the "how" in RM processes. Among them, PRINCE2 stands out giving a more actionable guidance to project and RM, even though it has omissions in its prescriptions.

For instance, while ISO and PMI provide a list of tools and techniques, they lack guidance on how to select appropriate tools or their specific application nuances. This deficiency is compounded by the fact that some of the suggested methodologies are tailored to specific industries and situations (e.g., HAZOP), where a basic knowledge may not suffice for deciding which tool to employ and how to tackle the issue effectively. Their approach assumes a certain level of expertise and skill among practitioners that might not be widespread, potentially leading to gaps in the effective application of RM strategies.

Another example, where PRINCE2 is not an exception, covers risk mitigation strategies. Standards outline general risk response strategies — avoid, reduce, transfer, or accept. While these categories are helpful for conceptualizing responses, they do not offer actions or specific measures to take or factors to consider the mitigation possibilities. Knowing that a risk needs to be mitigated does not inherently provide a clear path for how to mitigate it.

The expertise and resource accessibility vary among practitioners, making it difficult for individuals to seek out practical solutions. It was already mentioned that one of the problems in RM is the lack of sufficient knowledge among practitioners (Banaitiene & Banaitis, 2012; Bahamid et al, 2022). Additionally, the variability in organizational contexts, risk profiles and project specifics make it impractical for standards to prescribe detailed actions.

However, a constructive improvement to the existing RM frameworks would be the creation of guidelines on factors that could help organizations and practitioners focus more on the “how” aspects of RM and could empower them to translate RM standards more effectively into actionable, context-specific strategies.

2.2. Other RM shortcomings

Beyond the deficiencies in standards and recommendations for RM, there are other issues compromising the efficiency of the RM process.

2.2.1. Project complexity

Construction project complexity stands as a significant cause contributing to RM inefficiencies. The context of construction projects is identified as the most complex endeavors across industries (Baccarini, 1996). The dynamic, risky and challenging nature of construction has led to a notorious reputation for managing risks effectively, with numerous projects failing to meet their deadlines and cost targets (Mills, 2001). While various frameworks and methodologies have been developed to identify and evaluate project complexity, they segregate complexity from risk (Qazi et al., 2016), overlooking the interdependencies between these factors. Traditional project management

approaches, which view systems as static and simplistic, struggle to apply their methodologies effectively to the nonlinear, complex and dynamic phenomena observed in construction (Bertelsen, 2003; Cristóbal et al., 2018). These approaches fail to capture the effects of risk and complexity interplay (Son, 2022; Qazi et al., 2016), leading to negative impacts on project performance and the risk of selecting suboptimal risk mitigation strategies. Furthermore, Hartono (2018) pointed out that different risk assessment techniques may perceive project complexity dimensions variably, highlighting the importance of selecting an appropriate risk assessment methodology to enhance RM efficiency.

As an idea to resolve the raised problem, studies put focus on collaborative approaches to navigate the uncertain nature of project complexity and enhance project performance. Floricel et al. (2016) suggest combining traditional predictive strategies with flexible integration-collaboration strategies, leveraging both existing and newly developed knowledge. Similarly, Thamhain (2013) advocates for collaborative and adaptive RM approaches to address unforeseen risks and contingencies. However, the actual adoption of these solutions in practice and their effectiveness are topics for further investigation. The difficulty in embracing complexity within RM is still a significant issue that continues to affect project outcomes.

2.2.2. Stakeholder Management

The construction industry, known for its inherent fragmentation, results in the involvement of multiple stakeholders and disciplines within a single project, highlighting the complexity and diversity of interests involved (Underwood & Khosrowshahi, 2005). This diversity introduces various risks, as both internal and external stakeholders have significant, interconnected impacts on project outcomes (Leung & Olomolaiye, 2009). Collaborative integration, leveraging the specialized knowledge and expertise of these stakeholders and risk sharing opportunities, is grounded on mutual trust and transparency in theory. Yet, these foundations are not easily established and require time. Therefore, challenges remain in addressing potential opportunistic and strategic behaviors, information withholding, shifting stakeholder objectives, introduction of new issues and other issues related to role interdependencies, cooperation, social interaction, unbalanced information exchange, that can jeopardize both project success and established relationships (De Bruijn et al., 2008; Bilgin et al., 2022).

RM and stakeholder management are often examined in isolation in the literature, disregarding the potential in combining them. Yang, Zou, and Wang (2016) introduced Social Network Analysis (SNA) to enhance stakeholder analysis thereby contributing to risk analysis by demonstrating the often-ignored social, relational and behavioral dimensions. Xia et al. (2018) supported the necessity for more integrated approaches to risk and stakeholder management. They pointed out a lack of mechanisms for collaborative efforts that could foster a broader risk-oriented stakeholder analysis and multilevel RM. Another gap that could aid in addressing stakeholder-related risks involves examining factors associated with stakeholders or the construction project itself, which lead to variations in how stakeholders perceive risks and make decisions or handle these risks (Xia et al., 2018). Understanding these factors can facilitate the creation of effective, collaborative strategies for RM. Thus, addressing stakeholder-related risks remains an open challenge, calling for solutions that bridge the risk and stakeholder management.

2.2.3. Front-end project planning

Planning plays a significant role in the success of projects, with front-end planning (FEP) being particularly critical as decisions made during this phase significantly influence the overall project trajectory (Gibson et al., 2006). FEP involves pre feasibility and feasibility studies, along with basic engineering that encompasses preliminary design and RM to allow for an investment decision to be made (Hansen et al., 2018). The objectives of RM at this stage are to define the project's risk profile

and balance between the limitation of potential risks and maintaining the flexibility for unforeseen changes throughout the project lifecycle (Beckers & Stegemann, 2013). With a proper FEP process, project teams are better equipped to identify and mitigate risks early in the planning phase, enhancing overall project outcomes (Hansen et al., 2018).

Yet, the FEP process often lacks structure and clarity, leading to biases from reliance on guesses and intuition (Hansen et al., 2018; Wu et al., 2021). Projects sometimes proceed without sufficient FEP, resulting in scope changes with negative influence on costs and deadlines (Hansen et al., 2018). Furthermore, FEP faces challenges such as its undervalued importance, the unavailability or unreliability of information at early stages and insufficient time allocated for FEP processes (Aghimien et al., 2018).

To deal with this, recent studies have advocated for a data-driven approach to FEP. Wu et al. (2021) suggested using machine learning to extract objective, engineering-focused and design-driven insights from historical and early-stage project data. Similarly, Jung (2008) and Jung et al. (2009) developed a method for automatically generating critical-path-method (CPM) schedules and cost plans for FEP in construction projects. While these tools aim to support rather than directly improve RM, they provide a level of certainty to the FEP environment where the RM is carried out. However, specific tools and methodologies for enhancing RM during FEP are yet to be developed, marking a significant area for improvement.

2.2.4. Data management

In the Front-End Planning (FEP) phase, the predominant challenge is the absence of information. As the project progresses, RM is confronted with the overwhelming volume of data that has been collected or generated throughout the project's lifecycle (Hooper & Ekholm, 2010). Consequently, it must deal with various data management issues, including data redundancy, inherent randomness in certain variables, challenges with data interoperability; and the presence of inaccurate, imprecise, incomplete or unreliable data, along with approximations in the statistics used (Zhou et al., 2019; Choi & Mahadevan, 2008; Davies et al., 2017; Solihin et al., 2017). Additionally, problems arise concerning the channels of information exchange and maintaining an appropriate balance of information exchange among stakeholders, which impacts the quality of data being used (Bilgin et al., 2022). It has been identified that in the construction industry, issues with data management can lead to missed opportunities, financial losses and the need for rework (Tanga et al., 2022).

To counter these issues, companies have turned to information communication technologies like Building Information Modeling (BIM), cloud storage and web-based software, among others (Deep et al., 2021; Tanga et al., 2021; Dimitrieska et al., 2018). While these technologies aim to mitigate project risks and ease concerns among construction parties, they have not been entirely successful in achieving these goals (Tanga et al., 2021). In terms of RM, Papachatzki and Xenidis (2019) developed a BIM-based RM model that simulates risk scenarios using uniform project data from modeling software. Nevertheless, the RM software utilized in their study requires manual data entry, indicating that data must be processed prior to employing the proposed model, leaving some data management challenges unaddressed. Choi and Mahadevan (2008) introduced a risk assessment model that leverages vast quantities of existing data with project-specific new information and updates.

Given these considerations, the question of how construction companies prepare, share and manage project information, including the accumulation, processing, storage and utilization of historical data for RM, remains open.

2.2.5. Knowledge management

As previously highlighted, another challenge influencing the RM process within the construction industry is the deficiency of knowledge and experience among RM practitioners (Banaitiene & Banaitis, 2012; Bahamid et al, 2022). Often, construction professionals rely heavily on their subjective judgment for making risk-informed decisions, lacking a structured process for knowledge-based RM practices (Okudan et al., 2020). This reliance on intuition rather than formal processes can lead to a limited understanding of risk responsibilities, event conditions, risk preferences and the organizational RM capacity (Banaitiene & Banaitis, 2012).

RM is a process rich in knowledge creation and utilization (Yildiz et al., 2014). It is heavily dependent on tacit knowledge, which typically remains unrecorded and not formally preserved within an organization-level risk memory (Okudan et al., 2020). The challenge lies in the ability of construction companies to capture and leverage risk-related knowledge from past and ongoing projects to enhance the RM of current and future projects (Kivrak et al., 2008; Alashwal & Abdul-Rahman, 2014). To address this challenge, several tools have been developed aimed at improving the capacity of companies to capture, store and disseminate such knowledge, thereby optimizing RM for future projects (Dikmen et al., 2008; Goh & Chua, 2010; Yildiz et al., 2014; Okudan et al., 2020; Fan et al., 2015). Despite these ideas, the adoption of these tools within the construction industry in practice remains relatively low. This lack of integration can be attributed to the absence of a learning culture within the industry (Fordet et al., 2000; McLaughlin et al., 2008).

This lack of a learning culture and knowledge management in construction might be a reason that undermines the effectiveness of RM, underlining an area for attention and improvement.

2.3. Data analysis

In this section, the collected material will be analyzed to zoom in and define the relevance order of gathered RM deficiencies. While all nine deficiencies were noticed to be at the operational level, the potential to resolve them at this level should be studied. The following criteria were introduced:

- a. Include the ones that have a process-oriented nature.
- b. Include the ones that have relevant practical data / are relevant for the company now / are a part of a current trend in the construction industry.
- c. Include the ones that could be addressed at operational level.

The first criterion was introduced to focus efforts on the workflow improvements. Addressing such deficiencies can result in immediate improvements in how tasks are performed and managed. Additionally, lean tools are inherently process-oriented, therefore, focusing on process-oriented deficiencies facilitates smoother lean integration.

The second criterion ensures that the defined problem is based on real-world conditions, thereby increasing stakeholder support and offering potential organizational benefit. This approach keeps the research relevant and influential, contributing to broader discussions and driving advancements within the field for a more significant impact. This criterion will be applied during the next step of the research – the interviews.

The third criterion serves for keeping focus on deficiencies whose root causes are specific and actionable at the operational level, excluding those with broad underlying overarching causes that require strategic-level solutions and fall outside the scope of this research.

2.3.1. RM deficiencies within the scope

According to the second criteria, the combination of a **lack of “how” focus, unclear response strategy development, selection and implementation**, along with **insufficient knowledge management for RM**, has been identified as promising areas for resolution at the operational level. These three were united because the general know-how primarily resides in the tacit knowledge and experience of industry practitioners who have successfully implemented RM in projects. Consequently, the challenge lies in externalizing and integrating this practical knowledge.

Externalization is a part of knowledge transfer, which might be a significant root cause of the lack of focus on the "how" aspect and which usually creates a disconnect between theory and practice. This disconnect can be seen when practitioners struggle to apply what is written on paper to real-world situations (Van de Ven & Johnson, 2006). Moreover, since industry experts author most RM guidelines and standards, there emerges a reciprocal issue: practitioners often prioritize less on learning and fail to integrate their practical experiences back into theoretical formulations (Van de Ven & Johnson, 2006). This longstanding issue has been a source of criticism from both theoretical and practical perspectives for several decades.

According to Aven (2023), a central issue is the distinction between fundamental knowledge, which pertains to general risk science, and practical knowledge, which relates to applied risk science. These two types of knowledge fulfill different roles: practical knowledge involves knowing how to handle specific situations and cases, while general knowledge entails understanding how these specific instances fit into broader phenomena and processes (Aven, 2023; Van de Ven & Johnson, 2006). The interaction between these types of knowledge forms a cycle where practical experiences generate new insights, which ideally are integrated into fundamental, generic knowledge, thereby enhancing the overarching theories of science. These theories, in turn, guide practical applications later. Theoretical work often focuses on identifying broad patterns and principles, which can result in the oversimplification or omission of details critical for practical application. This can restrict the utility of such generalized knowledge in specific contexts. Similarly, preserving detailed information for future use can hinder the ability to generalize and identify broader patterns.

Scholars debate whether theory should align more closely with practice or vice versa, or whether a balanced approach, where theory and practice collaboratively bridge the gap between generalization and detail, is preferable. Additionally, a significant challenge arises in generating knowledge within practical settings. Many companies experience relatively low pressure to engage in learning (Zouaghi, 2011), and they only learn if they make a deliberate choice to do so (Kim, 1998). Yet, it has been shown that in this ever-changing and progressing world, only those who learn to adapt, remain flexible and enhance productivity will succeed (Senge, 1990).

Both external and internal factors influence the reluctance to learn within organizations. Among them, the experience of the employees is particularly evident at the operational and organizational levels (Namada, 2018) and is a crucial contributor to the technical aspect of tacit knowledge, which is essential for specific know-how within a given context (Nonaka, 1994). For effective organizational knowledge creation, it is necessary to articulate this tacit knowledge explicitly. However, because tacit knowledge continuously interacts with codified knowledge, many individuals struggle to discern the boundaries between them, leading to confusion about what knowledge should be transferred (Nonaka, 1994). Additionally, personal worldviews, perceptions of reality and visions of the future affect the potential for knowledge transfer (Nonaka, 1994). Moreover, sometimes individuals who hold such operational knowledge are, unfortunately, viewed as easily replaceable,

which discourages efforts to integrate their knowledge into the organizational memory (Hugo-Burrows, 2002).

Various methods have been developed for the externalization and dissemination of tacit knowledge, including causal and cognitive mapping, the Self-Q technique, semi-structured interviews, the use of metaphors, analogies, examples and storytelling, as well as observations (Ambrosini & Bowman, 2001; Nonaka, 1994). In this context, specific lean tools could enable employees to break down, label and comprehend the process structures they interact with. A detailed process line within the fundamental RM phases — identification, analysis, mitigation and control — could facilitate the externalization of know-how and expose the vulnerabilities of the established approaches within the employees' knowledge base.

The primary investigative areas within the know-how knowledge include the methods of risk identification, how they achieve the understanding of the nature and relevance of the risk in a specific scenario; the process of computation and analysis, how the percentages in the risk register are defined and translated into financial terms; how response strategies are developed, uncovering the rationale behind the decision-making process and selecting particular mitigation measures as effective.

Regarding the **iterative nature** of RM steps, scientific literature currently offers limited insights regarding the frequency of iterations within the RM process. Since the root causes of lack of information regarding the understanding how often RM steps should be reviewed and adjusted throughout a project are not available, this aspect will be studied and assessed during the interview stage of the research, where practical insights and experiences will be gathered directly from practitioners.

2.3.2. RM deficiencies beyond the scope

RM deficiencies, such as **the lack of data during FEP, overwhelming amount of information at later stages of construction projects and stakeholders' influence on the process**, were excluded as being the consequences of higher-level problems.

The challenge of **managing intuition and guesses in RM during the FEP** phase stems from several underlying issues. These include a deficiency in the skills and competencies of project managers to handle the front-end, coupled with the difficulty in acquiring the necessary skills and knowledge (Meier, 2008; Williams & Samset, 2010), ambiguous roles and responsibilities during the FEP (Meier, 2008), behavioral problems such as a reluctance to challenge higher management (Flyvbjerg, 2013; Babaei et al., 2021), excessive confidence in FEP outcomes (Klakegg, 2009) and a lack of initiative to explore alternative solutions (Williams & Samset, 2010). Addressing these foundational issues often requires cultivating an organizational culture that promotes learning and the development of strategic competencies among employees (Babaei et al., 2021). Thus, the way these problems are tackled highlights the significant role of leadership and top management, suggesting that the issue is broader than the scope of this research.

In the context of **proceeding with RM during FEP with limited data and time**, a primary challenge is that decision-making, despite the analytical processes involved, ultimately rests at the top political level where decisions may not always be rational (Samset & Volden, 2016). Additional contributing factors include reliance on detailed information that may not accurately predict outcomes due to the long-term nature of construction projects, leading to quickly outdated data, rather than on strategically selected facts and judgments aligned with the company's strategic planning (Samset & Volden, 2016). Addressing operational issues through improvements in data processing or decision-

making algorithms at a lower level might not address the real problem if the decisions at the top do not adhere to rational processes. Thus, the whole deficiency falls beyond the scope of the research.

The challenge of **managing an overwhelming amount of data within RM in the later stages of construction projects** also stems from a broader issue. Numerous methods for collecting and categorizing data have been validated and are utilized in modern data software; however, these methods still struggle with redundancy, imprecision, or incompleteness of information (Brown & Kros, 2003). The fundamental problem lies in the data processing algorithms and pattern recognition techniques, which are not fully developed (Brown & Kros, 2003). This situation brings to the forefront a more conceptual question: what data is truly necessary to create, accumulate and organize for the success of the project? Without resolving this fundamental issue, efforts to streamline or optimize processes at the operational and organizational levels may prove ineffective, as they merely address the symptoms rather than the root causes of inefficiencies. This realization calls for a deeper, more strategic approach to how information is handled in construction projects, potentially reshaping the entire framework of data management within the industry.

Another overarching problem lies behind the **influence of stakeholders on the RM process**. At the operational level, the challenges caused by stakeholders are mainly sourced from resource constraints, differences in obligations and incentives, integration and coordination issues, and power dynamics. While literature emphasizes the importance of effective communication in addressing these issues (Galli, 2019; Yang et al., 2011; Kaoud, 2017), it does not sufficiently detail how to achieve this. Tools developed within the stakeholder management domain to align expectations and foster transparency have not successfully mitigated communication barriers, which continue to increase costs, lower quality and delay projects (Galli, 2019). Implementation of communication strategies is inconsistent among project managers, many of whom lack formal communication training, leading to casual approaches (Galli, 2019; Kaoud, 2017). This is compounded by the fact that traditionally, communication in projects has been informal and noncompliant with established protocols (Galli, 2019). Furthermore, the temporary nature of projects complicates communication, requiring additional efforts to build trust (Grabher, 2002). Despite recognizing these communication barriers, practical solutions for effective stakeholder management remain to be established (Yang et al., 2011). Yet, there is a lack of a formal and systematic process for stakeholder management in real-world projects and the absence of routine functioning strategies, plans, methods or processes (Karlsen, 2002). These observations suggest that the issues related to stakeholder influence on the RM process are consequences of a more profound problem requiring a strategic, overarching framework for addressing stakeholder management at a deeper level. Thus, the issue goes beyond the scope of this research.

Complexity is also seen as beyond the scope of operational RM. One underlying issue is that complexity is difficult to understand. Manson (2001) notes that the abstract nature of complexity makes practical application difficult and requires better understanding and proper interpretation. Rigby et al. (2022) argued that complexity has a contested meaning, raising questions about its practical utility. Many people and organizations treat complexity as a theoretical concept without utterly understanding it. Furthermore, people may recognize an issue as complex but fail to see their role within the complex system. Erol et al. (2020) and Thomé et al. (2016) found that the relationships between risks and complexity need to be analyzed in a network due to their duality and interconnectedness. Current approaches, however, cannot grasp such a network (Qazi et al., 2021). Therefore, before addressing complexity within operational RM, it is essential to first resolve the problem of its understanding. Furthermore, while operational managers can identify complexity elements and related risks, not all of these fall within their control. Erol et al. (2020) found that

managerial and organizational risks are the hardest to predict and manage, even though they originate within the organization. Operational-level RM can only identify and escalate these internal threats, as they lie beyond their influence. Consequently, operational RM cannot fully address the complexity inherent in construction projects. Overcoming these challenges requires higher-level, strategic intervention beyond the capabilities of operational RM.

2.4. Conclusion

This chapter aimed to examine RM strategies employed in the construction industry, highlighting their theoretical shortcomings and advantages.

Despite variances in focus points, there is a consensus among established standards and guidelines on a foundational RM approach within any given project. This approach encompasses stages such as preparation, risk identification, analysis, mitigation, coupled with ongoing monitoring and control. In essence, the RM framework provides a solid foundation for managing risks within construction projects. However, the reviewed recommendations demonstrated the lack of clarity concerning the frequency of RM steps, the criteria for choosing specific tools and methods, the guidance on developing and selection of risk responses and their implementation within the project lifecycle.

Further investigation into the literature uncovers several theoretical gaps that compromise the efficiency of the RM process. These include challenges in fully understanding the multifaceted nature of construction projects and grasp the project's complexity, the influence of various stakeholders involved, the lack of data in the early stages juxtaposed with an overload of information as the project progresses. Additionally, there are identified deficiencies in knowledge management within the RM framework.

After diving deeper into RM deficiencies, the following chapters will be focused on the **understanding of know-how within the RM process, externalization of such knowledge and potential improvement.**

3. Interviews

This chapter covers interviews with industry practitioners to accumulate the practical knowledge that supports the research. This chapter answers sub-questions 2:

SQ2: How is risk management done in practice? What works well and what requires improvements in current risk management strategies?

The chapter starts with the company selection and analysis as explained in Section 1.2.4, which contributed to the preparation for the interviews, followed with the interviews themselves and their analysis, and ends with the updated RM baseline adapted to the real-life practice.

3.1. Interview preparation

The interview questions and prompts were developed (Appendix D).

The interview group consists of seven professionals, including four senior risk managers with 18-30 years of experience, a program manager, a business unit risk manager and an enterprise risk manager with 8-12 years of experience. While four of these participants have extensive operational-level expertise in RM, the remaining three focus on the strategic development of RM within the company. This diversification aids in addressing misalignments between strategic perspectives and operational realities, and in understanding the rationale behind the implementation of specific operational practices.

Table 1 - Interviewee's information

Interviewee	Position	Years of experience
1	Senior risk manager (operational level)	25
2	Senior risk manager (operational level)	30
3	Enterprise risk manager (strategic level)	8
4	Business unit risk manager (strategic level)	10
5	Program manager (strategic level)	12
6	Senior risk manager (operational level)	25
7	Senior risk manager (operational level)	18

3.2. Interview results and data analysis

3.2.1. The “how” focus within the RM process

Regarding the RM process, although the literature often outlines it as a sequence of steps, in practice, these steps may be executed simultaneously (Table 2). Each risk manager decides their own approach to performing these steps.

Table 2 - Evidence demonstrating the approach to RM process.

Citation	Meaning
“... it's always like, I just talked to people and ask them, OK, this is the risk. What if we do nothing? What will the impact be? And they could say, OK, this and this and this and this happens. So it costs you that much of money. OK. How and what do you think the likelihood of occurring? The risk without any mitigation highly likely. OK. Highly likely you have some categories. It's	RM steps are covered during one conversation

<p>subjective, I know, but then again, it's all we have. Then we say, OK, what can we do to prevent it? Then you can put in all kinds of mitigation measures. OK. And then we say knowing we put all put in, all those mitigation measures, is there likelihood still the same? No, depends, most of the times, no, it's less, and then [...] knowing we put all put in all those mitigation measures and what if the risk still occurs, is the impact is same or lots of times the impact is not the same because we put in some mitigations to limit the impact” – Interviewee 7</p>	
<p>“... you just start with an open identification session where everyone can just state or write down what they see as potential risks. [...] And then you set the next session, you do a first quantification and then you get like high risk, low risk or something. Then you can start prioritizing on risks, which you want to manage or exclude in a tender phase, which risk you can take with you in the execution phase and also which opportunities you can cash in on in a tender phase, so it's usually multiple steps depending on the size and the duration of the tender as well.” – Interviewee 5</p>	<p>RM steps happen in different time and sessions</p>

While dividing the approach into different sessions can provide structure and thoroughness, it can also be time-consuming and may result in data omissions. This is because factors influencing opinions can vary between sessions, making it difficult to recreate the same conditions and thought processes as before. Conversely, completing the RM cycle in a single session allows people to make the best out of the situation, but ideas that could arise from a fresh perspective might be overlooked. Therefore, a hybrid approach, combining elements of both methods, could be an effective way to enhance the RM process.

The outcome of each step in the RM process can be viewed as a professional judgment (PJ) on a specific matter. To make these PJs, interviewees begin with gaining a clear understanding of a project and forming an impression of the environment in which they will conduct RM (Table 3).

Table 3 – Evidence related to the context of RM process and PJ.

Citation	Meaning
<p>“I want to have some context about what the project or the contract is about. [...] You always need to know the context of what it's all about” – Interviewee 5</p>	<p>Understanding the context of the project is the base for data generation within RM process</p>
<p>“It's just the context that you collect in your head and which allows you to ask questions.” – Interviewee 5</p>	
<p>“I try to get a clear picture of everything that's relevant within a project” – Interviewee 7</p>	

<p>“So, you know for a moment when on which part of the project, which subjects, things can go wrong” – Interviewee 1</p> <p>“when we think that something's gonna happen, we look into, we look into the risk register and we use the risk register as our guide”- Interviewee 2</p> <p>“Somewhat is matching with what we expect as risk managers, [...], we make a risk opinion on that”- Interviewee 4</p> <p>“you expect a certain risk profile of say 4 or 5%. If it's much lower, than you start asking questions” – Interviewee 5</p>	<p>Risk managers make their PJ regarding the relevant subjects as something they “know”, “think” or “expect” to be within the set context.</p>
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This approach facilitates informed decision-making, helping to identify potential issues unique to specific circumstances and to define appropriate mitigation actions. It also aids communication by fostering a shared understanding based on context. However, PJs are inherently subjective, influenced by personal worldview, experience, and emotions. Additionally, they may not always be based on comprehensive data. Relying solely on PJs can result in misjudgments and omissions, particularly with new or unique risks.

The interviewees identified several criteria they consider when making their PJ within the RM process. For internal assessments, they use qualitative and subjective criteria, e.g. “ *if they **wrote it down in a proper way**, if they **did the right estimation** of the impact, but also if they **give a complete overview** of the project with the opportunities and risk, like the discovery if they are **not missing some parts in it**” (Interviewee 1). These assessments are primarily based on their personal professional experience. However, for risks related to stakeholders, objective information becomes more significant. The interviewees mentioned using the most recent **financial results** of stakeholders, number of contracts they have this year, information regarding their **processes and stability of these processes**, the presence of **previous experience with the stakeholder**.*

Each type of criteria has its strengths and weaknesses. Experience can offer deep insights into specific situations, but it may lead to inconsistency as such criteria can be interpreted differently. Conversely, using objective data can enhance accuracy and minimize personal biases, but it might miss important contextual nuances, resulting in misjudgments. Thus, finding a balance and combining qualitative and quantitative criteria could be an option to stimulate the efficiency of the RM process.

3.2.1.1. Standards and set procedures.

The interviewees rely on the company’s internal RM standard and supporting processes to ensure proper RM (Table 4).

Table 4 - Evidence regarding the standards and set procedures in the company.

Citation	Meaning
<p>“we have a mature process, [...], it's got an established regime. [...]. The risk process has been here for 9 years through the company, so the same process still going.” – Interviewee 2</p>	<p>Interviewees follow the internal guideline set for the RM process.</p>

<p>“we try to work for the standard procedures and standards systems, and then, we call it [standard name]” – Interviewee 3</p> <p>“in the current company’s baseline, that's basically the standard that says that defines all the definitions of projects that we accept, and [standard name], all the documents that the tender team needs to show so that the management can make a decision, whether we accept the tender or not.” – Interviewee 5</p>	
<p>“We have, of course, a lot of processes in place which must be used within the preparation of project or tender. [...] we have, for instance, uh, a third party screening process in which we like [...] to learn about your potential supplier or sub contractor.” – Interviewee 1</p> <p>“I think what we try to do, but don't do too often, is some sort of peer review process. So if I've worked with a tender and I've set up the risk register, I always find it very helpful to have a colleague of mine check my work, just to check for blind spots or just to challenge each other.” – Interviewee 5</p>	<p>Interviewees rely on other processes to ensure the quality of their work.</p>

The use of the established approach to RM, along with support from other departments and processes, ensures consistency in RM across projects. This consistency allows for comparison across projects and periods, contributing to the systematic improvement of RM quality and outcomes. It also ensures compliance with European tender regulations, benefiting the company in numerous ways and maximizes the use of relevant expertise, enhancing the depth of RM.

However, reliance on PJ and personal experience predominates over the use of the internal standard. The internal instruction specifies the content required at various stages at a general level, suggesting that quality assessment relies on PJ. Consequently, this leads to varying approaches in executing the same process (see Table 2), potentially resulting in different outcomes.

The key developers of the process were unit directors, which means content experts were not involved because “you **don't need content experts to think about the process**, you only **have to secure that the process** which you're going to design **is able to identify risks and opportunities from different topics**” (Interviewee 6). However, as was mentioned before, the context in which the process is executed is crucial for effective RM (see Table 3). Moreover, the literature review on RM standards indicates that the basic process should be customized for the industry. This implies that the full potential of the established internal standard is not being realized.

3.2.1.2. Communication

The primary source of data gathering during the RM process is communication. Interviewees heavily depend on information from individuals and the professional judgments of other specialists in the field (Table 5). This data is collected through group risk discussions, individual interviews, and informal conversations. The latter approach indicates that RM is regarded as an important topic on

people’s agendas, encouraging them to share their thoughts and potential concerns about a particular subject with one another.

Table 5 - Evidence related to the communication within the RM process.

Citation	Meaning
<p>“you ask the project leader or the tender manager of such projects, did you sort those things out and did you find out any special issues about this? [...] focusing on the content of their risk management file and discuss with them, well, if you do it this a little bit more like that, then you can maybe more clarify what the impact is, or, well, that's sort of things” – <i>Interviewee 1</i></p> <p>“There are so many people around me that I get gather information from and find from. [...]. I have to rely on the people that understand the scope and they come to me, they know when the scope is changing, they know when things are happening on the project, I have to rely on the people that I'm speaking to. And that's basically how I gather it.” – <i>Interviewee 2</i></p> <p>“it's just like the taking away blind spots just by having the conversation. [...]. I have individual interviews with the people who mentioned the risks or are the potential risk owners in order to get more definition on the risks” – <i>Interviewee 5</i></p> <p>“all the information has to come from the team, [...], I ask the right questions to get the relevant input from the team members” – <i>Interviewee 7</i></p>	<p>To understand the context of the project and gather potentially relevant risks within the project, interviewees communicate with people involved in the project and use people’s information to make their PJ.</p>

The selection criteria for individuals involved in risk discussions are based on the project's parameters (Table 6). The aim is to gather input from experts across various disciplines related to the project. The participants in risk meetings vary depending on the needed skill set, but typically include a tender manager, contract manager, lawyer, permit manager, stakeholder manager, and occasionally individuals with operational experience. Some risk sessions also involve the project owner and managers of relevant work packages.

Table 6 - Evidence related to the people involved in risk discussions.

Citation	Meaning
<p>“project directors, the owner, white collar management, people that sit within the project controls or the director of each one of the packages” – <i>Interviewee 2</i></p> <p>“we started with tender manager who the one who is just pulling the process. Then you look at the contract, so we need a contract manager. You need a lawyer. Then if you sit, for example, if you do a project in the</p>	<p>The communication scope and group composition are dictated by the project objectives, requirements and context.</p>

<p>middle of the Amsterdam, there's lots of <i>environment</i>, there's lots of <i>stakeholders</i>, there's lots of <i>permits</i> that you need. So you need a manager for that, so you want to have that person available at your risk session. And if you say contract that's contains building and also <i>maintaining</i> building or road for say 15 to 25 years, you need someone with operational experience. So it's always looking at the contracts, looking at the objectives and then determining what people you need, what skill sets you need in order to get the work done.” – <i>Interviewee 5</i></p>	
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This approach enhances RM quality by involving individuals with diverse expertise, enabling the identification of potential issues that may not be immediately apparent to a single person or department. Their specialized experience allows for more precise risk evaluations and the discovery of creative and effective RM strategies that might not have been considered otherwise.

However, this method of data gathering can face obstacles. For example, if RM is not prioritized, individuals may be unable to share their expertise, which undermines the RM process and its outcomes (Table 7). Given that communication is a crucial source of relevant input, addressing such barriers should be a top priority for improvement.

Table 7 - Evidence related to difficulties in communication within RM.

Citation	Meaning
<p>“the hardest part is just getting people brought to the process, that's the hardest part.” – <i>Interviewee 2</i></p> <p>“What I do not like is when I don't get access to those people in the project, yes. So if you want to do the job, you need to be able to talk to people. And if people don't have time or don't give priority to risk management, yeah, that's not what you want. [...] So yeah, if you want to set up a proper risk register and there's no contract manager available, then you can easily miss out on any contract risks, for example. [...] I was working on a project and I couldn't get access to the management team of the project. So then the only thing I could do was say OK, I can't do my job, so I'm off. Good luck.” – <i>Interviewee 5</i></p>	<p>There were incidents in interviewees' experience when they were not able to gather information from people due to the lack of priority given to the RM.</p>

Another issue related to communication involves the subjectivity and biases introduced by professionals (Table 8). This can result in inaccurate risk identification and assessment, improper prioritization and resource allocation, leading to lower quality outcomes. These factors can obstruct decision-making and learning, thereby hindering the organization's ability to improve RM practices over time.

Table 8 - Evidence related to subjectivity and biases in communication in RM.

Citation	Meaning
<p>“The project team is. Uh. Subject to all kinds of biases. So for example, if on their last projects there was a leakage in the sheet piling. If the same project team goes to the new project, there will be a lot of sheet piling risk and opportunities in the register, and probably that risk will not occur.” – Interviewee 6</p> <p>“It's subjective, I know, but then again, it's all we have. [...] Yep, I accept their position. Because he gets into every station and I can only say I think they have put on, they have too optimistic view. That's the only thing I can say, but that's it. So it's more kind of a feeling and it's not objective, really not” – Interviewee 7</p>	<p>Subjective perspective and biases held by the professionals giving input into RM process influence the quality of RM outcomes.</p>

3.2.1.3. Documentation review, personal experience, past projects

Document review, past projects and personal experience were also cited as sources of information in the RM process (Table 9). However, these sources were mentioned far less frequently than communication, indicating their smaller impact on the overall process.

Table 9 - Evidence related to the use of other sources of information for RM.

Citation	Meaning
<p>“reading all the contract documents, I want to have some context about what the project or the contract is about, [...], read some of the reporting, [...], review the register and have an idea whether it is complete or not, whether the quantification is more or less realistic” – Interviewee 5</p> <p>“of course, I will check something on the contract, but then again I rely on them as professionals, on their judgment on the contract and what are the relevant items” – Interviewee 7</p>	<p>The use of project documentation as an information source for RM</p>
<p>“we match it with our experience, so we check this register, somewhat is matching with what we expect as risk managers” – Interviewee 4</p> <p>“So we've seen lots of projects, contracts. It's just the context that you collect in your head and which allows you to ask questions. So yeah. It's a lot of individual experience” – Interviewee 5</p> <p>“sometimes you know from other projects what might be a bit higher, so you experience that they are too optimistic in estimating in determining the likelihood” – Interviewee 7</p>	<p>The use of personal experience as a source of information for RM</p>

<p>“We are checking the contents of that and we match that with a projects from the past which have certain matching characteristics” – <i>Interviewee 4</i></p> <p>“What I also try to do, if we have those available, are the risk registers of comparable projects, but at the moment we are still building up a database, so we don't really have a lot of historic data available. Unfortunately, it's mostly in people's heads, you know, at the moment” – <i>Interviewee 5</i></p>	<p>The use of past projects, if available, as an information source for RM</p>
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Employing alternative information sources aids in anticipating similar risks in current projects and applying proven strategies that may not emerge through communication alone. These sources provide an evidence-based foundation, grounding the process in documented reality rather than relying solely on subjective PJ. However, their use is limited due to data and knowledge management issues within the company (detailed in section 3.3.2.)

3.2.1.4. Frequency

The interviewees defined the frequency at which they review and update RM in a project (Table 10). Participants reported timeframes ranging from weekly to quarterly. Within the company, two-monthly or monthly project reviews are held with senior management, during which project progress must be disclosed. These reviews may or may not include updates on RM.

Table 10 - Evidence related to the frequency of RM review.

Citation	Meaning
<p>“let's just say frequently, I don't wanna put a time or a date on it, because sometimes I could do it in a six weeks. It might be done in four weeks. It could be done in two weeks, depending on how far something's going” – <i>Interviewee 2</i></p> <p>“it's multiple sessions per week. [...] if you are in a very big project like the [project name], then you have every month you go through the sequence of updating your risk register. They do that at multiple levels in the organization, so then you have a couple of sessions per week.” – <i>Interviewee 5</i></p>	<p>Outlined varying frequency of RM reviews within the project lifecycle</p>
<p>“Each time you present your financial updates to the management, and usually that's every one or two months every project manager sits with management. [...] that's kind of standard procedure in which [...] risk management is just a discussion point on the agenda” – <i>Interviewee 1</i></p> <p>“we do have certain stage gates, we call it with moments in the projects life cycle where we check the report, we</p>	<p>The company checks that RM is updated at least every two months since it is a subject to deliver for the progress track meetings.</p>

go into the details. We do have a moments of feedback.” – Interviewee 4	
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Participants mentioned several criteria that influence the frequency of risk register updates (Table 11). These include:

- the pace of project phase development: the faster the progress, the more frequent the reviews (e.g., every two weeks instead of every six weeks).
- the proximity of a particular project phase: more frequent reviews for the current phase.
- the project's risk profile and complexity: higher risk or more complex projects are reviewed more often with senior management.

Table 11 - Evidence related to the criteria determining the frequency of updates.

Citation	Meaning
“design is going quite fast, so we do it every two weeks. Uh, if we talk about production of the elements that are in the production area, they're not so quick. So you tend not to do an update maybe six weeks” – Interviewee 2	The criteria the interviewees taking into consideration when decide how often RM should be reviewed
“we do it at key moments and we, depending on the complexity of the project, we do more often or a little bit less.” – Interviewee 4	
“it is good practice to go through the risk cycle again through every project phase. So the you always focus on, OK, where are we now? What are the next activities? Have we identified risks, opportunities or can we think of any new ones?” – Interviewee 5	

There are no established procedures to determine the efficiency of the selected frequency. Inefficiency is only identified through project’s failures, making the evaluation process purely post-mortem with no proactive pre-mortem assessments conducted (Table 12). The company mandates that reviews be conducted at least once every two months, or monthly. However, if a more frequent review schedule proves to be ineffective, there is no preemptive mechanism to identify and address inefficiency before it leads to project failures.

Table 12 - Evidence related to the effectiveness of selected review frequency.

Citation	Meaning
“if the project goes well, it's enough. And if the project goes bad, it's not enough. Then you're too late. So but yeah. I am always hoping that we do a monthly update. If you do it once a quarter, then it's not enough.” – Interviewee 5	The way the efficiency of selected frequency is measured within the company

Given this, there is a need to establish methods to overcome the challenges associated with selecting the appropriate review frequency. Developing clear procedures and evaluation criteria may help prevent future project failures.

3.2.1.5. Assessment and prioritization

Risk assessment and prioritization are conducted through discussions with field experts, leveraging their professional judgment and personal experience (Table 13). Comparing and contrasting their perspectives ensures that the assessment is both comprehensive and contextually relevant.

Table 13 - Evidence related to the assessment and prioritization in RM.

Citation	Meaning
<p>“when you talk to people, you score in your risks, right for severity, cost, schedule, probability of it happening, Environmental, Quality, all of those sorts of stuff, all goes into the risk register [...]” – Interviewee 2</p> <p>“it's always like I just talked to people and ask them, OK, this is the risk. What if we do nothing? What will the impact be? And they could say, OK, this and this and this and this happens. So it costs you that much of money. OK. How and what do you think the likelihood of occurring? The risk without any mitigation highly likely. OK.” – Interviewee 7</p> <p>“it's really strange if you ask a project manager what are your top items when they come up with something entirely different than my top five list and there's some at least something to discuss on because it should be aligned. [...] if they think it's really relevant subject and it's all the way on the bottom of my list, then there's something wrong with the likelihood or the impact” – Interviewee 7</p>	<p>Assessment and prioritization done in a conversation, mainly based on PJ, personal experience, and their comparison</p>

Monte Carlo simulation is occasionally used, but most interviewees rely on the ‘heat map’ or a 5x5 ‘impact x probability’ grid. This grid distributes qualitative assessments from “very low” to “very high.” Each grade corresponds to a percentage of monetary value established at the project's outset by senior management. These connections are determined based on the project's characteristics, primarily its duration and costs (Table 14).

Table 14 - Evidence related to the conversion of qualitative assessment into monetary values.

Citation	Meaning
<p>“if the project is worth £10,000 or €10,000, there's no point in having a risk impact of 20,000, it doesn't make any sense, so you have to scale it based on the size of the project, and that's cost as well as time and then that's so you're scale is set, 5 by 5.” – Interviewee 2</p> <p>“if the project is a million, I'm not gonna put a risk in there for a million, right? Because it will blow the budget, it'll be bigger than the project.” – Interviewee 2</p>	<p>Conversion of qualitative risk evaluation is done with the scale based on the project size and duration.</p>

Another method for calculating risk impact in monetary terms involves tallying all additional costs that would arise if the risk materialized (Table 15). These costs include extended site presence, team salaries, materials, on-site office support, penalties for late project delivery and any replacement expenses. However, these estimates are not entirely accurate for individual risks because multiple risks often occur simultaneously or in a chain-reaction manner, cumulatively affecting the project schedule.

Table 15 - Evidence related to the risk cost calculations.

Citation	Meaning
<p>“you have to remain on site for assured an extra period, that cost a lot of money, [...], your the full team has to stay in the project for a few months extra and you have to remain your site, support the offices on the site, you may be confronted to a penalty because you're not delivering your project in time” – <i>Interviewee 1</i></p> <p>“anything that you have to replace for example or break, [...], you've got a get more people in or pay extra money, you know salary or stuff like that, it's delay on activities you know, what's the biggest expectant delay on any activity, whether it's whether it could be stand down” – <i>Interviewee 2</i></p>	<p>Risk costs are defined as a sum of all extra costs that would take place in case the risk occurs.</p>
<p>“this is not, uh, absolutely accurate, [...], you will probably find that you overestimated it, and the other risk you have underestimated. And overall, it's gonna give you quite an exact number anyway. [...]. We do not usually administrate the individual impact of those risks on the delay, but we just say, well, we have a delay because of all the things that happen on the project. Measuring the individual impact of risk itself is very difficult, it's too difficult and probably it's gonna take more effort than it will deliver” – <i>Interviewee 1</i></p>	<p>There is no such a goal as to precisely determine the risk costs separately, the overall number forming risk budget for the project is important.</p>

There are no established criteria for selecting which approach to use when calculating risks in monetary terms, and neither method clearly corresponds with each other. The concern raises the question of how the set percentage in the first approach can ensure coverage of all extra costs calculated by the second method. Since the resulting sum will be included in the tender price as the expected risk reserve, it is crucial to ensure accuracy in these estimations to avoid financial shortfalls.

However, the issues in risk assessment are not done yet. The calculated sum forms the expected risk reserve for the project and becomes a part of the tender price offered to the client. Once the project is awarded, the expected risk reserve becomes a “frozen bag of money,” which may or may not match the actual risk reserve. Interviewees mentioned that this mismatch occurs frequently and is not always favorable for the company (Table 16). While minor discrepancies are manageable, significant mismatches require the company to cover the shortfall of its own funds, leading to financial losses.

Table 16 - Evidence related to the issue caused by risk assessment.

Citation	Meaning
<p>“in a tender you decide how much risk reserve you want to bring to a project and there always is a mismatch between those two. [...]. If there's a mismatch between those two for certain percentage, we have to act and we have to fill the actual risk reserve. So that means in our financial statements that will be noted as a loss for the next quarter.” – Interviewee 4</p> <p>How often does it [mismatch] happen? These huge mismatches.</p> <p>“A lot.” – Interviewee 4</p>	<p>The mismatch between the expected and actual risk reserves happens quite often and is not always favorable for the company</p>

Rather than improving risk cost calculations or making the conversion of subjective qualitative assessments into monetary terms more fact-based, the assessment step is not prioritized (Table 17). Even risk managers place greater emphasis on awareness over better calculations. While awareness is valuable for understanding and managing risks, it aids less in formulating the tender price. Despite knowing what the realistic price should be, there is a “strategy to win” and inputs from other specialists, often leading to “putting on sunny glasses, **benchmarking to get to the 100 million.**” (Interviewee 7)

Table 17 - Evidence related to the mismatch in risk reserves.

Citation	Meaning
<p>“As a risk manager, you often say, hey, we think it's a little bit too less, but as a tender manager you often hear, yeah, but we cannot take more because otherwise we are not competitive. So that's a moment where there are some mismatch. The mismatch is made and that's why you often see that the mismatch goes in the wrong direction.” – Interviewee 4</p> <p>“it keeps happening that way and we all know it isn't correct and we do quite know what real price should be, but if you put in a real price then we don't get a contract” – Interviewee 7</p> <p>“then again, I don't really care how they assess the likelihood and the impact, I care about, umm, putting in risks, knowing, be aware of the risk and mitigate them, that's the main thing for me” – Interviewee 7</p>	<p>While knowing and dealing with the risks is more important than getting the exact calculation of risk costs, the mismatch is created as a response to competitive market environment.</p>

While awareness remains a priority, assessment is getting less attention, despite its crucial role in shaping the risk budget and tender price. As a result, calculations are done hastily, and it is widely recognized that they may not be thorough. This perception can lead to a belief that reducing the risk budget to meet the tender price is acceptable. Consequently, a mismatch between expected needs and actual resources appears. However, reducing the risk budget does not reduce awareness of risks; it simply means less money is available to manage them. Therefore, alongside improving calculations,

there should be a shift in thinking to ensure adequate risk reserves are maintained, regardless of budget constraints.

3.2.1.6. Mitigation

The interviewees noted that mitigation measures should be specifically tailored to address the underlying causes. One participant mentioned employing the SMART (specific, measurable, achievable, relevant, and time-bound) technique to create effective mitigation strategies (Table 18).

Table 18 - Evidence related to the mitigation measure formulation.

Citation	Meaning
<p>“So basically your mitigations need to be specific enough against your causes and they should always link, [...] Cause is the truth. So if you get the cause right, your risk would follow and the impact will follow from that. Now, your cause could have more than one mitigation or mitigation could impact more than one cause. OK, so it flows both ways, but they need to be SMART” – Interviewee 2</p> <p><i>How do you select the measure?</i></p> <p>“it's purely by osmosis. Sometimes it doesn't even have any relevance to it. Somebody could just be doing something and it would impact something else or help mitigate something else.” – Interviewee 2</p>	<p>The key goal of mitigation development is to identify an action dealing with the cause of a risk. Therefore, the cause should be identified correctly. Formulation of the mitigation action should be SMART: specific, measurable, achievable, relevant and time bound. However, the selection of a measure is given up to their PJ without certain criteria, resulting in a decision being influenced by continuous exposure to information, experience, and environment, rather than by actively seeking out and analyzing specific options.</p>

Interview participants found it challenging to articulate the criteria and strategies for formulating and selecting mitigation measures, due to their context-specific nature. Therefore, there were few examples illustrating their approach to developing and selecting mitigation actions (Table 19). According to these examples, risk managers begin with the understanding of the context, evaluating the environment and running potential risk scenarios within it. After that, they brainstorm actions to prevent or rectify potential risk outcomes, considering their feasibility and practicality. Once an action is approved, they set a deadline for its implementation.

Table 19 - Evidence demonstrating the logic behind the mitigation development.

Citation	Meaning
<p>“So preventative action might be you've gotta put something in place for safety, right? So if you've got a risk there and you've got people, let's just say walking off the end of a pier, OK. I don't want people to walk off the end of the pier. So what am I gonna do? My mitigation is to put handrails around, OK? And when are you gonna put the hand rails around? Yeah. Maybe next year, when that's not good enough. I've got people coming on in three weeks time. OK, I'll have it done in a week. Very specific, very measurable. And there's gonna be an end point to it. That's preventative. OK, so you're gonna put something in. You got people coming. I'm gonna do that. It's gonna be in a certain time. It's</p>	<p>Interviewees gave examples demonstrating the way of thinking underlying the mitigation development.</p>

<p>realistic. It's gonna be done. You can see it. It's tangible, right, because even in your head now you're looking at a pier and a handrail will goes around it. But I don't want people to fall off. Corrective mitigation is a bit more difficult because people are then on the back foot, so when they're trying to correct something, in other words, something already gone wrong, we got a hole outside. People have already fallen into it. Oh, OK. But it's the whole on a pedestrian way? No, it's off to the side. So why are people falling in it? There's no signage or there's no barrier around it, so we're then into a corrective action, but still has to be specific enough and has to be achievable when a time bound on it. I've got cattle coming through there and I don't want to fall into the hole. Right, let's put a barrier around it. It's gonna cost us a bit of money for now and then we'll deal with something else later.” – Interviewee 2</p>	
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The fallback plans, which are used in case the selected mitigation fails, were mentioned to be developed on an occasional basis. They strive to create them whenever feasible, however, in many instances, these fallback plans fail, resulting in the acceptance of risks that cannot be further mitigated or managed (Table 20).

Table 20 - Evidence related to the fallback plans.

Citation	Meaning
<p>“fallback plans, so we do, if a mitigation fails, then sometimes we have a thing called a fallback plan. Sometimes there aren't any fallback plans. It's just once you've done your mitigation and it doesn't work or it hasn't done anything or you've done it up to a point, there's a flip over risk, so it becomes accepted as an accepted risks. You would then turn around and say can't do any more mitigation. I've chucked loads of money at it. If it happens, I've just got to accept the fact that I'm gonna have to take the course, and I'm gonna have to take the cost and the schedule hit on it.” – Interviewee 2</p> <p><i>How often does it happen?</i> “Quite a lot. [...] Yeah, it happens all the time, all the time.” – Interviewee 2</p>	<p>Fallback plans are developed occasionally. In case these fail, risk becomes accepted. Failure cases were noticed to happen often.</p>

Given the challenges experienced by interviewees, it is important to delve deeper into the subject to clarify criteria and approaches in greater detail than currently understood by covering a wider range of examples. Creating checklists, templates or data sets with mitigation actions may guide them towards making decisions regarding mitigation measures more effectively.

3.2.2. Knowledge and data management for RM

According to 3.3.1., the interview participants rely on communication with other specialists, followed by their personal experience, project documentation and past projects. It was noted that the company has only recently begun to accumulate risk-related data (Table 21).

Table 21 - Evidence demonstrating the limited historical data available.

Citation	Meaning
<p>“Some of the other companies do, there's a database and you would feel it would be part of the risk database and you would feed your lessons learned in and then link it to the risk that's been that's been done. I don't think that's here.” – Interviewee 2</p> <p>“we are not that data driven, so we have certain objective indicators, but we also used the professional judgments.” – Interviewee 3</p> <p>“but at the moment we are still building up a database, so we don't really have a lot of historic data available. Unfortunately, it's mostly in people's heads, you know, at the moment.” – Interviewee 5</p> <p>“I always put it [risk register] in the system but from the past I've been the only one.” – Interviewee 7</p>	<p>Historical risk-related data base is limited in the company</p>

Despite the lack of a centralized risk database, interviewees mentioned that they maintain and use their own Excel sheets. This data is primarily stored on individual laptops if it is not kept “in people’s heads”. Sometimes the information is uploaded to an internal shared environment, but it cannot function as an effective database because it is difficult to search through for potentially relevant risks, their assessments, and mitigation measures (Table 22).

Table 22 - Evidence related to the unstructured data storage.

Citation	Meaning
<p>“I guess she has put on an Excel spreadsheet and nobody sees it so” – Interviewee 2</p> <p>“the Excel spreadsheets are all over the place. They may be on individual people's laptops and, when they leave the company, the data is gone.” – Interviewee 5</p> <p>“but at the moment we are still building up a database, so we don't really have a lot of historic data available. Unfortunately, it's mostly in people's heads, you know, at the moment.” – Interviewee 5</p> <p>“I always put all my projects on my register on SharePoint for our department, so it's always accessible also to other team members.” – Interviewee 7</p>	<p>There is a low consistency in storing risk related information</p>

Recognizing the inconvenience of the previous data storage methods, the company recently transitioned to a web-based application (Table 23). Initially implemented for larger projects, its use became mandatory for all projects last year. This shift allows for the use of keywords to search the database for relevant potential risks, their assessments, and mitigation measures, significantly improving accessibility and usability.

Table 23 - Evidence related to the new web-based application deployed in the company.

Citation	Meaning
<p>“now we have implemented a system which is web based in which uh contracting and tender managers and project managers can also look at all the projects which are similar and see what they have experienced on risk and how they estimated it and which measurements they have taken to control the risks. [...] So you can look up certain keywords and see what the system has in place on that particular subject and see if you can apply that on your own project.” – Interviewee 1</p> <p>“Last year, we cut out the Excel and we only want to use our digitally online available application. [...] It's mostly a recent information from when we started doing it [using a web-based app], but we have our big projects were already in [app name], so those were digitally available ” – Interviewee 4</p> <p>“[...] the application is user friendly, that we have now within the Company. So I hope it will be used in the future” – Interviewee 1</p> <p>“It's about driving things back into the project to make them better, [...], I use it like looking at lessons learned because they give me an opportunity to look at risks for other projects” – Interviewee 2</p>	<p>A new web-based application was introduced, making it easier for risk managers to store and use the data.</p>

Several external and internal reasons prompted this change (Table 24). Strategic-level managers were primarily concerned with external factors like legislation and clients’ wishes, while operational managers focused more on preserving experience, preventing potential knowledge loss, and improving communication.

Table 24 - Evidence covering the reasons to create risk database.

Citation	Meaning
<p>“our external accountants just want us to be in control. And so for every reservation of money, we need to show how that is built up, and if you can't supply the risk register, then the accountant will say I will cancel the reservation for future losses.” – Interviewee 5</p>	<p>External pressure to make RM more explicit</p>

<p>“we want to make data explicit, [...], there's a lot of financial legislation forcing it to be explicit” – Interviewee 6</p>	
<p>“But when you look at the company level, that's really important to collect the data and in the right system. And we can learn from it and then we can be more predictable in the end.” – Interviewee 3</p> <p>“if somebody has been filling their database for a number of years in the near future, and then is retiring, that knowledge is not wasted, but you can still look it up and it's still stored somewhere in the database and can be used.” – Interviewee 1</p> <p>“storing experiences, storing knowledge in a database, so it's accessible especially for people who are just starting.” – Interviewee 2</p> <p>“We do need to make things explicit. We do need to report on the relevant subjects because we also need it for management and it's also a way of communicating with the other people.” – Interviewee 7</p>	<p>Internal reasons to create a storage for risk related data</p>

However, the company has already encountered issues with collecting risk-related data (Table 25). Participants highlighted challenges with limited information in new domains the company is exploring, data protection due to the need for close collaboration with external stakeholders, and the unique nature of some “one-off” projects that limit data reuse potential. Additionally, to make accurate predictions, the information used needs to be recent, which is difficult to maintain as data quickly becomes obsolete. Consequently, past projects have not been integrated into the new system. Furthermore, the quality of data input remains a concern.

Table 25 - Evidence demonstrating hardships with data gathering and storage.

Citation	Meaning
<p>“impossible to get into details of all these tenders and projects.” – Interviewee 1</p> <p>“for some domains there is not much information or difficult to grasp it” – Interviewee 3</p> <p>“But I do think it's a very good to look at past, but for now I think reach the information which is current is a little bit more interesting because things like payment criteria, you want to use the criteria that are active now, not the ones that were active couple years ago.” – Interviewee 4</p> <p>“most projects are one off. So we built a specific building and that has specific requirements. So you cannot just</p>	<p>The issues related to the collection and storage of risk related data</p>

<p>copy risks and opportunities from the past. You always have to rethink whether they are applicable in the new situation, and that makes projects a bit more difficult than, for example, the maintenance contracts that we have as well, that run for 15-20 years because then you have you collect data from every year.” – <i>Interviewee 5</i></p> <p>“you really have to think about protecting those data and also who needs access to those data” – <i>Interviewee 5</i></p> <p>“company is a very heterogeneous company, right? We don't have a concrete and that's it, no, we have houses and bridges and railways and roads and, but we also make clinical rooms for CPU producers or and hospitals.” – <i>Interviewee 6</i></p> <p>“it's always garbage in, garbage out. So you're input needs to be valid and correct and relevant.” – <i>Interviewee 7</i></p>	
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3.2.3. Senior vs operational management

3.2.3.1. Perception difference

Analyzing the responses from senior-level managers and operational risk managers revealed several discrepancies. Firstly, there is a gap in the perception of the RM process (Table 26). Senior managers believe the process is straightforward and that anyone can handle it, while operational managers think the opposite. They emphasize that context significantly influences the process, presenting major challenges in achieving desired outcomes. The key factor that enables them to produce RM documents of decent quality is their deep understanding of the context, developed over decades of professional experience. From their perspective, this understanding is crucial to the entire process, as noted previously (see 3.3.1), and is rooted in the specific environment where RM is conducted.

Table 26 - Evidence showing the difference in process perception.

Citation	Meaning
<p>“really tell them what's important and why it's important and why it's not that difficult and you shouldn't make it too big and it's not shared with other people, et cetera, et cetera” – <i>Interviewee 6</i></p>	<p>Senior management doesn't consider RM as something difficult.</p>
<p>“I find it very important that you use risk management pragmatically. [...] they really are doing risk management for risk management, and not in order to lay control and support your project in an efficient and effective way.” – <i>Interviewee 1</i></p> <p>“There's lots of facets to risk management. [...] If you sat in the company business, the risks that are in the</p>	<p>Operational risk managers see that RM process is quite complex because they must deal with the lack of understanding of the complexities involved, lack of pragmatic use, lack of clarity on what needs to be done.</p>

<p>company come from the bottom up. What impacts them? This is project risk. This is real nitty-gritty. You know, I call it dirty risk management. Basically, it's just. Yeah, you're in it. You're doing stuff, but yeah, there's so many different facets to it." – Interviewee 2</p> <p>"risk management is probably one of those things that's less understood, but everyone thinks they can do right and everybody thinks they can do risk management." – Interviewee 2</p> <p>"most things aren't a technical problem, but it's more organizational or process related problem that people don't know what they're doing." – Interviewee 7</p>	
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This difference in perception might explain why the internal standard was developed without context considerations (see 3.3.1.). Additionally, if these perceptions are not aligned, senior management may underestimate the resources needed for effective RM or may fail to fully support RM initiatives, seeing them as either unnecessary or complex. This misalignment has already led to negative consequences within the company, such as differing priorities and levels of importance assigned to operational RM (Table 27).

Table 27 - Evidence related to the consequences of the difference in perception.

Citation	Meaning
<p>"depends on the priority that senior management gives to risk management. They've seen your says it's important, than it will happen. If not, then you might as well go. It's pointless." – Interviewee 5</p> <p>"we don't have such an important role as you are describing, not yet, but at the moment we are in the situation where we are just consultants on projects, making a risk register and assessing things together with the team and we are not involved in all the decision making and all. [...] We're still not really involved in the decision making, but we have more input to tender teams and to stage gate processes" – Interviewee 7</p>	<p>Senior management may not put emphasis on the RM in a project, resulting in the absence or lower quality of RM. Additionally, RM does not have enough weight in decision making process.</p>

Although strategic-level managers need to concentrate on overarching goals, risks and issues, most inputs originate from the operational level. This misperception creates additional internal problems, complicating the work for both levels. The general process has been in use for years, but RM results frequently fail to align with reality.

3.2.3.2. Reasons behind the problems in RM process

Another difference concerns the reasons behind malfunctions in the RM process. From the senior management perspective, human factors such as resistance to change, lack of cultural shift and personal reluctance are seen as the main sources of hardships in the operational RM process (Table 28).

Table 28 - Evidence related to the reasons behind the problems in RM process.

Citation	Meaning
<p>“I just want a project A to disclose that they're not doing good because the other six project are doing good. So that's not a problem, but project manager A doesn't want to disclose that his project is on fire”</p> <p>“people don't like changes that are coming from the main office. So that's always a little bit of a struggle for my work.” – Interviewee 4</p> <p>“I think a lot of the resistance towards the procedures, towards the tools, [...] there's a lot of financial legislation forcing it to also be explicit, and I think a lot of the resistance is towards information being explicit, [...] ambiguity in interest of the different people is complex in the context of this management. [...] I do understand that a risk management preventing issues is a bit lower on the plate on the priority list. So it might be related to that, and otherwise I think it's quite personal. [...] the resistance towards writing stuff down. [...] I do risk management the whole day. Why do I have to write it down?” – Interviewee 6</p>	<p>Senior management sees the reasons aggravating RM process as human-related: unwillingness to share the information and make it explicit, to accept changes pushed from the top, to follow the procedures and use tools, but also diverse interests and personal priorities of the lower-level employees.</p>

Like senior management, operational managers do face a significant amount of administrative work which is not particularly enjoyable. However, this issue is common across all departments and processes (Table 29).

Table 29 - Evidence supporting a problem relevant for the operational level managers.

Citation	Meaning
<p>“I like to interview, but putting it on paper takes me the same time, I don't like it, but I really have to do it, [...], you have lots of paperwork, but that's not only on risk management. It's all aspects of a project. You have lots of paperwork, which is, yeah, getting more and more and more over the years, yeah.” – Interviewee 7</p>	<p>Operational managers admit the resistance towards writing things down</p>

On the other hand, as noted in 3.3.1. and 3.3.2, operational managers have a positive perception of the web-based application and stage gate procedure, which were pushed from the top, and genuinely rely on them. This presents a contrasting view from senior management, who see these aspects as problematic.

While senior managers’ concerns may still affect the efficiency of RM, operational managers continue to focus on the lack of general understanding among the people involved. For example, despite the resistance towards procedures noted by senior management, operational managers observe that employees follow instructions only because they are told to, rather than seeking support for their projects. They attribute this to a lack of understanding of RM objectives and the actions required to achieve them (Table 30).

Table 30 - Evidence related to the reasons behind the problems in RM.

Citation	Meaning
<p>“they really are doing risk management for risk management, and not in order to lay control and support your project in an efficient and effective way. [...] constantly be aware of what you're doing and what you're doing it for” – Interviewee 1</p> <p>“you've gotta get people to think about it in a slightly different way, [...], getting risks, sometimes getting mitigations, getting people to update them, understand what it is, what people understand or don't understand. [...] the more people that understand risk management, the more mature your business and your project will be because people understand it” – Interviewee 2</p> <p>“most things aren't a technical problem, but it's more organizational or process related problem that people don't know what they're doing.” – Interviewee 7</p>	<p>Operational risk managers notice that people involved in RM do not completely understand the essence and purpose of RM, pointing out that priority should be given to cultivating RM knowledge among the employees and creation of a RM mindset.</p>

3.2.3.3. Level of details in RM

There are some differences in the level of detail required in the RM process to ensure quality results, primarily among operational risk managers. Both operational and strategic managers indicated that, during discussions, they try to prevent specialists from getting bogged down in technical details and instead focus on maintaining relevant information at a broader level. Specific details, if needed, can be obtained later, but they do not add significant value to the process (Table 31).

Table 31 - Evidence supporting broad data gathering in the process.

Citation	Meaning
<p>“everyone can just state or write down what they see as potential risks. I tried to collect very widely and then after the session I do the administration, so I write it down and then I have individual interviews with the people who mentioned the risks or are the potential risk owners in order to get more definition on the risks” – Interviewee 5</p> <p>“if the project manager opens within talk and he will start talking about the biggest risk of this project, this is our planning. Well, then, in-depth workshop. You're going to get a lot of his opportunity concerning planning, so my instruction to the project manager always shut up. Don't talk about risk, just about the technicalities of your project, this scope, the context, et cetera.” – Interviewee 6</p> <p>“when they try to go very into detail into all kinds of things. I'm like, OK, two steps back. What's the problem?”</p>	<p>Interviewees prevent people involved in RM from going into details and keep the data gathering at a broad level.</p>

[...] all those technical details which are nice for them to know, but not really always relevant for the projects.” – Interviewee 7	
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On the other hand, interviewees highlighted that every project requires constant customization and detailed analysis, indicating that information should be specific to each project's unique conditions and contract terms (Table 32). This view is supported by sections 3.3.1 and 3.3.2, which state that RM should be context-specific, and that professional judgment is used to tailor the data for each project.

Table 32 - Evidence supporting detailed data gathering in the process.

Citation	Meaning
<p>“I was teaching people that they had to be as concrete, as smart as possible in defining a risk. Now I say no, no, no, please don't do that. Please write every little bit of prose you can think of. The large piece of text because it's all valuable information for our data.” – Interviewee 4</p> <p>“you always have to and go into depth into the specific context, the specific contract and the specific things, and it always comes from the contract and the team.” – Interviewee 7</p>	Interviewees mention that information for the RM must be extensive and detailed because it all can be useful

Supporting this point, they have a failed attempt to create a generic database that proved inconvenient and ineffective, as it required customization for each specific project (Table 33).

Table 33 - Evidence related to the failed attempt of using generic data base.

Citation	Meaning
“we've tried it in many ways, we've made a generic risk database once which was just generic risks , but that didn't work because they were generic , and it was a list of thousands risks, so someone had to scroll through, and no one really wants to scroll through a list of thousands risks. ” – Interviewee 4	Failed attempt to keep risk database generic

Given these points, it can be concluded that achieving a balance in the level of detail is a significant challenge and an essential factor to consider when working on improvements.

3.2.4. What requires improvements in current RM process

During interviews, participants were asked to identify aspects of the RM process that are working well and those needing improvement, although most of these points were mentioned casually in the context of other discussions. Despite the company's long history in the market and years of experience in RM, the list of gathered deficiencies significantly outweighed the list of advantages. This discrepancy suggests that, over time, certain inefficiencies and issues may have become ingrained, overshadowing the process's strengths.

The compilation of deficiencies includes eighty pieces of evidence, which were organized into subgroups within 9 categories (Table 34). Some evidence was relevant to multiple subgroups. The participants' main challenges in executing RM effectively were primarily associated with an extensive workload and reporting requirements, a lack of general understanding of the process among those involved, the influence of a competitive market on RM outcomes, and limitations in data storage and structuring.

Table 34 – Topics requiring improvements identified by industry practitioners.

No	Category	Subgroup	Meaning	Number of evidence
1A	Technical & Complexity	Complexity	Issues related to complex systems and outside changes	2
1B		Technical	Issues related to struggles with quantification	2
2A	Information Gathering, Processing & Storing	Storage	Issues related to storage system and accumulated resources	6
2B		Details & quality	Issues related to the quality of information and possibility to gather all required specifics	3
2C		Data Processing	Issues related to translation and structuring of information for storage	2
2D		Lack of information in a certain domain	Issues related to data availability or existence	2
2E		Preservation & Accessibility of Experience	Issues related to gathering and storing experts' knowledge and experience	1
3A	PJ & Experience	Knowledge loss	Issues related to information losses due to retiring, workplace changes, etc.	
3B		Personal Knowledge	Issues related to personal approaches and knowledge of professionals	
3C		High reliance on PJ & Experience	Issues resolved or caused by reliance on PJ and experience of professionals	3
4A	Communication	Information Withholding	Issues related to information extraction from professionals	2
4B		Influence of personality on communication results	Issues related to biases, optimism, etc.	3
4C		Transparency	Issues related to intentional deception and contradictory communication	2
4D		Access to people	Issues related to the limitations on communication channels	3
5A	Understanding	RM goals & process	Issues caused by lack of general understanding of the process	7

5B		Balance	Issues related to harmony between RM and the rest of a project	2
5C		Context	Issues caused by lack of understanding of the context of RM	3
6A	Reference System	Structure for mitigation development	Issues related to the lack of guidance on mitigation development	1
6B		Level of details	Issues related to differences in required level of details for RM	1
6C		Criteria for risk ranking	Issues related to the lack of guidance on risk prioritization	1
7A	Market Challenges	Actors	Issues related to staff and clients	4
7B		Competitive Environment	Issues caused by the need to stay competitive	6
8A	Internal Organizational Issues	Weight in decision making	Issues related to the lack of weight given to RM in decision making	4
8B		Political games	Issues caused by company's politics	2
8C		Strategic behavior	Issues caused by self-interest of professionals	3
8D		Misperception	Issues caused by overestimation of company's own potential	1
8E		Top-Down Push	Issues related to changes forced from the top down	4
8F		Culture	Issues related to organizational culture	2
8G		Priority	Issues related to the priorities given by senior management	4
9A	Administration & Workload	-	Issues related to the time-effort ratio and paper works	9

Among these points for improvement, sections 3.3.1, 3.3.2 and 3.3.3 already reviewed 17 issues (1A, 1B, 2A, 2D, 2B, 2E, 3A, 4B, 4D, 5A, 6A, 6B, 7B, 8C, 8E, 8G, 9A). These points were divided because many of them are related to the focus of the research — lack of knowledge management and know-how. However, other points, while influencing operational RM, stem from factors beyond the scope of the study. Nonetheless, they remain relevant and are a part of the research findings.

3.2.4.1. Additional issues with Information Gathering, Processing & Storing

The remaining thirteen factors contributing to the company's processes not running as smoothly as desired include, for instance, challenges related to data processing (2C). These challenges involve difficulties in translating information between different levels and finding a suitable structure that works across all company units.

3.2.4.2. Additional issues with Professional Judgements & Experience

Regarding issues related to personal knowledge and approaches (3B), professionals sometimes performed different calculations with the same data, leading to varied outcomes that confused decision-makers. Another issue in this subgroup is that new hires come with different standards and knowledge bases, resulting in inconsistent outcomes. High reliance on PJ and experience (3C), as

described in 3.3.1, is an integral part of the RM process but is also cited as a cause of misjudgments. Risk managers, who generally lack specialized knowledge, heavily depend on the PJ of others since they can only challenge the information at a general level, not on specific content. Corporations often structure their work so that specific parts of several projects fall under the purview of individual specialists within the department. This setup prevents risk managers from obtaining a second opinion on certain subjects. Additionally, the confidential nature of this information makes it impossible to seek external opinions. Given that instances of misjudgment by specialists are frequently reported, the issue warrants reconsideration.

3.2.4.3. Additional issues with Communication

Information withholding (4A) was noted in cases where stakeholders deliberately do not share information. Additionally, sometimes it is necessary to extract information from staff, who may be unwilling and not obligated to provide it. This can lead to misjudgments in RM. Regarding transparency (4C), internal situations were mentioned where senior management sends mixed signals to operational employees, such as expecting transparency and openness while withholding certain information that could affect the stock price. This behavior can lead project managers to take strategic actions, like keeping management unaware of financial buffers in their projects. These manipulations with information can result in RM not producing a high-quality outcome.

3.2.4.4. Additional issues with Understanding

Issues related to balance (5B) involve challenges in finding the right equilibrium between RM and other aspects of the project. There were instances where some individuals neglected RM in their projects, while others overemphasized it. This indicates that professionals lack a clear understanding of what constitutes a manageable balance and how to achieve it in their projects. These issues also surfaced at the portfolio level. Achieving balance heavily depends on understanding the project context, which presents another challenge (5C) for professionals. It was noted that individuals need to consider the long-term impact of risks and opportunities on their projects. Misjudgments about the context have led to situations where initially beneficial decisions later became problematic.

3.2.4.5. Additional issues with Reference System

Risk ranking, as discussed in section 3.3.1., primarily utilizes a 5x5 “impact x probability” grid, rating assessments from “very low” to “very high.” This evaluation relies solely on the PJ of the involved experts and lacks a clear assessment criteria system. The absence of defined criteria (6C) leads to discrepancies between the assessments of professionals and risk managers. While these differences can be negotiated and aligned, the process remains vulnerable to biases and other influencing factors. This is because risk managers possess only a general level of knowledge about the specifics and are not fully equipped to challenge the professionals' judgments.

3.2.4.6. Market Challenges

Market challenges concerning the actors (7A) encompass both the Dutch labor market and internal company dynamics. The RM department has a limited number of professionals, and given the company's expanding strategic ambitions, this significantly increases the workload and affects the results. Additionally, hiring more personnel is difficult because many potential candidates prefer freelancing for multiple companies rather than committing to a single employer. Such a commitment is not viewed by the company as advantageous. Additionally, for certain units within the company, the client market is also limited, which reduces the company's market power. Conversely, it was noted that there are more projects available in the market than there are staff to handle them, which allows the company to better prepare and select the projects they prefer.

3.2.4.7. Internal Organizational Issues

Regarding the influence of risk managers in decision-making (8A), operational level interviewees stated that they are **“not that important [...], not yet”** (Interviewee 7) in the process. Their primary role is to create risk registers and facilitate decision-making. The fact that their results are later reduced to stay competitive (see 3.3.1, Assessment and prioritization) indicates a lack of priority and value placed on RM by senior management. While senior managers claimed that the **“attention for RM is stabilizing at a very high level at the moment”** (Interviewee 6) within the company, the reality suggests otherwise. Therefore, there is still a need to elevate the role of risk managers and ensure their assessments are given consideration and weight.

Political games (8B) were identified as a challenge for risk managers. For instance, there are situations where everyone is aware that the available risk reserve is insufficient to complete the project, yet no one raises the point and addresses it. Similarly, when a partner is clearly incapable of finishing the job, it remains unspoken despite everyone being aware of the risk. Several reasons might explain such behavior, e.g., senior management's desire to avoid conflicts, maintain a facade of stability, protect their interests, hope for improvements, or follow internal politics that prioritize image over transparency and problem-solving. However, these political maneuvers undermine RM and project success, turning the work environment into "somewhat of a big circus" (Interviewee 4).

Another organizational issue involves decision makers developing overly optimistic perceptions about the company's capabilities. There have been several instances where the company agreed to undertake projects under unrealistic conditions. A few years ago, this nearly led to bankruptcy and resulted in the closure of several branches. While it was noted that lessons have been learned and such situations occur less frequently now, decision makers are still prone to misperceptions (8D), thereby hindering their own progress. Such unrealistic commitments and misjudged capabilities lead to inadequate risk assessments, insufficient risk reserves, and ultimately, project failures.

The cultural issue (8F) revolves around a leadership style that tends to criticize employees harshly for suboptimal results. However, the way the operation works now is a direct outcome of the company's education, for which management lacks accountability. This implies that until management evolves at a higher level, operational practices will have struggles which affect the quality of work done. Such blame culture discourages open communication about risks, and prevents constructive feedback and continuous improvement, leading to lower-quality RM outcomes.

3.2.5. What works well

There were 21 pieces of evidence dedicated to the positive sides of the current RM process. These were divided into 5 categories (Table 35). Some evidence was relevant to multiple categories. In general, participants mostly led to the ability of current approaches to prevent mistakes and issues in the projects and the positive impact of communication on the process and its outcomes.

Table 35 - Advantages identified by industry practitioners.

No	Category	Meaning	Number of evidence
1	Communication	Points demonstrating positive influence of collaboration and communication	5
2	Simplification of complex environment	Points demonstrating positive influence of structuring of a difficult project environment	3

3	Preventive influence	Points demonstrating reduction of mistakes within projects	7
4	Learning	Points demonstrating positive influence on knowledge generation and use	
5	Increased organizational resilience	Points demonstrating positive influence on organizational ability to adapt or get better conditions for itself	3

The current RM process relies heavily on communication and integration, which are seen as opportunities to share risks in a healthy way and explore more negotiation options. Furthermore, the current RM approach is considered a team effort, encouraging people to discuss it with each other and share risk-related concerns. Communication is seen as a proactive function within the RM process allowing for shared understanding and joint approach which help prevent significant losses for any single party.

RM helps create a structure that simplifies the complex project environment, making it more concrete, specific, and easier to understand. With fact-based input, this approach enhances predictability and reduces uncertainty, decreasing the reliance on assumptions. By providing clarity and specificity, RM facilitates informed decision-making and helps ensure that potential issues are identified and addressed proactively, ultimately contributing to the project's overall success and stability.

To some extent, RM prevents many mistakes and leads to better projects. When the risk register is well-maintained, the team can adapt and handle appearing changes effectively. By anticipating potential risks, the project can remain stable even when challenges arise, preventing immediate declines in results. This forward-thinking approach enhances the project's adaptability, allowing the team to respond to issues and maintain progress.

The generation of ideas and lessons learned were mentioned as strengths in the RM process. Some practitioners consistently apply their lessons across various projects. Additionally, by mobilizing knowledge, RM moves projects toward the ideal of comprehensive risk coverage, ensuring that potential issues are anticipated.

RM stimulates organizational resilience by preventing the company from agreeing to unrealistic contract conditions. It ensures that commitments are feasible and aligned with the company's capabilities, thereby safeguarding against potential project failures and financial losses.

3.3. Conclusion

This section provides an overview of the RM process within the selected company. Key points raised in Chapter 2 were supported and discussed in depth, laying the groundwork for Chapter 4. Additionally, new topics that were not covered in Chapter 2 have emerged. While this research focuses on the lack of "how" in the process, insufficient knowledge management and the process-based nature of the issues, most of the newly identified problems fall outside the scope of this research. Therefore, the RM deficiencies related to the outlined topics in Chapter 2, which constitute the main input for the following chapter, are as follows:

1. Know-How:

- The need to identify and establish an approach to select the review frequency.
- The need to assess the effectiveness of the review frequency selection.
- The need to ensure access to people and their PJs in the RM process.

- The need to customize the internal RM guideline.

2. Insufficient Knowledge Management:

- The need to understand the context to make accurate PJs.
- Frequent misjudgments and omissions in PJs.
- The influence of subjectivity and biases.

The need to develop criteria and approaches for mitigation development was excluded from further research due to insufficient information available: more participants and examples are needed to find connections, which is not feasible with the current data. Similarly, converting qualitative assessments into monetary values, customization of selected RM tools and guidance on the assessment of PJs were excluded. Such an improvement should be based on analyzing documented historical information to identify criteria and connections. However, the company currently lacks such a database. Without it, any assessment would be another subjective judgment without proper support. Additionally, tool selection was not included because the tools chosen are widely recommended (see Appendix A) and acceptable. However, the issue lies in the lack of sufficient customization, leading to difficulties with conversion and objective assessment. Therefore, the point of customization becomes more prominent and will be addressed further.

Identified advantages are noted to be employed and maintained in the process as much as possible.

4. Lean RM Framework Development

This chapter focuses on the development of a lean RM framework aimed at resolving the issues identified and supported in Chapter 3. This chapter answers sub-questions 3 and 4:

SQ3: What are the lean tools used in construction?

SQ4: How can lean construction tools address the deficiencies in RM?

It begins with the literature review on lean tools used in construction to identify the scope of potential solutions. Then, these tools are analyzed to understand whether these lean tools can address the identified issues and detail how they can be adapted to the context of RM in construction projects. After that, lean tools are integrated into the existing RM process, thereby producing a new framework. The framework is later verified and validated with semi-structured interviews.

4.1. Literature review on lean tools used in construction

To cover the SQ3, various lean tools and techniques employed in the construction industry will be examined. The goal is to collect and analyze the wide array of lean methodologies used in construction projects, with a particular focus on identifying how these tools and techniques can hypothetically or evidently mitigate the deficiencies in existing RM processes.

In total, 58 lean tools and techniques were found to be used in the construction industry. They were categorized based on the application level, phase, and process. The full table is presented in Appendix C.

Among the listed tools and techniques, eight have been identified as already used for RM. These include constraint analysis, variance analysis, cause and effect diagram, prompt lists and checklists, Failure Mode and Effects Analysis (FMEA), root-cause analysis and Pareto charts. Additionally, several lean tools share objectives or methodologies with RM tools. For instance, Reliability Centered Maintenance (RCM) focuses on identifying, understanding, and preventing issues that affect the functionality of production equipment, like the objectives of the Total Productive Maintenance (TPM) technique in lean. Likewise, pre-mortem analysis, a forward-looking tool, is designed to foresee potential failures and address them in a proactive manner. Similar approach is found in Lean tools like Reverse Phase Scheduling (RPS) and Lookahead Planning (LAP). Furthermore, RM status meetings, recommended by the PMI (2022), share goals with lean daily huddle meetings, both aiming to disseminate project results and engage employees in collective problem-solving and planning efforts.

In addition to these similarities, many lean approaches are hypothetically suitable for RM, especially from a production standpoint. For example, one of the outputs of RM is the risk register, which is essential for enhancing the likelihood of project success (PMI, 2022; PeopleCert, 2023). The creation of a risk register involves processes defined by RM methodology, which, in turn, utilize specific RM tools and techniques. The process of developing a risk register could benefit from lean tools like Muda/Gemba walks, PDCA cycles or First-run Studies to identify and address problems at each production step. For instance, managing the vast amounts of data involved in RM can be theoretically handled with Muda/Gemba walks by pinpointing specific issues within a broader data management problem, potentially leading to effective solutions. Alternatively, applying the Value Stream Mapping (VSM) tool to examine the RM process from a value creation perspective could identify wasteful activities, such as frivolous data storage that slows down information retrieval and processing, and pave the way for a more streamlined process.

4.2. Lean tools potential for defined RM deficiencies

4.2.1. Main findings

In this section, the identified lean tools are filtered. The selection criteria used are:

- a. The ones that are process-based tools and techniques will be included.
- b. The ones that require minimum adaptation to address the defined RM deficiencies will be included.
- c. The tools that have not been already applied in RM will be included.

The first criterion was introduced to concentrate on process-based tools and techniques, which are typically more relevant to addressing operational-level issues. The purposes of the second criteria are to reduce additional risks caused by initially bad fit for the existing RM framework and to allow for a smoother integration with the current systems and processes within the organization. By excluding tools that have already been applied as per the third criteria, the research will not replicate existing studies or practices, thereby helping in generating new knowledge and insights.

The tools were evaluated based on their potential to contribute to problem solving. Two levels of contribution were identified: primary and secondary.

5. primary contribution means that using the tool or technique will potentially resolve, clarify, or significantly improve the issue.
6. A secondary contribution implies that while the tool or technique may not potentially resolve or greatly improve the issue and may require additional solutions, it will at least clarify the problem.

Based on these criteria, the tools were ranked, giving preference to those that offer both primary and secondary contributions, followed by those with only primary contributions, and finally, those with only secondary contributions.

The result of application of three criteria and contribution range is presented in Table 36, There are **14 tools left**, with 1 having only secondary contribution, 10 with only primary contribution and 3 with both primary and secondary contribution.

Table 36 - Risk Deficiencies and Lean tools

	Deficiency	Explanation	Lean tools: primary (1) and secondary (2) contributions
1.1	Know-how	The need to identify and establish an approach to select the review frequency and assess the effectiveness of this selection	work structuring (2), SWLA (1), WWP (1), daily meetings (1)
1.2		The need to ensure the access people and their PJs in RM process	SWLA (1), WWP (1), daily meetings (1)
1.3		The need to customize the internal RM guideline	const proc analysis (1), work structuring (1), VSM (1), RPS (1), SWLA (1), WWP (1), visualization (2), suggestion schemes (1), standardization (1)

2.1	lack of knowledge management for RM	The need to deal with subjectivity and biases in PJs used for making risk-informed decisions (leading to misjudgments and omissions)	SPC (2), standardization (1)
2.2		The need to cover a lack of a structured process for knowledge-based RM practices (including the need to understand the context to make accurate PJs)	SPC (2), standardization (1)
2.3		need to turn tacit risk-related knowledge into explicit knowledge at the organization-level risk memory	Muda walk (1), visualization (1), suggestion schemes (2), Gemba walk (1), A3 (1)

For instance, the weekly work plan (WWP) is a lean tool employed to craft a detailed schedule for each week. This practice requires regular weekly meetings and discussions concerning project progress, safety and quality concerns, and resource requirements. Developing a WWP involves identification of constraints, which may include potential problems that could be anticipated for the following week. Therefore, through weekly discussions and planning sessions, RM could be continuously updated on a weekly basis (deficiency 1.1, Table 36). Furthermore, the detailed analysis of upcoming week's processes may enable the identification and communication of both new and secondary risks, their prioritization and mitigation. Thus, it can be used as an algorithm clarifying the “how” of RM (deficiency 2.2, Table 36).

Another example is the A3 tool, commonly used in lean management for structured problem solving and continuous improvement. Its primary strength lies in its ability to cover both the background of an issue under review and the desired outcome in a single template, enhancing understanding of the situation being addressed. Within the RM, this tool may facilitate the conversion of tacit risk-related knowledge into explicit information at an organizational level (deficiency 2.3, Table 36) by delineating the logical connections that practitioners use for identifying and analyzing risks. The A3 tool makes these insights accessible and clear to all relevant stakeholders, thereby serving as an effective communication tool (deficiency 2.2, Table 36). Furthermore, as it covers the target state, the tool fosters the development of fit-for-purpose risk responses and supports the retention of this new knowledge within the organization.

4.2.2. Additional findings

Although the research identified nine deficiencies in the RM process (see Sections 2.1 and 2.2) most of these are consequences manifesting at the operational level and cannot be resolved there (see Section 2.3.2). Addressing the root causes is ideal, but lean tools can be utilized to mitigate the effects. While this approach may not be sustainable in the long term, it has the potential to improve outcomes.

The result of application of three criteria and contribution range for the rest four groups of deficiencies is shown in Table 37. Out of **13 tools**, 4 have only secondary contributions, 8 have only primary contributions and 1 tool contributes both primarily and secondarily. Additionally, the deficiency of **grasping project complexity** was found to be beyond the scope of lean tools.

Table 37 – Other Risk Deficiencies and Lean tools

	Deficiency	Explanation	Lean tools: primary (1) and secondary (2) contributions
1.1	difficulties with grasping complexity	need to deal with unknown unknowns	X
1.2		different risk assessment techniques perceive project complexity dimensions variably	X
2.1	stakeholders' influence on the process	need to deal with multiple interests, goals and preferences of people involved that cause variations the RM process	SMART goals (1), WWP (2), visualization (1), daily meetings (1), QFD (1)
2.2		need to grasp the influence of interconnections between stakeholders on RM process	const proc analysis (2), SWLA (2), WWP (2), visualization (1), daily meetings (1)
3.1	lack of data during FEP	need to deal with guesses and intuition in RM at FEP	SPC (2)
3.2		need to find a way to proceed in such an environment with limited data and time	const proc analysis (2), standardization (1)
4.1	overwhelming amount of various data at later stages	need to deal with data redundancy, inherent randomness in certain variables, challenges with data interoperability; and the presence of inaccurate, imprecise, incomplete, or unreliable data, along with approximations in the statistics used	5S (1), SWLA (1), daily meetings (1), standardization (1)
4.2		need to find the way of information exchange and maintaining an appropriate balance of information exchange among stakeholders	daily meetings (1), kanban (2), A3 (1)

The remaining deficiencies could potentially be addressed with SWLA, WWP, and daily meetings, just like the ones selected in this research. These tools are versatile and capable of managing a wide array of issues that require control and oversight. Breaking down the scope into smaller segments better identification and management of stakeholder relationships before they negatively impact the process. These tools also help eliminate unnecessary information production and storage by cutting it out of the scope. Similarly, CPA with PMs structures stakeholder relationships within the process, providing an objective basis for decision-making even when complete information is not yet available. However, even with the assistance of lean tools, there remains a need to clarify which information is unnecessary or address stakeholder interconnectedness, as simply identifying its influence will not resolve the issue.

Among the interesting ideas worth exploring is the 5S tool. The 5S methodology, which stands for Sort, Straighten, Shine, Standardize and Sustain, is traditionally a workplace organization tool used to maintain cleanliness and tidiness (Salem et al., 2005). However, in the context of RM, it can be adapted to create a structured database that the studied company needs. The process can be seen as follows:

- **Sort:** This involves analyzing the gathered risk-related information to determine what is needed and discard what is not.

- **Straighten:** This step focuses on creating an easy-to-use structure for storing the information, e.g., by utilizing tags like project type, stakeholders involved, method of construction, high-impact risks, high-probability risks, etc.
- **Shine:** This means ensuring that the workspace and data systems are in optimal condition by cleaning and inspecting them regularly. This may include reviewing and cleaning digital spaces, removing redundant or obsolete data, keeping documents organized in labeled files and folders, and even using color-coding or tagging systems for easy retrieval.
- **Standardize:** This involves maintaining the first 3S's by creating a consistent approach for tasks, procedures, or documents.
- **Sustain:** This step focuses on making the process habitual. Although challenging, it requires behavioral change and overcoming the tendency to revert to old habits.

If successfully implemented, this tool could help the company avoid challenges related to data redundancy, interoperability, or issues with inaccurate, imprecise, incomplete, or unreliable data. However, it remains essential to determine which data is necessary, and to explore the data further to find the best way to structure its storage.

4.3. Framework development

To address SQ4, this section begins with outlining RM inputs, such as the RM baseline, the scope of the framework's use, its target audience, and the necessary requirements. Once these are set, the matches in RM deficiencies and lean tools, identified in Section 4.2.1, are chosen, and integrated into the framework.

4.3.1. RM inputs

The RM baseline for the process, as defined in theory and supported in practice, constitutes a sequence of fundamental steps, including identification, assessment, mitigation, and control. Each step is supported by communication and documentation.

The framework is designed to support operational-level management. Therefore, the target audience includes operational managers such as risk managers, project managers, site managers, procurement managers, contract managers, and other relevant personnel identified based on the project skill set.

The requirements to the framework are derived from the needs and values of the interviewees mentioned in Section 3 and defined RM deficiencies:

- **Integration with existing processes:** the framework should seamlessly integrate into the existing system, offering flexibility and adaptability for different projects.
- **Data-driven decision making:** the framework should provide objective input to promote decisions grounded in objective knowledge.
- **Support collaboration and communication:** the framework should facilitate regular team meetings and the formation of cross-functional teams.
- **Contextual understanding:** the framework should ensure a deep understanding of the project context.
- **Proactive character:** the framework should promote a proactive approach to RM, identifying and addressing potential risks before they become issues.
- **Feedback and continuous improvement:** the framework should facilitate regular reviews, data gathering and refinement of the tools to ensure learning within the process and organization.

The framework covers RM during the tender, planning & development, and execution phases. In the tender phase, inputs include contract conditions, project requirements, phase schedule, resources needed, technical solutions, methods of construction, and sometimes preliminary design. Once the project is awarded and enters the planning and development phase, inputs are refined as the dates become defined and greater clarity is achieved with the progression of the design. The focus in both these stages is on identifying and resolving potential threats before the construction stage, given the higher influence over risks and their resolutions at the beginning of the project. Therefore, there is a need to understand the context, reduce the omissions and subjectivity, and ensure access to relevant expertise.

In the execution phase, inputs consist of design, detailed schedule, and work-in-progress updates. The focus shifts more towards damage control and ongoing RM. This phase requires maintaining the same needs as the tender phase with an added emphasis on increased review frequency.

The key issues to resolve with the framework are:

- The need to identify and establish an approach to select the review frequency
- The need to assess the effectiveness of this selection.
- The need to ensure access to people and their PJs in the RM process.
- The need to customize the internal RM guideline.
- The need to understand the context to make accurate PJs.
- The need to deal with frequent misjudgments and omissions in PJs.
- The influence of subjectivity and biases.

4.3.2. Lean integration into RM process

Based on the inputs, the Lean RM Framework was developed and is illustrated in Figure 4. The following section provides an explanation of its implementation and use. The detailed version of the framework is presented in Appendix D.

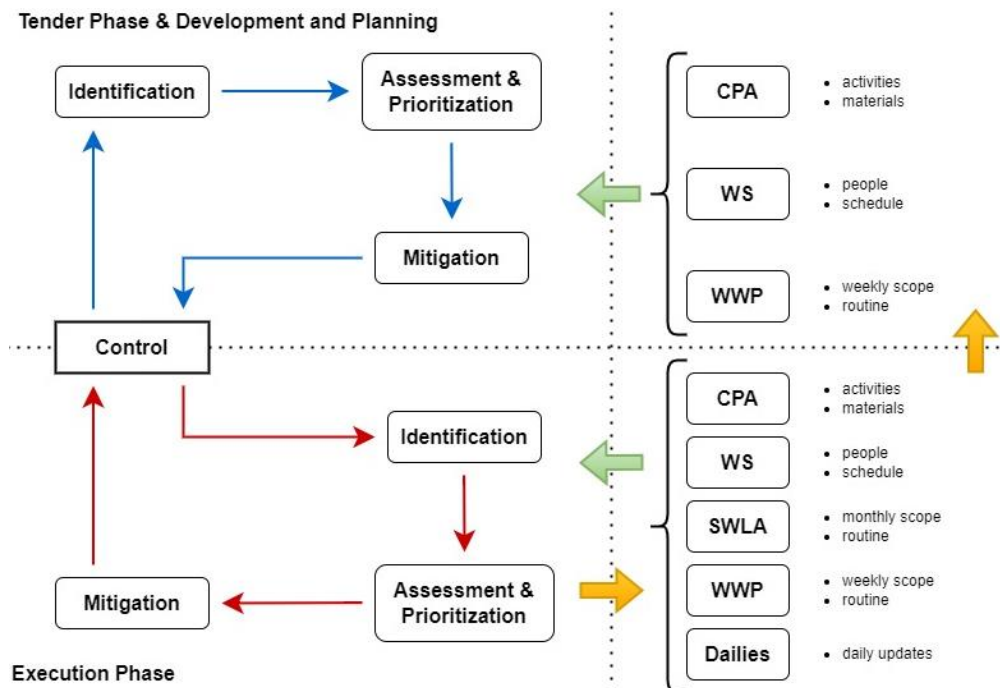


Figure 4 - Lean RM Framework

Used abbreviations: CPA – Construction Process analysis; WS – Work Structure; WWP – Weekly Work Planning; SWLA – Six-Week Look Ahead; Dailies – Daily Huddle meetings.

4.3.2.1. Preparation

To enhance understanding of the context, the choice of lean tools focused on Construction process analysis (CPA) and Work Structuring (WS).

It is important to ensure that PMs and WSs are stored in a centralized location for easy access. Once the system of PMs and WSs is developed, they can be applied in the RM process.

Both WS and PMs serve to provide a comprehensive understanding of the project context, which was defined to be essential for RM. By detailing the sequence of activities, necessary resources, inputs and outputs from different teams, quality control points, required expertise, expected durations with buffers and potential risks, both tools contribute to more objective decision-making and ensure that assumptions are grounded in the realities of the project.

4.3.2.1. A Process maps

CPA involves creation of detailed maps of construction processes from initiation through design, execution, and completion (see Figure 5). These charts use standardized symbols to clearly describe the flow. Each recorded step within the process map (PM) can include flows between units, sections, departments or within departments. They can also detail the steps that workers, materials or parts go through.

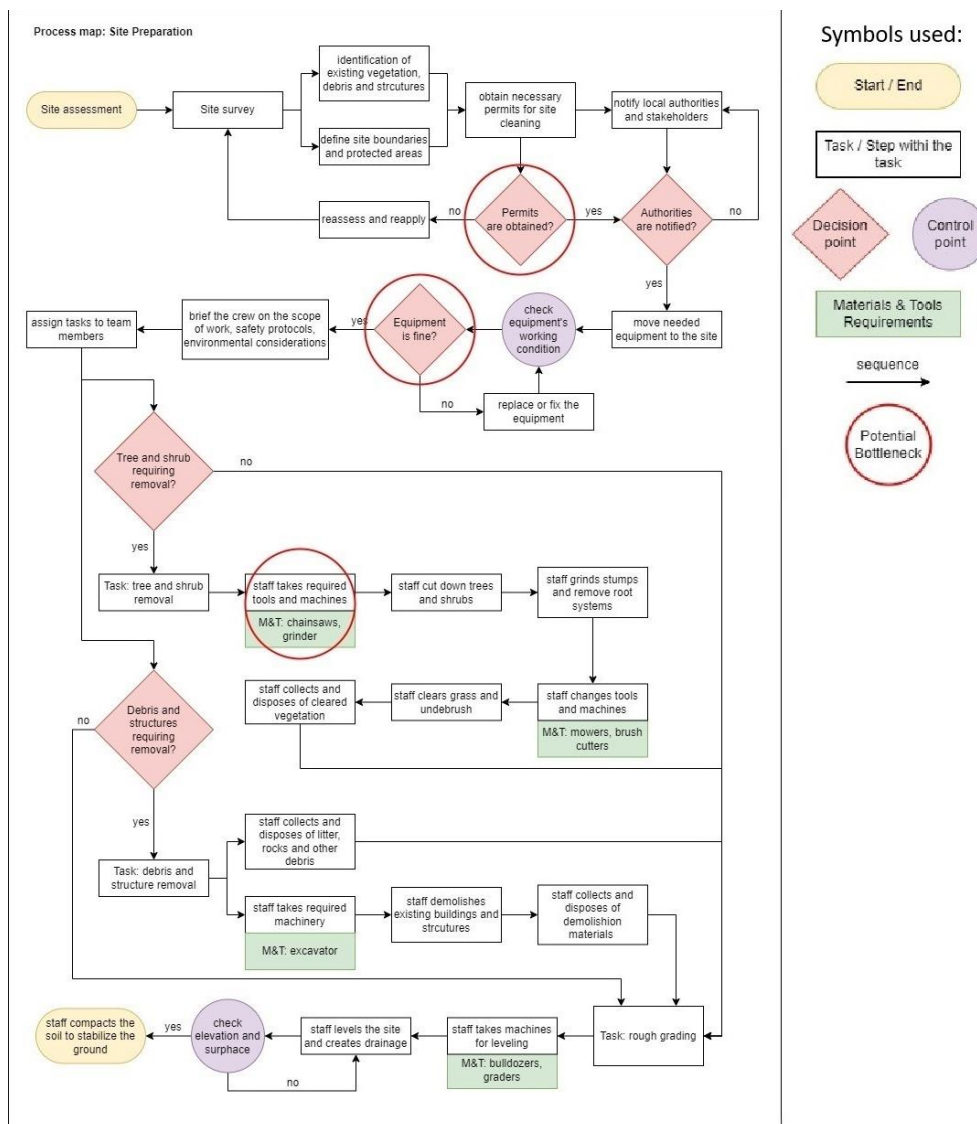


Figure 5 - Process Map Example: Site Preparation

PMs can be adapted to any process at any level of detail, outlining internal tasks, steps, decision points, permits needed, resource requirements, movements, and documentation production. Given the foundational nature of construction processes and their sequences (e.g. windows cannot be installed without a wall, a beam cannot be placed without piles, or a wall cannot be built without a foundation), PMs can be created for each type of activity involved in the project for any specific project type (e.g. PM for site preparation, tunnel element submerging, wall panel placement, etc.).

The starting point of a PM can also include the prerequisites needed before the process starts (e.g., before starting the process of window installation, the wall placement process must be completed), connecting all needed PMs into the overall construction PM.

With these PMs, any lack of knowledge and understanding of specific activities can be compensated for and clarified through visual representation. Analyzing such PMs highlights all key activities and interdependencies, leading to the identification of potential bottlenecks of various natures, which are important for RM. Therefore, CPA enables early detection of risks by highlighting potential issues in the construction process before they become problems. This adds a proactive element in the tender phase, allowing for the preparation of accurate bids. Additionally, it stimulates a detailed understanding of the construction process and context, fostering informed choices about risk mitigation strategies and ensuring that all potential and relevant risks are considered.

4.3.2.1. B Work Structures

As for WS, in lean management, WS is a process design tool which breaks down a project into manageable tasks and assigns them to specific teams and members. Unlike a traditional work breakdown structure, WS includes information about the specialists assigned to each task, work package sequences and decoupling buffers (Ballard, 1999) (see Figure 6). This detailed information clarifies the allocation of responsibilities and ensures coverage of all project aspects, reducing the likelihood of oversights.

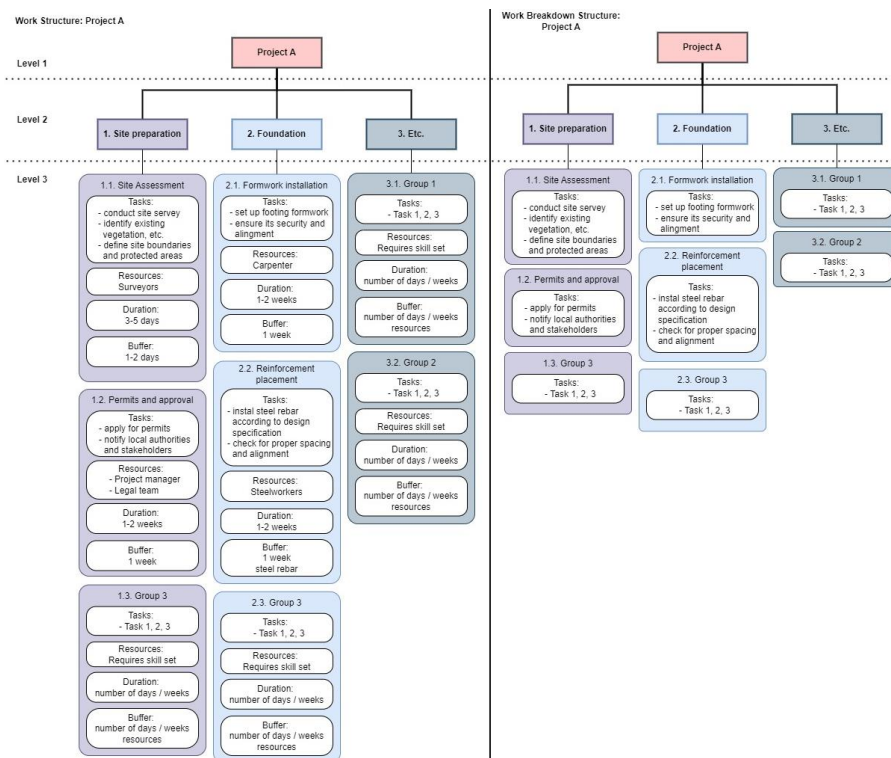


Figure 6 - Work Structure (left) and WBS (right) Example: Project A

The key difference: WBS outlines only tasks, while WS includes tasks, resources, duration, and buffers.

WS optimizes resources by aligning tasks with team members' skills and availability, ensuring efficient resource utilization. Additionally, WS incorporates scheduling for various project parts, allowing for early and precise identification of potential delays. This helps in analyzing the impact of potential risks on project milestones and overall completion dates, leading to more informed decision-making.

With WSs, it becomes easier to grasp the project context, conduct scenario planning and assess how different risks can impact various parts of the project. The clear division of roles and responsibilities ensures that any changes in the project context can be promptly communicated and addressed.

4.3.2.2. Tender phase

In the tender phase, where nothing is built or sometimes even designed yet, the main goal of RM is to identify, assess and mitigate relevant potential problems in advance. Therefore, understanding the context becomes crucial, as highlighted in Chapter 3.

Figure 7 demonstrates how the RM process with the new framework is going in the tender phase. Based on the initial document set, the project team can utilize the necessary PMs and WSs at each step of the RM process. Both tools help in understanding the project's overall scope and objectives, main tasks, and deliverables, identifying key phases and milestones.

Using the information in WSs, the *required skill set* can be identified and assigned to risk meetings. Both tools facilitate brainstorming potentially relevant risks and *bottlenecks*, providing a visual representation that is easily communicated to everyone involved. For the assessment, PMs and WSs highlight where potential risks may have the most significant impact, based on the *schedule* and *key activities* outlined. Additionally, PMs simplify the integration of selected mitigation measures into the overall project workflow. Moreover, additional PMs and WSs can be created for implementing mitigation measures, ensuring the tracking of implementation progress, identification of any potential deviations that may affect the project, and clarity on the assigned responsibility for implementation.

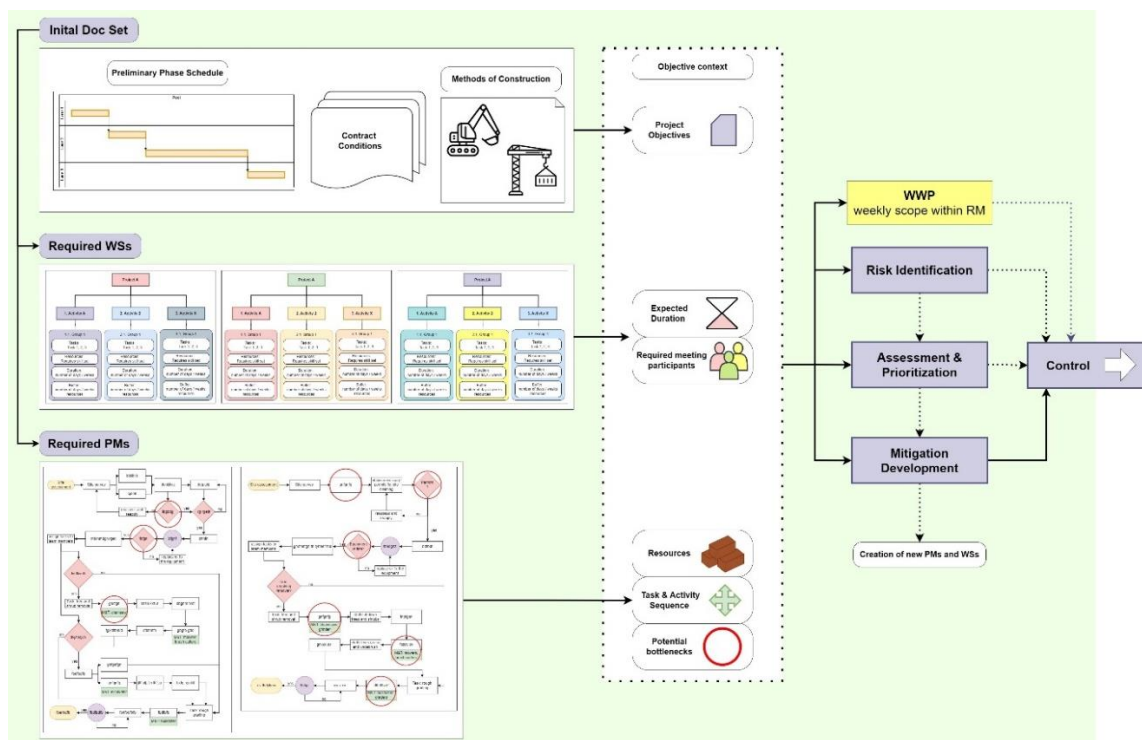


Figure 7 - Lean RM framework in use: tender phase.

WSs and PMs provide an objective foundation for decision-making, reducing the likelihood of guesses, assumptions, and professional biases. Clear information flows depicted in PMs help limit the influence of subjectivity and biases. Additionally, detailed WSs and PMs minimize the chance of omissions. Newly generated and updated PMs and WSs serve as visual reports, effectively communicating information to everyone involved.

4.3.2.2. A Use of Weekly Work Plans

Since nothing is built yet, regular updates can be ensured through Weekly Work Plans (WWPs). As was explained before, WWPs are short-term, detailed plans used to ensure that specific tasks and activities are planned and executed over a one-week period. They focus on immediate tasks, aligning them with overall project goals and plans. Using these tools establishes a routine where the project team has weekly meetings and updates on urgent needs, thereby improving communication and progress tracking.

The WWP in this context differs from its usual application in the execution phase. Instead of focusing on week-to-week and day-to-day construction activities, the WWP during the tender phase is adapted to meet the strict deadline for the bid application and specific duration for the preparation, typically around 2 months or 8 weeks. During this period, the WWP guides the development of the bid, ensuring a structured approach to the formulation of a price, selection of construction methods, plans for logistics, safety and RM. Each week within this period is planned to ensure that all aspects of the bid are developed, refined, and aligned with the client’s requirements, leading to a competitive and compelling proposal.

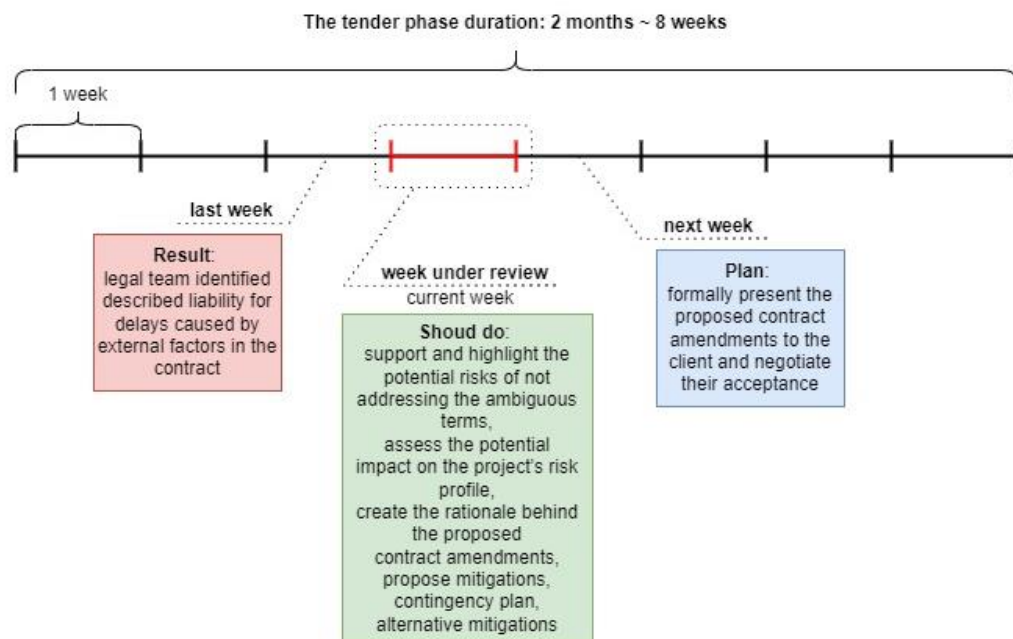


Figure 8 - WWP for the tender phase: Task example.

The broader tasks and objectives for the entire tender process are not disregarded or excluded. The key approach is to break down these larger plans into smaller, more manageable segments that are limited to a one-week timeframe. By doing so, the project team can maintain a clear sense of progress, making it easier to manage resources, monitor progress, and adjust to any unforeseen challenges.

The main input of WWP into the RM is ensuring access to relevant expertise and the consistent flow of information through weekly updates. This allows RM to become more inclusive and responsive to the dynamic needs of the project, keeping all parties informed about progress, emerging risks, and any necessary adjustments. WWP supports communication, allowing timely interventions and ensures that decision-making is based on the most current and accurate information. Besides enhancing clarity and accountability within the team, it strengthens the overall capacity to manage risks by leveraging the collective expertise.

4.3.2.3. Planning & Development Phase

After the project is awarded and before construction begins, it transitions into the planning and development phase. This phase brings increased clarity regarding timelines, design specifics and resource allocation, allowing the project team to address and refine the assumptions made during the tender phase. Therefore, this process requires RM support as the primary objective is to achieve an even deeper understanding of the project context, to anticipate and mitigate potential issues beforehand.

As during the tender phase, the lean RM framework continues to facilitate structured risk identification, enabling the team to maintain control over the project as it evolves and ensuring that every emerging detail is considered, and that risks are systematically assessed and addressed. Consequently, the project moves into the execution phase with a solid foundation, ensuring smoother execution and reducing the likelihood of costly surprises.

The set of PMs and WSs, as well as the documents themselves, are not static; they are dynamic tools that must evolve as latest information, and changing circumstances arise within the project. These tools and sets may require updates to reflect the latest understanding of the project's needs and challenges. This adaptability helps keep the planning and execution approaches accurate and relevant, allowing them to accommodate shifts in project scope, requirements, or external factors. By continually updating these tools and tool sets in response to the latest information, the project can stay aligned with the current realities, ensuring that all processes are properly mapped, and risks are effectively managed.

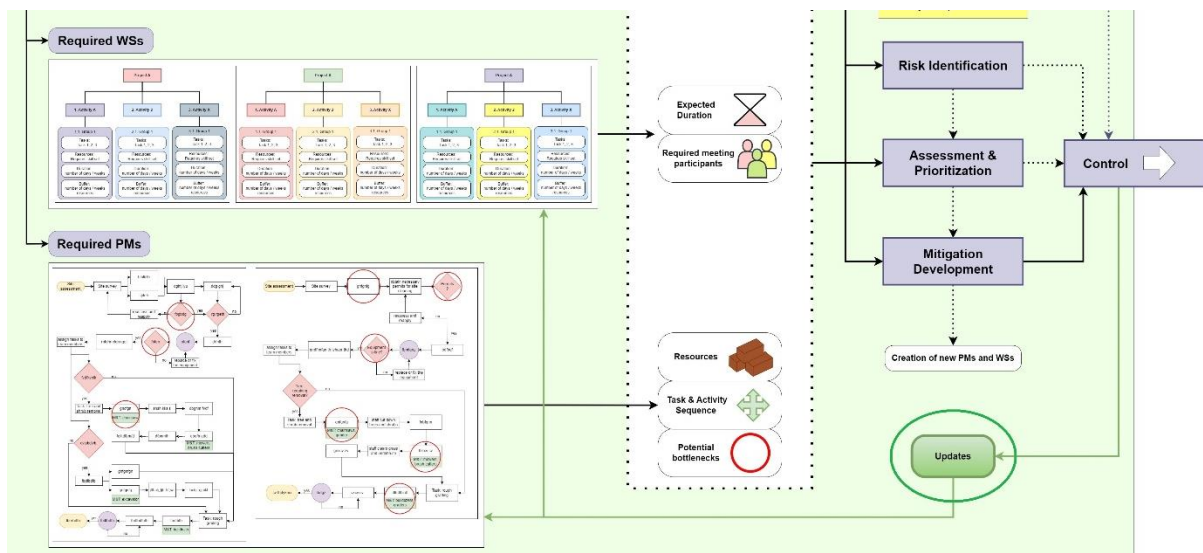


Figure 9 - Lean RM framework in use: integrated feedback loop in the tender and planning & development phase.

4.3.2.4. Construction phase

After the project is awarded, the focus of RM shifts toward damage control. As the project progresses, more information becomes available, allowing for a more detailed exploration of the context. It is crucial to keep team members updated on the project's context, and both PMs and Ws continue to be used for this purpose. Additionally, it is important to proactively explore the context since the ability to influence potential risks diminishes during the construction phase. Therefore, SWLA and daily huddle meetings are incorporated into the process for better scope control. Figure 8 shows how the way of proposed framework changes in the construction phase.

4.3.2.4. A Use of Six-Week Look Ahead

SWLA (Six-Week Look-Ahead) is a key component of the Last Planner System (LPS) used in lean management for planning, elaborating, and scheduling work over a six-week period. This tool helps project managers and teams anticipate and prepare for upcoming tasks, ensuring that all necessary resources are allocated, and potential constraints are identified and addressed.

SWLA establishes a fixed six-week timeframe, limiting the scope and allowing the project team to focus on a smaller, more manageable environment rather than an entire phase or work package with multiple activities. This focused approach enhances coordination among stakeholders, optimizes the use of labor, equipment, and materials, and ensures earlier risk identification and prioritization, providing space for proactive mitigation.

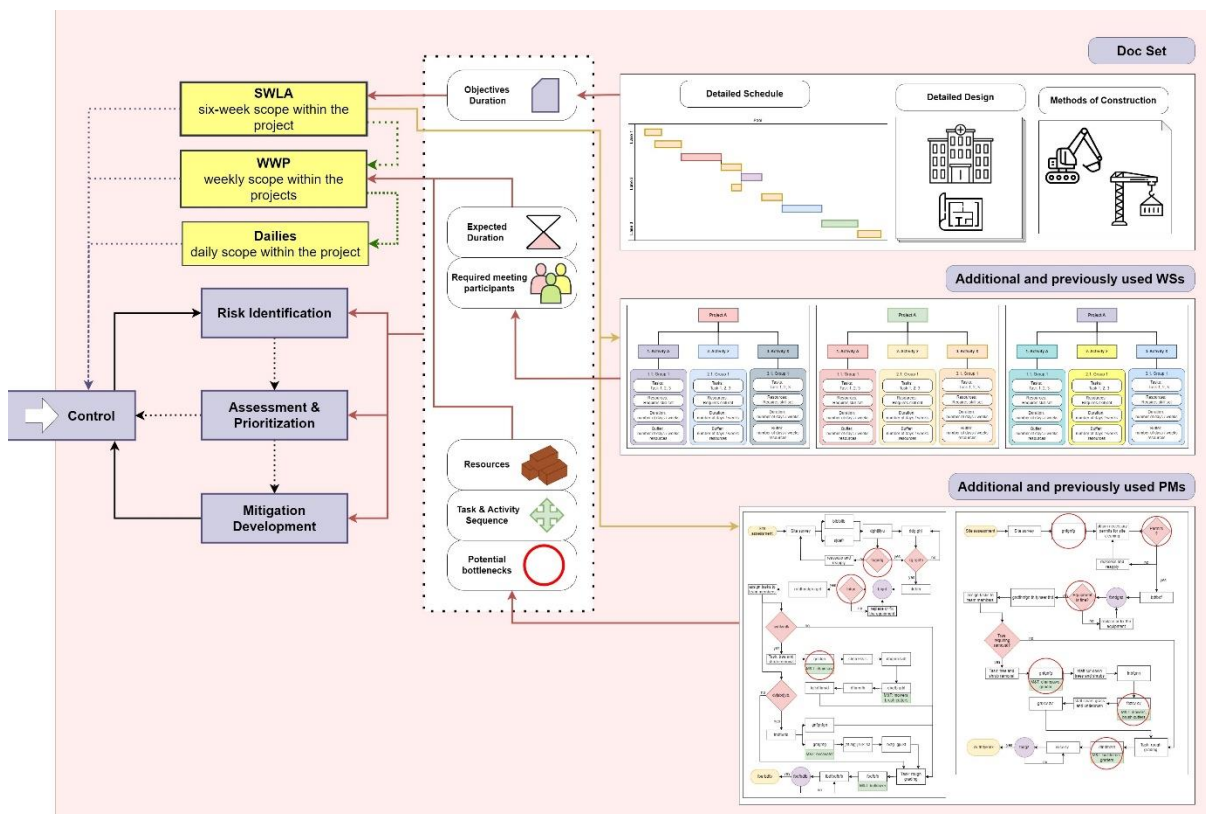


Figure 10 - Lean RM framework in use: construction phase.

4.3.2.4. B Use of Daily meetings

Within SWLA, WwPs detail the six-week planning to address urgent weekly needs. However, due to the dynamic and complex nature of construction projects, daily meetings should also be introduced. Dailies, or daily huddle meetings, are short, focused gatherings held at the same time and place each day, usually lasting 15 minutes or less. These meetings ensure effective communication,

coordination, and problem-solving within the team. They typically cover three main topics: what was done yesterday, what will be done today, and any obstacles in the way. These meetings ensure that everyone is aligned, aware of each other's progress, and able to quickly identify and address any issues or bottlenecks.

While daily checkups and progress control, as practiced in lean methodologies, are effective for maintaining a steady workflow, identifying potential issues on such a short timeframe (e.g. discovering a problem based on what happened yesterday) often leads to a situation where the risk is simply accepted, which is far from ideal. The real value lies in planning daily activities within the context of a weekly plan. By breaking down the weekly objectives into detailed day-to-day tasks in advance, there is an opportunity to identify and address potential issues before they become immediate problems. This approach enables the team to notice trivial details early on, providing the space to make necessary adjustments, minimizing disruptions to the overall schedule.

The use of SWLA, WWP and Dailies sets a regular frequency for RM updates, encouraging issue-oriented thinking and proactive mitigation within the project's controllable scope. This limited scope, combined with the aid of PMs and WSs, allows for a deeper exploration and understanding of the project context.

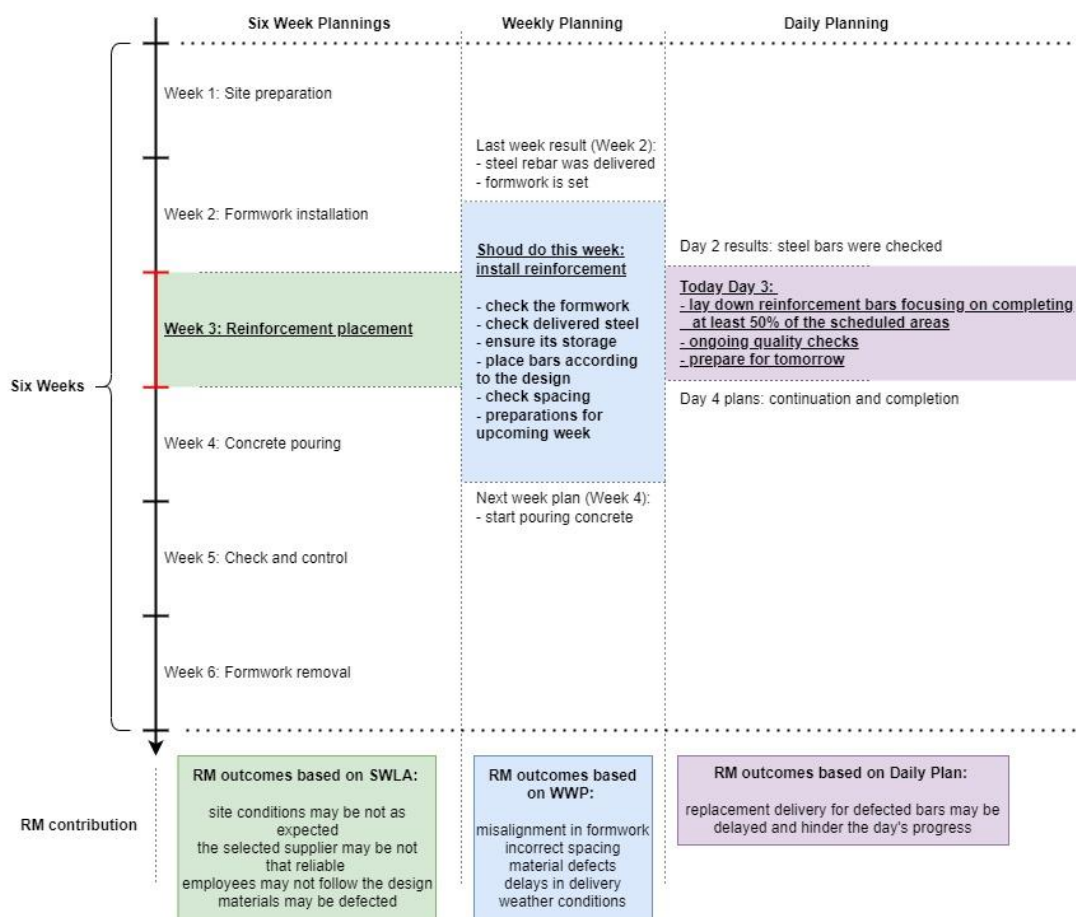


Figure 11 - The use of SWLA, WWP and Dailies for RM in the construction phase.

Furthermore, as the project progresses, WSs and PMs can be updated to reflect reality, creating a *feedback loop* that aids in the tender phase of future projects by providing a clarified, objective basis for decision-making (see Figure 12). Lean tools like Gemba/Muda Walks can be used

for these updates. Additionally, the constant communication established through SWLA, WWP, and Dailies ensures that knowledge and understanding are regularly externalized, allowing for their collection and preservation within the organizational memory or integration into PMs and WSs.

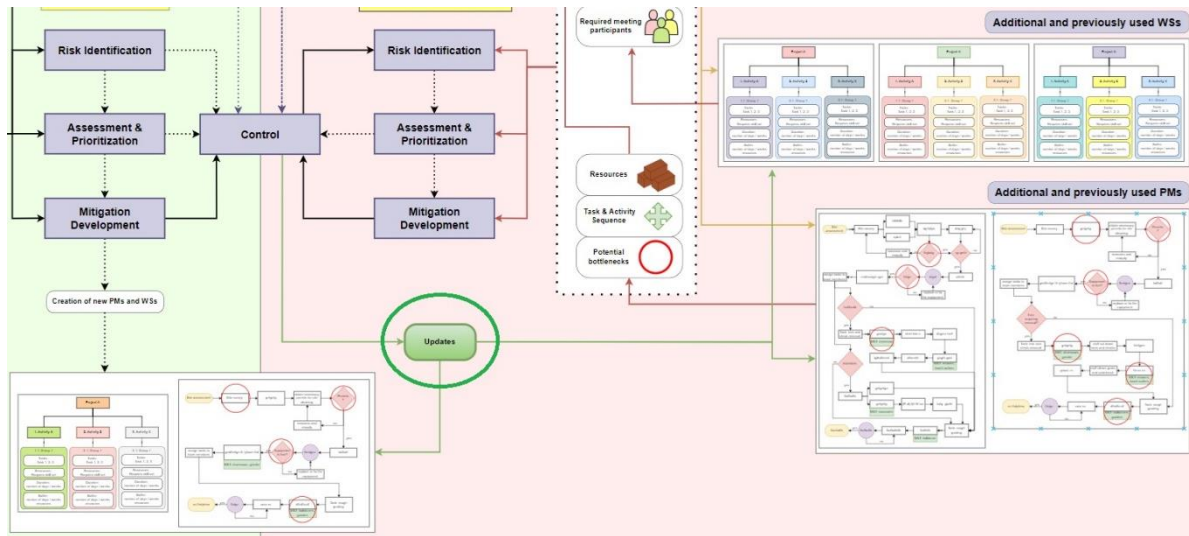


Figure 12 - Lean RM framework in use: integrated feedback loop in construction phase.

4.3.2.5 Contribution summary

Here the contributions of selected tools to the RM are summarized. The results present in Table 38.

Table 38 - Lean tools contributions

Lean tool used	The preference addressed	The need addressed	How it is addressed
Construction Process Analysis & Process Maps	Data-driven decision making;	Understanding of the context to make accurate PJs;	By providing a structure that outlines activities, resources, and timelines, they offer a clear view of the project context, which aids in making accurate judgments and informed, data-backed decisions; they incorporate mechanisms for regular feedback and updates, ensuring continuous improvement and more accurate judgments over time
Work Structures	Contextual understanding;	Reduce frequent misjudgments and omissions in PJs, subjectivity, and biases	
Six Week Look Ahead	Support collaboration and communication;	Establish an approach to select the review frequency;	By creating regular touchpoints for team interaction, allowing for timely updates and adjustments, promoting review cycles, and ensuring that all relevant
Weekly Work Planning	Feedback and continuous improvement		
"Dailies"			

		Ensure the access people and their PJs in RM process	stakeholders could contribute their insights and decisions in the RM process.
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4.4. Verification and Validation

To confirm that the framework addresses the intended objectives, delivers intended results and is suitable for the specific context of application, an expert review of the developed framework and interviews are conducted. This step includes the identification of additional potential benefits and limitations.

4.4.1. Preparation & Data collection

As mentioned in Section 1.3.4, the interviewed team consists of lean expert, RM and lean expert from the studied company and RM expert from a different company.

Table 39 - Interviewee's information

Interviewee	Position	Years of experience
1	Lean expert	12
2	Senior risk manager (studied company)	18
3	Contract & risk manager (different company)	14

The evaluation protocol is needed for guiding the discussion with the experts and is presented in Appendix E.

Since the framework involves a shift in organizational culture and routine, it is not feasible to conduct a field application review during the research phase to assess its utility. The changes required mean that practical implementation and evaluation will need to occur in a controlled setting post-research, allowing for adjustments based on real-world feedback and experiences.

4.4.2. Expert review results

The interviewee unanimously agreed that the proposed framework contributes to the RM process by providing objective inputs, facilitating regular team meetings and the formation of cross-functional teams, fostering a deep understanding of the project context, and enabling more accurate PJs. It promotes a proactive approach to RM, supports regular reviews, data gathering and refinement, and ensures continuous learning throughout the process. Additionally, it provides access to key personnel and their insights, helps in dealing with subjectivity and biases, is user-friendly and comprehensive enough for practical application and has proven to enhance the effectiveness of the RM process.

4.4.2.1. Review frequency

As for the review frequency, the requirement was not fully satisfied due to differing perspectives on the appropriateness of the proposed solution (see Table 40). According to Interviewee 2, having daily reviews can be excessive, pointing out that a weekly basis is more suitable for construction where certain activities are not that changing. On the other hand, Interviewee 3 pointed that daily would be much appreciated as these helps to create *“more or less a continuous cycle, [...], so while you are working in that cycle, it's just **feels like way of working**, [...] it becomes more fluent, becomes more natural to incorporate it in your daily activities”* (Interviewee 3). According to the

opinion of Interviewee 1, weekly reviews and updates are the basic approach allowing to catch up with the project progress, but daily updates will not make it worse.

The difference in these views indicates that the framework's review frequency requirement may not be fully meeting the needs of all stakeholders. While daily reviews foster continuous engagement and responsiveness, they may not be practical or necessary for all construction activities, particularly in areas where progress is slower and less dynamic.

The idea that running the framework multiple times would lead to an understanding of the optimal frequency, based on which the number of reviews could be adjusted, was not convincing to the interviewees. This indicates that further research is needed to determine what constitutes a clear understanding of this specific parameter.

Table 40 – Evidence related to the review frequency.

Citation	Meaning
<p>“I would focus more, I think on a weekly basis than on the daily basis, [...], I think weekly would make it less complex, [...], construction progress is going not that fast to have it daily, [...] so it's more on construction” – Interviewee 2</p> <p>“It, you know, real time, actually, when you say the real time, it's not exactly in a minute or second base of kind of update, at least weekly basis. So, for our construction project, you know, that's absolutely fine. [...] weekly update, weekly fixing, it's a real time for us, you know, rather than fixing minutes or seconds or days, fixing weekly we can catch up. Still, it [daily checks] won't bother.” – Interviewee 1</p> <p>“Today, we may say one thing, but tomorrow that priority will change. So maybe the daily huddles be allowed to keep it up much more important, saying that, OK, what we really having these things you know, will be able to do it” – Interviewee 1</p>	<p>The view on sufficiency in review frequency differs among the interview participants.</p>

4.4.2.2. Scope breaking down

Interviewee 3 has concerns regarding the Six-Week Look Ahead (SWLA), noting that some potential issues could be beyond the six-week scope (see Table 41). Interviewee 2 supports this sentiment by pointing at the strong reliance on traditional planning for the entire project and a mindset focused on being fully prepared for all possible outcomes before taking any action. However, according to a lean expert, the six-week timeframe is effective in lean construction projects, as it allows for the identification and mitigation of most potential issues.

It is important to recognize that SWLA is typically used in lean construction as part of the Last Planner System (LPS), which complements, rather than replaces, a higher-level master schedule that outlines the basic planning for the entire project. In the framework being discussed, the SWLA is also designed to work alongside the existing general planning. This suggests that the SWLA should consider potential issues from the broader plan, especially when their identification and mitigation require a

planning horizon longer than six weeks. Furthermore, the lean tools used in the framework help break down the larger scope, enabling teams to focus on its parts and ensure that no mitigations are missed, and all details are considered.

Table 41 - Evidence related to the scope breakdown.

Citation	Meaning
<p>“I think the why not is fairly clear on the six week benchmark, there are definitely a risk which are further down the road and six week is just too small of the time frame” – Interviewee 3</p> <p>“before we start activities, we try to think it all over, we try to have mitigation in place just in case something goes wrong, that we already have equipment in place and whatever” – Interviewee 2</p> <p>“you are following the six week look ahead window [...] surprises can be addressed during that window, [...] they won't have too much of surprises. Too many surprises, but they will get hit the ground. They will be able to achieve the targets. [...] Yes, there are minor surprises that will be addressed during the daily huddles, but that can be taken care by my engineers, so I can worry about other things actually” – Interviewee 1</p>	<p>The set scope limitations have its advantages, disadvantages, and preferences from the viewpoint of experts.</p>

4.4.2.3. Guideline customization

According to Interviewee 3, over time, the framework could help build a robust database that captures knowledge and experiences from projects (see Table 42). This information enables a company and its teams to analyze what approaches, strategies and solutions have proven most effective in various situations, and better understand what practices are most suitable for future projects. As a result, this knowledge can be leveraged to tailor internal guidelines specifically to the needs of different units or upcoming projects.

However, Interviewee 2 highlights a significant challenge with this approach, indicating that there is a key gap between the ideal use of the framework and actual practice. In reality, the potential of the framework in customizing internal guidelines depends heavily on the consistent and thorough input of data into the system. Without it, the database of best practices remains incomplete, and the framework may fall short of its intended impact.

Table 42 - Evidence related to the guideline customization potential.

Citation	Meaning
<p>“you have, uh, like a best list of best practices. your database or your quality management system would eventually fill up with all the specifics you ever did, and you pick the one which is which most closely aligns to new project” – Interviewee 3</p> <p>“most people don't register that information, so that's the weak point in all those models. [...] The assumption</p>	<p>While the use of a framework helps with the creation of a database, which can be used to update the internal guidelines, it heavily relies on consistent data input.</p>

is that people always put in the information in the systems, [...], And in lots of times, people are really busy fixing things " – Interviewee 2	
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4.4.2.4. Feasibility

Given that the framework was developed using data from a large company, interviewees agreed that its implementation would be feasible for large organizations (see Table 43). Interviewee 3 noted that smaller companies might find it too demanding or resource-intensive to implement. This highlights that the scale of the framework aligns well with the capacities and needs of larger organizations.

However, despite its potential fit for large companies, integrating the framework into an existing system could be demanding, as the environment within a large company involves numerous constraints and factors. Interviewee 1 emphasized the importance of effective change management and a thoughtful approach to implementation. This suggests that, while the framework may be well-suited, it must be carefully adapted and tested within the specific context of each company to account for the various existing processes, limitations and dynamics that could impact its effectiveness.

Table 43 - Evidence related to the framework's feasibility.

Citation	Meaning
<p>"I think that's not for very small companies. I believe this is way too much work that they're never going to do it. [...] I think when you go to the to the bigger construction or the biggest construction companies. It the way you described, especially the, let's see, it reminded me of the way Siemens Germany works, [...] I think for a company that big it's definitely feasible." – Interviewee 3</p> <p>"There are too many change management. My concern is that unless we take this one this take this particular framework and go to the project site and we'll actually try to do some kind of file it implementation only then we can clearly say that yes, there are certain things." – Interviewee 1</p>	<p>The feasibility of the framework is questionable until it is tested in the real world.</p>

4.4.2.5. Barriers and risks for implementation

All interviewees identified organizational cultural and procedural barriers within organizations as the main challenges for implementing the framework, citing issues already present within the studied company (see Table 44).

Reluctance to learn and adopt novel approaches.

The employees with established habits may resist adopting the new framework, seeing it as a disruption to their routine. Furthermore, there's also resistance to learning new systems or methodologies, indicating that employees may prefer to stick with familiar approaches, even if the new ones offer improvements.

Need to document and maintain processes.

Another challenge is the hesitation to document and maintain processes. The success of the framework is heavily dependent on diligent data entry, which can often be overlooked in favor of more immediate tasks. Whether due to a tendency to avoid extra administrative work or an imbalanced workload, as observed in the studied company, without precise and timely data input, the framework may fail to deliver its intended benefits.

Lack of emphasis on RM in organizations

There is also a concern that many organizations do not place enough emphasis on risk management. Without proper prioritization and empowerment within the company, risk management initiatives may lack the necessary support and attention, leading to ineffective implementation.

Need for alignment with existing systems.

Additionally, the interviewee highlighted the need for the framework to align with existing higher-level systems and organizational processes. For the framework to be effective, it must be compatible with the existing reporting and control systems already in place within the organization.

Table 44 - Evidence related to the barriers and risks of implementation.

Citation	Meaning
<p>“some people are really struggling to, you know, they're in the actually, you know, change in mindset, a kind of a phase because most of these managers are 10 to 15 years of experience and they have the reluctance to learn something new.” – Interviewee 1</p>	<p>Evidence outlining the barriers and risks for the framework implementation.</p>
<p>“They're very stubborn [...] and once you get used to one of those systems, then it's very difficult to get to know another system and try to get it work differently.” – Interviewee 1</p>	
<p>“Yeah, it has to do with people and registering things and applying things and keeping it up to date. I think that would be the obstacle and people always think our processes and takes a lot of work and people don't really like paper and all that's the thing.” – Interviewee 2</p>	
<p>“But the person who's responsible for the process doesn't have, like, the power within the company to get all the inputs and make sure that risk management is being here and that is one of the biggest challenge. I don't think that's necessarily a problem of the framework. It's more of the mindset on how companies look at risk management” – Interviewee 3</p>	
<p>“they may be updating the weekly update or fortnightly or monthly update to their, you know regional level or head office project control [...] if you give them this particular framework, they will say, OK, so this is not something aligned to the expectation from our head office” – Interviewee 1</p>	

4.4.2.6. Additional benefits

Clarifying interfaces and dependencies

The framework helps map out all activities, interfaces, inputs, and outputs required for a project, creating a clear view of dependencies and responsibilities. This transparency ensures that everyone involved understands the flow of process, information, and resources.

Encouraging structured thinking and planning

The framework helps teams to structure their thinking enabling them to consistently plan ahead and remain focused on their objectives. By considering all necessary aspects of their tasks, the likelihood of overlooking critical elements can be reduced.

Reducing micromanagement and enhancing job satisfaction

One of the key advantages of the framework is its ability to reduce the need for micromanagement. By setting clear expectations and providing all necessary information upfront, the framework enables team members to work more independently and effectively. Another benefit is enhanced job satisfaction. When there is a lack of clear communication or timely access to necessary information, employees may feel unproductive and frustrated. However, with the framework in place, when all required information and resources are gathered upfront, team members can immediately focus on their tasks.

Making implicit knowledge explicit

As intended, the framework helps to make implicit knowledge and processes explicit, ensuring consistent practices across different teams and phases of a project. This formalization of knowledge supports better decision-making and allows for more effective training and onboarding of new team members.

Improving phase transitions

Finally, the framework addresses a common challenge in project management: the transition between phases, such as from the tender phase to the planning and development, and then to the construction phase. By making information in PMs and WSs accessible across different phases, essential knowledge is available from the outset, enabling more accurate risk planning throughout the project.

Table 45 - Evidence related to the benefits of the framework.

Citation	Meaning
<p>“all the interface, all the activities with the interfaces and the conditions. you can also see the links and the interfaces and who needs uh, what input and output.” – Interviewee 2</p>	Evidence outlining the benefits of the framework implementation.
<p>“it might really help them to get on track and to think of things that they might otherwise forget. So it helps you in structuring things and over thinking and thinking ahead. So that's nice. [...] people working are always thinking that way and always try to stay on track.” – Interviewee 2</p>	
<p>“instead of micromanaging, we give them a kind of a freedom for them to execute. [...] once they know the crystal clear things about the work, what they're expected to do [...] they will do much more wonders than</p>	

what we expect in terms of the productivity achievements.”– Interviewee 1

“If I wait for the information, some kind of a support from my supervisors or others, **I feel like I'm getting wasted and I'm not satisfied in that the day**. So, **when everything is gathered, I start doing the work** rather than waiting for information and other things” – Interviewee 1

“I think it helps to make implicit ways of thinking to make it explicit. So I think we already do all those things, but more in an implicit way, by thinking ahead and all, and this would help you to make it more explicit and **not to rely on uh expertise and knowledge from people in the project**, but also to **have some additional information** to help to think on the right things” – Interviewee 2

“it would definitely help because the thing is when you change a project from the tender phase to the construction phase, this whole different team will mostly at different team, uh involved people who are eventually going to build it are not included in the tender phase. So certain risk are only becoming present when you're getting into the construction phase” – Interviewee 3

4.4.2.7. Points for improvement

Focus on people over technicalities.

While the framework emphasizes the technical side of construction projects with resources and activities, Interviewee 3 believes that effective RM is more about the people involved and their skills rather than just the technical details. Although the framework is designed to complement and support the skills and expertise of people by providing objective data and a structured process to aid in better decision-making, there is an opportunity for further research to explore how it can better recognize and incorporate the human element of RM.

Learning within the current project

Interviewee 1 emphasizes the importance of learning from surprises and integrating those lessons back into the ongoing project, not just saving them for future projects. The framework primarily focuses on context understanding and feedback collection, which provides limited support for the immediate integration of lessons learned. In terms of RM, some lessons are only learned after unexpected issues occur, meaning that the only option within the ongoing project is to accept these outcomes. This points to a potential research opportunity to explore how insights can be promptly applied within projects for a better RM.

Addressing repetitive root causes

Another key area for improvement is the focus on identifying and addressing repetitive root causes of issues. Rather than simply documenting problems as they occur, the framework should

incorporate analytical tools to prevent these issues from happening again, fostering more sustainable improvements, and enhancing RM practices over time. Although RM guidelines do suggest using analytical tools like the fishbone diagram or Bow-Tie Analysis, the implementation of these tools ultimately depends on the organization, as discussed in section 2.1. Therefore, the challenge may lie more in the organizational domain than in the framework itself.

Citation	Meaning
<p>“it's about like the people who do it and their skill set and not necessarily about the machines or materials they're using. So I think that's a it's a very clear distinctive difference between how risk management works as I know it and how your framework puts it” – <i>Interviewee 3</i></p> <p>“it's also quite important learning and what are we learning from that project to implement within the project, not for the future project. people will always say yes. I'm keep documenting this for now. Future project, but that will never know, you know, happen. Yes, we'll document it, but we'll never study that these document for future projects, yeah.” – <i>Interviewee 1</i></p> <p>“we need to keep updating keep it dynamic because these root causes. [...] We'll try to fix it and over the period also if the same root cause is keep coming up again and again. So we'll have to go and address it despite need of some kind of resources.”– <i>Interviewee 1</i></p>	<p>Evidence outlining options for further improvements.</p>

4.4.3. Changes and Adjustments

Based on the feedback from the expert team, no adjustments or changes have been implemented at this stage. Most of the recommendations provided involve complex issues that require further in-depth research and practical application of the proposed framework. These areas go beyond the scope of this research. Therefore, while expert insights are valuable, they represent a starting point for continued exploration rather than immediate changes.

4.5. Conclusion

In this chapter, lean tools were studied. Out of 58 tools identified as being used in construction, 14 were found to have the potential to address know-how challenges in the RM process. Five of these tools were integrated into the existing RM approach, with potential benefits and disadvantages notes.

Validation revealed that the selection of Process Maps and Work Structures could enhance understanding of the project context, leading to more accurate professional judgments by providing objective inputs and mitigating subjectivity and biases. The implementation of core elements from the Last Planner System, such as the Six-Week Look Ahead, Weekly Work Plans, and Daily Meetings, helps facilitate regular team meetings, foster the formation of cross-functional teams, provide access to key personnel and their insights, support ongoing reviews and encourage continuous data gathering and refinement. However, there were differing opinions on the suitability of the proposed review frequency and the approach to breaking down the project scope.

5. Discussion

This chapter focuses on discussing the research results. The aim is to interpret research findings and place them within a broader context, identify limitations and their effects on the research outcomes, compare the results to previous studies and highlight novel contributions.

This chapter is structured as follows: it begins with a discussion of the findings related to the RM, followed by a discussion of the lean and its potential within the realm of construction RM. The chapter concludes with research limitations.

5.1. Traditional risk management in literature and practice

Despite the extensive history of RM in the literature, it was surprising to find that there is little guidance on its execution and customization. Records of simplified risk analysis date back to around 3200 B.C. (Covello & Mumpower, 1985), indicating that humans have dealt with the issue of risk throughout history. RM science has evolved significantly over the years, particularly with the development of probability theory in the 17th century, which enabled scientists to better identify and measure risks, leading to an increased number of formal quantitative risk analyses. Additionally, there has been a societal shift towards a preference for protection, planning, and early warning over reactive responses (Covello & Mumpower, 1985). However, despite this extensive database of knowledge, there is still little information about how RM should be conducted in specific environments. As demonstrated in this research, these contextual factors play a crucial role in the effectiveness of RM.

Furthermore, this study focuses on three widely used standards: PMI, ISO and PRINCE2. Other standards, such as Risman (a Dutch standard) (Projectbureau RISMAN, 2002) or DOE (an energy industry guideline) (DOE G 413.3-7A: Risk Management Guide, 2015), and various scientific articles were not explored, and perhaps might offer more detailed instructions than those reviewed. However, not all industries and countries will go to the lengths of seeking out more specific standards and may instead rely on the ones overviewed as they are famous world-widely. This could pose a problem, as these general standards might not provide the necessary guidance for effective RM customization and implementation.

5.1.1. Deviations and alignments with previous findings on this topic

Based on the results presented in Chapters 2 and 3 (see Figure 13), the following key findings were identified. In summary, although most of the theoretical issues related to RM were generally supported in practice, the specific details of these problems were not fully explained in the same way as described in this research. Initially, the study began with nine theoretical problems, but the focus shifted towards two primary areas: knowledge management and know-how. According to the literature review, these areas were further divided into five aspects: challenges with the externalization of practical knowledge, lack of clarity on review frequency and its adequacy, ambiguity regarding the selection and use of assessment tools, insufficient justification for the chosen tools and unclear development of response strategies. Interviews conducted in this study revealed that these five aspects were attributed to seven data management issues, eleven process-related problems and five organizational challenges.

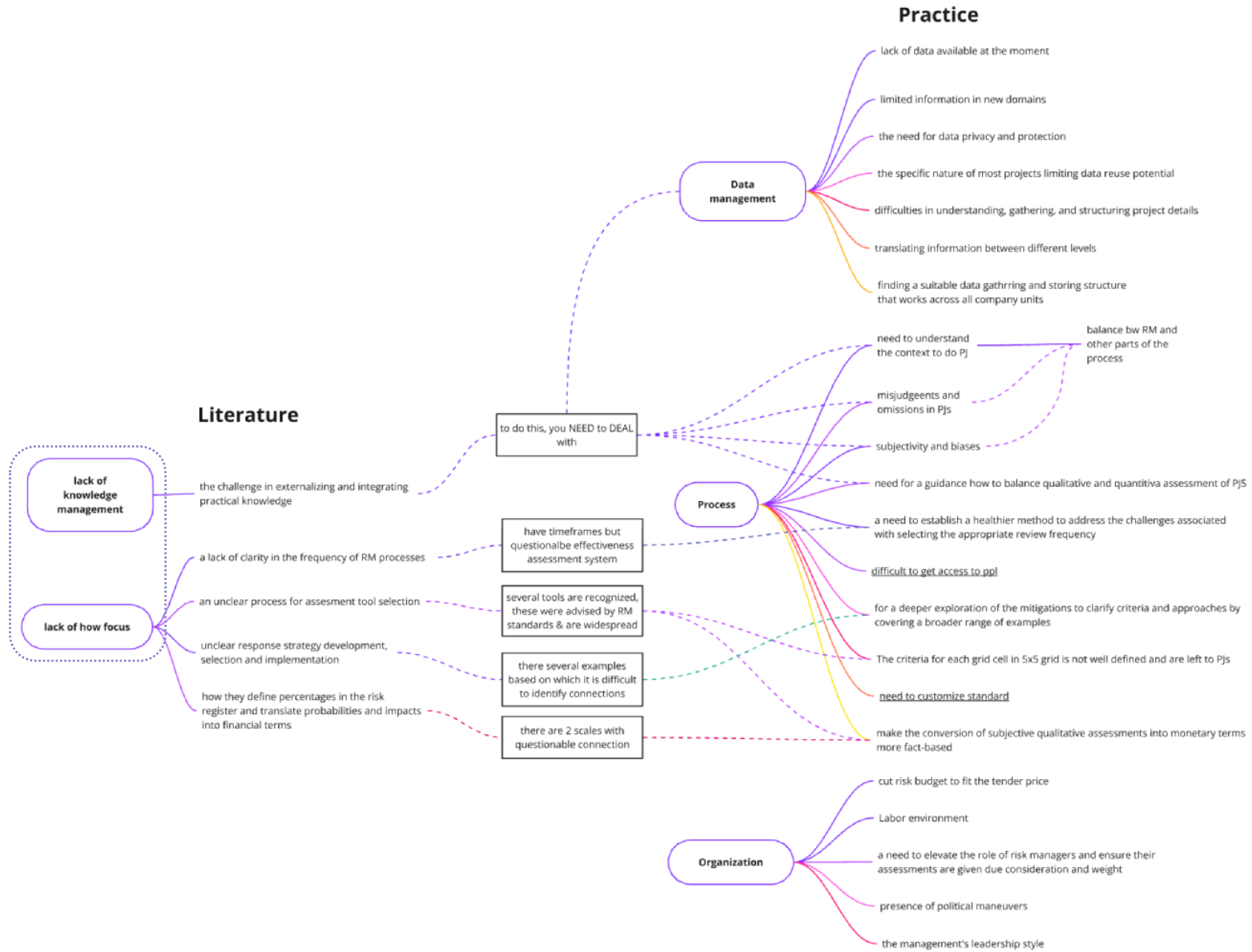


Figure 13 - Relation of gaps found in literature and in practice

5.1.1.1. Lack of Knowledge Management

The issue of insufficient knowledge management has been recognized within the company studied, suggesting that this challenge, although identified in other studies, remains pertinent in practical settings. Since the efforts to address it are still in their early stages, the use of professional judgements (PJs) remains prevalent in the process, supporting the point made by Okudan et al., 2020. Understanding the context is crucial for making accurate PJs, which has been challenging for those involved in RM. Furthermore, frequent misjudgments and omissions in PJs, the subjectivity and biases introduced, and the absence of guidance on how to evaluate PJs to ensure their relevance and clarity hinder the externalization and preservation of knowledge.

The company faces additional challenges in information gathering, such as the complexity of collecting and structuring details in projects and tenders, the one-off nature of most projects which complicates knowledge and data structuring and reuse, and difficulties in identifying what data is pertinent. Additionally, practice demonstrated the issue described by Aven (2023): practical RM is highly context-dependent, so when the company attempted to create a generic system for RM, it has proven ineffective, showing the limitations of a one-size-fits-all approach. Furthermore, in the development of mitigation measures, interviewees used practical examples, demonstrating the difficulty in defining specific criteria within their knowledge.

A positive side is that practitioners are applying their own lessons learned across projects and are now open to leveraging insights from other experts, facilitated by the recent switch to a web-based application. This shift has improved access to a broader range of lessons learned. That indicates that practitioners did choose to learn and adapt (Kim, 1998), even before the company recognized the problem and the potential and began addressing it. Despite these personalized efforts and the relatively recent focus on the issue within the company, ideas and models for knowledge-based RM, such as those proposed by Dikmen et al., 2008; Goh & Chua, 2010; Yildiz et al., 2014; Okudan et al., 2020; and Fan et al., 2015, and reviewed in Section 2.2.5, may serve as potential solutions or sources of inspiration.

5.1.1.2. Lack of Know-how

Preserving know-how has proven to be challenging. Both the company's standards and those reviewed in Section 2.1. emphasize what needs to be done rather than how to do it. This reflects a lack of standardization, as evidenced by the presence of different approaches to the same process and varying calculations, leading to different but acceptable outcomes due to the inability to verify them thoroughly.

There are several reasons why organizations often stop at defining "what" without specifying "how." Describing "how" is quite challenging because it depends on a wide variety of factors, including the specific situation, context, environment, available resources, and diverse scenarios. Additionally, detailing "how" might add rigidity to the process, hindering adaptability to changing circumstances. Without a prescribed "how," individuals have the freedom to experiment with different methods and discover what works best for them. Moreover, companies may not have sufficient resources to revise the standard. If the standard is perceived to be working well, there is little incentive to explore it further.

On the flip side, a lack of "how" might indicate that a company lacks the expertise needed to detail process steps sufficiently. They might be capable of outlining goals and objectives but may not possess the technical knowledge required for execution. Since processes in the construction field evolve slowly, a standardized "how" is unlikely to become obsolete quickly. Instead, it can improve construction efficiency, reduce variability, and increase reliability in outcomes. Diving deeper into the

"how" minimizes mistakes, especially in complex or high-stakes environments like construction. Additionally, it enhances transparency and accountability by making it easier to trace actions and identify those responsible for specific outcomes.

It is important to understand that detailing "how" will not compromise the deliverables outlined as "what." In fact, it will do the opposite. Given the diversity and simultaneous activities in construction, standardization can make valuable expertise more available by freeing professionals from constantly thinking about how to do things. Instead, their focus can shift to improvement and learning, moving the company towards greater efficiency.

However, given the major influence of context on the process, the first step could be to expand on the "what" aspect to further tailor the internal standard, shifting from a general company-level approach to a more specific unit-level guideline. Once the "what" aspects are sufficiently detailed to ensure consistency across projects within the unit, it would become much easier to standardize the methods for achieving these objectives, thereby creating, and preserving the "how."

Practitioners employ 5x5 impact x probability grid, brainstorming, document reviews, interviews and expert judgement in the RM process. The Monte Carlo simulation is used occasionally, making qualitative assessment the primary approach. Practitioners did not mention other tools and methods. The selection of these specific tools was not well explained, but since most of them are recommended by two or three of the reviewed standards (see Appendix A), it can be concluded that this toolset is well-known and has proven effective. However, there are two methods to convert qualitative assessments into monetary values, which are not aligned with each other. Additionally, as in the reviewed standards, the criteria for each grid cell in the 5x5 impact x probability grid are not well defined. There is still a need to make the conversion of subjective qualitative assessments into monetary terms more fact-based. This could potentially be achieved by leveraging lessons learned from completed projects. Analyzing and comparing the actual risk costs to the expected costs obtained through qualitative-to-quantitative conversion may reveal overlooked details and relations, incorrect perceptions, opportunism and other factors, thereby refining the conversion method with factual data. Such a change will require constant iterations and updates due to market influences.

Regarding review frequency, the company has more defined timeframes than RM standards suggest. However, since effectiveness is measured only after project failures, the selection process needs refinement. As mentioned earlier, lessons learned on projects can significantly aid in resolving this issue. For instance, using the framework proposed in this research, daily 15-minute discussions on a limited scope might be appropriate for some activities and excessive for others. By identifying the sufficiency of reviews for these activities during the process, they can be adjusted accordingly and later checked on other projects. This approach will help create a database for a flexible and adaptable review routine. However, the key challenge here is determining what constitutes sufficiency. Understanding the balance between thoroughness and practicality could be helpful in this regard.

5.1.1.3. Data management issues

Following the results of the literature review, issues related to data management, which are beyond the scope of this research, were identified and confirmed by industry practitioners.

Data management issues, explained in 3.2.1 and 3.2.4, indicate that the company does not face the problems identified in the literature review. Problems such as data redundancy, inherent randomness in certain variables, challenges with data interoperability, and the presence of inaccurate, imprecise, incomplete, or unreliable data, along with approximations in statistics (Zhou et al., 2019; Choi & Mahadevan, 2008; Davies et al., 2017; Solihin et al., 2017), were not mentioned by the

interviewees and do not appear to be relevant. The company is in the early stages of integrating risk-related data management, so it might not have yet encountered these issues. Some problems are simply avoided because historical data is not being integrated or widely utilized. Additionally, recent data might be more consistent and relevant, thus reducing variability and inaccuracies. However, these theoretical issues might become more apparent as the company continues accumulating more data in the selected system.

5.1.1.4. Organizational issues defined by industry practitioners

In addition to the process and data management deficiencies discussed earlier, industry practitioners have identified several other issues that hinder the efficiency of RM. These can be described as organization-based issues, encompassing internal organizational culture and structure. These aspects were not covered in Chapter 2, as these problems clearly stem from the organization's policies.

The leadership style was noted to be punitive toward individuals when results did not meet expectations. This practice aligns with authoritarian leadership, which is not typical for European countries (Wang et al., 2019; Lee et al., 2023). However, given the company's centralized organizational structure, it might be perceived as necessary to enforce rules and maintain order (Pizzolitto et al., 2022). Another probable reason, given the company's extensive history in the market, is that it may be a consequence of a long-standing tradition adopted by leaders who have advanced through the ranks in such environments, believing it to be effective (Lee et al., 2023). Additionally, after nearly facing bankruptcy, the company might still be operating in crisis mode, characterized by high levels of confusion and a lack of clear direction (Lee et al., 2023). While such a leadership style can sometimes yield short-term results, it often undermines employee morale, creativity and engagement in the long run (Pizzolitto et al., 2022; Wang et al., 2019). It is possible that these instances are not widespread and unique to some leaders within the company. However, the company's culture is often judged by the worst examples of its manifestation, as leaders and followers do not operate in isolation but mutually influence each other. Unfortunately, this problem extends beyond the RM domain and should be addressed at a broader organizational level.

Another issue is the lack of emphasis on the role of RM in projects. This problem is intriguing yet challenging, as it seems to be caught in a loop. One noted outcome is the reduction of the risk budget to fit within the tender price, despite knowing it will be insufficient. A key reason behind this is the unreliable calculations, which lack an evidence base and are often performed purely on PJs. This makes the calculations less trustworthy and diminishes the influence of risk managers' opinions. Furthermore, given the presence of instances of authoritarian leadership, changing the approach to calculations might be seen as excessive, requiring more resources than the added value of the results produced. Moreover, senior leaders already do not give enough weight to risk managers' opinions. As a result, simply refining the assessment may not be enough to elevate the importance of RM. The system itself needs to be reformed, emphasizing a cultural shift that values RM. This would require not only process improvements but also a transformation in leadership attitudes and organizational priorities to genuinely recognize the critical role of RM in project success.

Lastly, political games and labor issues clearly fall outside the scope of operational RM. These problems stem from the realms of human resources, psychology, organizational science and stakeholder management and are better addressed within these domains.

5.2. Lean management for Risk management

Lean is often regarded as a philosophy that is embodied in operational-level tools, highlighting the fascinating and close connection between management and operations. This approach bridges the gap between abstract management concepts and practical execution, and its potential should be exploited more than it currently is.

Lean construction tools have their origins in lean manufacturing, where they were adapted and refined specifically for the construction industry, primarily for the execution phase. However, some tools from the original lean were not adapted for construction, suggesting that there may be additional tools more suited for management processes than those currently used in the industry. Given the identified 58 tools, the lean arsenal available for improving various aspects of construction management is extensive. The fact that 14 tools were found to be potentially applicable in addressing five selected problems in RM, with only five integrated into the framework proposed in this research, suggests that there may be many more untapped opportunities for their application in RM and other aspects of construction project management. Additionally, since lean has not previously been integrated with RM in construction, there is a significant opportunity to enhance RM processes by adopting methodologies that have traditionally been outside its scope.

Furthermore, since lean originated in Japan, much of the foundational knowledge may exist in the original Japanese language and may not be fully covered by English-language sources. This indicates there could be further insights and methodologies within the Japanese literature that are yet to be explored and integrated into Western practices.

5.2.1. The integration of lean construction tools in RM

To understand the potential benefits and limitations of lean construction tools integration into the RM, there is a need to explore the arguments for and against this combination. These perspectives are compared to the traditional RM and project management approaches commonly used in construction companies.

5.2.1.1. Reasons for integration

The proposed framework outlines the use of five tools for addressing the issue related to the know-how at the operational level: Process Maps (PMs), Work Structures (WSs), Six-Week Look Ahead (SWLA), Weekly Work Plans (WWP) and Daily Huddle Meetings.

5.2.1.1. A PMs & WSs: general contribution

Document review (including contracts), analysis of past projects and personal experience are key methods used to develop an understanding of the upcoming project. While traditional project management does incorporate tools like process charts and Work Breakdown Structures (WBS), they are not as central to traditional methodologies as they are in lean or agile approaches (PMBOK® Guide, 2021; Process Groups: A Practice Guide, 2022; Agile Alliance, 2017). Additionally, the level of detail in these tools is not specified; process charts may lack some details, and WBS typically does not include resources, expected durations or buffers, as outlined in section 4.3.2. In this regard, PMs and WSs offer a significant advantage.

PMs and WSs, by visually representing all activities, their types and sequences, required resources, skill sets, expected durations, any necessary buffers and potential bottlenecks, offer a full understanding of the work to be done. Their ability to be detailed down to every movement helps clarify the contributions needed from different teams, pinpointing exactly when and where these inputs are required and how they might impact the overall outcome. Consequently, these tools provide

insights into the context of the upcoming project, which in turn enhances the accuracy of risk identification and management.

By mapping out the entire process, PMs and WSs allow project teams to see the bigger picture. When the entire process is laid out visually, it becomes easier to identify areas where things might go wrong. Furthermore, the structure provided by PMs and WSs ensures that no aspect of the project is overlooked in risk identification. Every step is accounted for, and the clarity these tools provide means that even complex projects with multiple parts can be broken down into manageable components. This level of detail aids in precise identification of risks associated with specific tasks or phases, making the risk management process more reliable.

Lean tools prioritize the use of accurate, real-time data to inform decision-making processes and cultivate a culture of objectivity in decision-making, which is important for maintaining consistent RM practices. This reliance on data reduces the subjectivity that can often obscure RM, ensuring that decisions are based on evidence rather than intuition or guesses. By analyzing process data and following the structure, these tools reduce the influence of cognitive biases in decisions and help teams to identify specific areas where risks are likely to emerge, based on objective data.

5.2.1.1. B PMs & WSs: contribution to knowledge management

In traditional project management, knowledge management primarily relies on formal documentation and reporting, post-project reviews and the archiving of all project-related documents (Pitagorsky, 2008). However, this approach limits the ability to capture knowledge generated during the project, as this research has shown that people often avoid paperwork and complete it sporadically, leading to significant information loss throughout the process. Consequently, while practitioners may have a strong understanding of how to conduct RM, this knowledge is rarely preserved (Section 2.1), and insights from past projects and accumulated data are seldom utilized.

In that sense, WS and PM provide an opportunity to overcome knowledge management challenges by transforming implicit, experiential knowledge into explicit, shared information. WS and PM help systematically document the steps, sequences and interactions involved in complex construction processes, capturing the often-unwritten know-how in a visual and organized form. For instance, when creating a PM, an experienced site manager can indicate that for a specific type of soil, it is more efficient to compact the ground immediately after excavation, rather than after all excavation work is complete, thereby preventing soil shifting or settling and future foundation problems. Thus, these insights, which might otherwise remain unspoken or emerge only when it is already too late, are recorded in the PM, making them accessible to others. Besides, by using PMs and WSs on a daily / weekly basis, they can be consistently updated to incorporate the most current information and knowledge.

Once knowledge is captured, WS and PM externalize this information, making it visible and understandable to all team members. The visual representation of processes allows complex knowledge to be communicated straightforwardly. For example, a WS that outlines tasks, expected durations and necessary resources at each step, helps demystify the expertise of professionals, breaking down their intuitive practices into step-by-step guides that others can follow.

Moreover, WSs and PMs facilitate the sharing of knowledge across various levels of the organization. By documenting and externalizing critical processes, these tools make it easier for knowledge to be transferred between teams and departments. This is particularly valuable in RM, where understanding and mitigating risks often require input from multiple stakeholders. For example,

WS and PM can serve as references during project planning meetings, ensuring that all participants are on the same page and aware of potential risks identified by experienced team members.

By capturing, externalizing and sharing knowledge, WSs and PMs enhance RM practices. They help create a more informed and knowledgeable workforce, where even less experienced team members can contribute to risk identification and mitigation. Additionally, they help standardize best practices across the organization, reducing the likelihood of errors or oversights that might lead to project risks. Finally, by making knowledge explicit, WSs and PMs ensure continuity and consistency in RM practices, even when key personnel leave or move on to other projects.

5.2.1.1.C SWLA, WWP and Daily Huddle Meetings: routine creators

As discussed in Section 2.1, traditional RM guidelines typically outline the importance of monitoring and reviewing risks but often fall short in providing specific instructions on how frequently these reviews should occur and how they should be consistently integrated into the project workflow. This oversight leaves the timing and regularity of reviews to the discretion of practitioners, leading to inconsistency in the process. As a result, there may be periods of inactivity where risks go unchecked, followed by rushed, reactive efforts to address issues that have escalated due to the absence of timely intervention. Furthermore, risks in construction projects can evolve rapidly, and without regular check-ins, there is a risk that issues could go unnoticed until they become critical.

Lean tools, like SWLA, WWP and Dailies, fill this gap by embedding regular, systematic reviews into the RM and project management process. By establishing a routine, these tools ensure that risk identification is an ongoing process rather than a sporadic activity.

SWLA is designed to break down the overall project timeline and scope into manageable segments, allowing teams to focus on specific tasks and milestones over a defined period. It provides a forward-looking view of the upcoming six weeks, highlighting the tasks that need to be completed, resources required and any potential obstacles that might arise. By structuring the review process in this way, teams can anticipate risks well in advance and develop strategies to address them before they escalate into more significant issues.

WWP takes this structure a step further by narrowing the focus to the week ahead. This tool encourages teams to plan their activities in detail, allocate resources and set priorities based on the latest project data. The regularity of this review ensures that any deviations from the plan are quickly identified and addressed. It also allows for continuous monitoring of progress, making it easier to spot emerging risks and take corrective action in real-time.

Daily Meetings offer an even more detailed level of review. Although these brief meetings are designed to align the team with the day's objectives, identify immediate challenges and discuss solutions, they may be less effective in addressing complex challenges within construction RM. Therefore, they are best used as day-to-day checkpoints for tracking progress while simultaneously creating detailed plans for the days ahead. This approach ensures that issues are identified early, providing sufficient time for mitigation efforts to keep the project on track.

5.2.1.1.D SWLA, WWP and Daily Huddle Meetings: communication enablers

Guidelines emphasize the importance of constant communication in project management, particularly in risk management (PeopleCert, 2023). However, in traditional structures, communication typically relies on a structured and formal approach, utilizing established channels and documentation to convey information. Information often flows up and down the chain of command, with project managers serving as the primary link between upper management and team members (PMBOK® Guide, 2021). This hierarchical communication can sometimes obstruct and delay the flow

of information (Whetsell et al., 2021). In contrast, lean management fosters a more dynamic, inclusive and continuous communication environment. Lean emphasizes frequent interactions, cross-functional collaboration, visual tools and decentralized decision-making, creating a more open and responsive communication culture that is crucial for managing complex, fast-paced projects.

The regular schedule of SWLA, WWP and Dailies creates consistent touchpoints for team interaction, ensuring that everyone remains informed, aligned and able to contribute their insights to the RM process. This helps to ensure that all team members are aware of potential risks and the mitigation steps being taken. These meetings provide a structured environment where expert judgments are not only captured once but are continually integrated into the project's ongoing risk assessment and management. This approach facilitates timely decision-making by ensuring that the right people are involved at the right moments. Additionally, these regular reviews foster a culture of accountability; with clear RM expectations set for each review period, team members are more likely to stay on track with their responsibilities and proactively contribute to addressing emerging issues.

5.2.1.2. Reasons against integration

5.2.1.2. A Technical scope

Lean construction companies typically do not engage in explicit RM as is known in traditional project management, as lean construction tools are inherently focused on identifying and managing waste and constraints. As noted in sections 1.1.1. and 1.1.4, waste and constraints encompass a broader range of issues, including risks. However, the lean construction tools studied are focused on technical aspects. Traditional RM takes a broader perspective, considering risks beyond the operations and processes, such as organizational, environmental, political, financial and legal risks. While some of these risks may be identified during operations (such as delays in obtaining necessary permits) and affect them, lean construction tools might have limitations in identifying issues like price volatility.

Lean focuses on ensuring that internal processes are completed efficiently, with a particular emphasis on maintaining takt time and continuous flow (Monden, 1983). Broader risks that don't immediately manifest as operational issues in that case may only be addressed after they start to cause problems, leading to rushed responses and potential disruptions. In this regard, lean management may not be as effective as traditional RM, raising the question of how this integration can be more comprehensive and prepared for a wider range of potential problems.

5.2.1.2. B Issues with the long-term planning

By breaking down the scope into smaller, manageable tasks, lean construction tools may lead to omissions as well. While this approach may make it easier for people to see the scope, achieve quick wins and short-term efficiency gains, this can sometimes come at the expense of long-term forecasting and planning. For example, based on Work Structures (WSs) and Process Maps (PMs), a company might identify the need for specific resources at certain times and decide to reduce inventory levels to free up cash flow and lower storage costs. While this decision might enhance financial performance in the short term, it could also make the company more vulnerable to supply chain disruptions, which could have a far more significant long-term impact. One validation interviewee noted that they prefer to maintain all necessary buffers, suggesting that such a decision is not in their best interests. However, similar situations do occur across various industries practicing lean (Dunn J. & Leibovici F., 2023; Martin B., 2021; Stone J., 2018). In this context, traditional RM provides a counterbalance by incorporating a long-term perspective, helping to ensure that long-term risks are known and managed.

5.2.1.2. C Process maintenance

Another disadvantage of lean in terms of RM is its focus on efficiency, which naturally leads to the creation of process standards and thus often hampers adaptability. While section 5.1.3 highlights

that having standards has both positive and negative sides, there is a need for constant maintenance. However, once standards are set, they receive less ongoing attention and updates, leading to reactive interventions rather than proactive improvements. This can cause the benefits gained from lean and standardization to gradually erode, resulting in a resurgence of inefficiencies (Rahmandad & Reppenig, 2015). Finding the right balance is particularly challenging in the dynamic and complex environment of construction projects, especially in RM.

5.2.1.3. Integration conditions

Considering the positive and negative aspects of lean construction tools integration into RM, contextual conditions should be considered as key decision factors. It is important to acknowledge that the existing literature on lean integration into RM, particularly within the construction sector, is extremely limited. As such, this research represents a pioneering theoretical effort to explore the potential application of lean construction tools in improving RM. In reviewing the literature on lean integration in RM across other sectors (section 1.1.2), it was evident that the integration of tools like PMs, Ws, SWLA, WWP and Daily Meetings had not been previously mentioned or explored. This research, therefore, fills a significant gap in the literature by demonstrating the potential of these tools to enhance RM. Nevertheless, the results are conceptual, meaning that in the real-world settings it may not behave as expected.

Given that, there could be some conceptual elaborations regarding the context in which it can be successful.

5.2.1.3. A Application for small projects

One of the validation interviewees pointed out that the developed framework might not be feasible for small companies because the amount of upfront work it requires demands significant resources, which translates to substantial costs. Smaller companies may not be willing or able to commit to such an investment. However, the extent of the upfront work needed depends on the type of projects the company undertakes. Smaller companies often face significant resource constraints, including limited financial, human and technical resources. This reality makes them more inclined to undertake smaller, more manageable projects that align with their capacity and avoid overstressing their limited resources (De Almeida Parizotto et al., 2020). Small projects typically involve a smaller number of activities and are often characterized by limited scope and resources (Kroll, 2007), which means the number of Ws and PMs required would be limited and manageable.

Moreover, as projects handled by smaller companies tend to be simpler, the activities within them are often straightforward (Kroll, 2007). These projects often involve repetitive activities, such as in road and residential construction, rather than the ones in unique cases, like building skyscrapers or stadiums. In the case of repetitive work, the return on investment (ROI) for creating Ws and PMs is high because these documents can be constantly reused across multiple projects. Additionally, some of these templates can serve as a foundation for developing specific Ws and PMs for more unique projects. It is true that unique Ws and PMs, such as those developed for tuned mass dampers used to reduce mechanical vibrations in high-rise buildings, would be utilized far less frequently compared to those for repetitive activities. However, this selective use can offer benefits to a small company by ensuring that the resources invested in creating these tools are maximized through their repeated application across similar projects.

Furthermore, smaller companies often have simpler communication structures, a more adaptable culture and fewer hierarchical layers, which enables faster decision-making and more direct communication among employees (Sopelana et al., 2012). With fewer employees and less rigid organizational structures, small companies can more easily maintain flexibility, implement new

practices and adapt quickly to changes. This flexibility can facilitate the adoption of frameworks like the one developed, as the process of integrating new tools and approaches into the company's operations may be smoother and more straightforward.

5.2.1.3. B Application for large and complex projects

The framework was developed using data provided by a large construction company that operates across Europe. This company has various units managing different types of projects, and its portfolio includes a vast number of small projects as well as well-known large and complex projects. As a result, the framework was unintentionally geared towards application by big companies able to manage large and complex projects.

Large projects are typically characterized by their scale, which includes extensive resources, long durations and significant budgets (Flyvbjerg, 2014). The complexity of these projects often stems from the number of elements involved, such as stakeholders, tasks and technologies. However, a large project can still be straightforward. In contrast, complex projects are defined by their intricate interdependencies and uncertainties, where changes in one part of the project can have unforeseen effects on others (Azmat & Siddiqui, 2023). This complexity poses significant management challenges, requiring continuous adaptation and problem-solving beyond simple scalability. Nonetheless, large projects tend to be complex, as they usually share interconnected characteristics (Miller & Hobbs, 2009).

Even in such challenging environments, the use of WSs and PMs within the lean RM framework can offer a clear understanding of the workflows, while also enhancing coordination among different teams and stakeholders. The framework provides a structure for identifying and managing operational risks, helping to prevent delays and cost overruns related to on-site activities and resource management. Given that large projects generate a tremendous number of lessons, the framework can help their ongoing capturing through established touchpoints. Breaking down the project scope makes it more manageable to gather and integrate these insights. Furthermore, the framework supports data-driven decision-making, which is needed for managing the complexity and scale of large projects.

However, as mentioned, such projects may require more upfront effort in creating WSs and PMs, with limited potential for reuse. Additionally, in projects with numerous interdependent activities, WSs and PMs can become overly complex, making their use, management and updating cumbersome. While these tools provide clarity, they can also introduce rigidity, making it difficult to adapt to unforeseen changes or shifts in project scope, which are common in large and complex projects. Furthermore, the framework could lead to a bureaucratic approach, where process management overshadows actual project execution, thereby slowing down decision-making. The framework also does not account for factors such as political risks, exchange rates or international collaboration, which can significantly impact project costs and timelines. This limitation reduces the framework's value for managing complex, unique projects.

5.2.2. The key challenges in using lean construction tools for risk management

Several limitations and challenges were identified in this research. However, it is important to determine whether these challenges are temporary and can be addressed with a change management plan, whether they are long-lasting issues that extend beyond the studied integration, or if they are inherent limitations of lean construction tools in the context of RM.

5.2.2.1. Temporary obstacles

The following limitations could be included in this group: the substantial amount of upfront work required, changes in daily work routines, the need for a company-wide shift and related

difficulties in implementing changes in organizations with complex hierarchies, and the need to align with existing systems. Most of these challenges can be managed through a gradual, phased rollout that focuses on short-term wins, supported by training programs, mentorship and the development of clear guidelines for the tasks required to overcome these obstacles. Additionally, creating an environment and culture that supports change, maintaining open communication and feedback channels, and demonstrating the value of the change would be helpful in managing the change (Phillips & Klein, 2022).

Implementing the lean RM framework requires a substantial amount of upfront work. However, the need to create numerous PMs and Ws is primarily an issue during the initial implementation phase. This challenge can be mitigated over time with training and experience. Once these tools are established and the team becomes familiar with using them, the amount of work required should decrease, indicating that this is not a permanent issue or a tool limitation. To address this, the company could begin by focusing on the most common processes across projects, such as site preparation and foundation placement, or prioritize the most critical and high-risk activities to achieve early success and immediate value.

Additionally, integrating this framework necessitates a change in daily work routines, which may face resistance from employees accustomed to existing practices. Nevertheless, the need to shift from occasional RM review meetings to regular 6-week, weekly and daily touchpoints have a temporary character. Once employees adapt to the new process flow, this obstacle naturally resolves itself and no longer impacts the project. This adjustment is simply a byproduct of implementing the framework. Guidance and support are needed to integrate this change into the regular workflow.

The need for a company-wide shift and the difficulties of implementing it in organizations with complex hierarchies highlight that changing only one department will not achieve the desired outcomes; the entire company needs to be involved to realize the full benefits. Although challenging, these issues are not permanent and can be addressed with a well-structured change management plan. Once new processes and cultural changes are embedded, the organization usually stabilizes, and the need for a company-wide shift is no longer a challenge. To address it, it is advisable to start with a simple pilot project, where the organization can test the new framework in a controlled environment before rolling it out across the entire company. Such a project team should include members from various departments to cover all aspects of the pilot project.

The need for alignment with existing systems is primarily a transitional challenge that arises during the integration of new elements into an organization's current operations. Once new systems are aligned, the challenge is resolved, and the tools can function effectively. Like the approach for managing a company-wide change, aligning with existing systems is good to start with a pilot project. Implementing the framework in a controlled, limited setting helps minimize disruptions and identify any compatibility issues that may not have been apparent during the planning stages.

5.2.2.2. Long lasting issues

The following limitations fall into this category: difficulties in establishing processes for new domains (such as sustainability and innovation), the potential for increased administrative work, reluctance to learn and adopt novel approaches, and a lack of emphasis on RM within organizations. Unlike temporary obstacles that can be addressed with a change management plan, these issues require a more holistic approach involving changes to mental models, culture, values and behaviors. Additionally, systematic shifts are needed to align all aspects of an organization (Lozano & Garcia, 2020). Sabini et al., (2019) suggest that such challenges may even necessitate changes in traditional project management practices.

Establishing processes for new domains represents a persistent challenge in project management. These areas lack a long-established history and are continuously evolving, making them recurring problems that project managers face, impacting aspects beyond RM. Initially, these processes would be based on assumptions and require refinement over time. However, the lack of established benchmarks can lead to uncertainty and potential missteps in early implementation stages, affecting confidence in the new system. Addressing these challenges requires ongoing adjustments in planning, resource allocation, stakeholder management and performance measurement.

The creation and regular updating of PMs and WSs can increase administrative tasks and consume valuable time, potentially overwhelming employees who are already dealing with heavy workloads. However, increased administrative work also falls into this long-lasting category due to the enduring aversion many people have toward administrative tasks. This reluctance is a consistent behavior observed over time, with employees often delaying or avoiding these tasks, leading to a buildup of work and a persistent administrative burden (Koppes, 2014). Training and change management strategies alone are insufficient to fully overcome the deep-seated resistance to performing these tasks. Similarly, reluctance to learn and adopt novel approaches is a deep-rooted behavioral issue (Laidoune et al., 2021). It is not confined to a single project or isolated incident but can have a lasting impact on various areas of project management.

The lack of emphasis on RM is often embedded in an organization's culture and values. This issue not only affects RM activities but also influences the entire project management environment. Shifting this mindset typically requires a significant cultural transformation that can take years to achieve, involving efforts from senior leadership, changes in policies, and ongoing education.

5.2.2.3. Inherent limitations of lean construction tools

The lean construction tools used in this framework are not without their flaws. While they are potentially helpful in addressing know-how issues in risk management, companies and users should be aware of their limitations and proactively find ways to mitigate or work around them to ensure they are applied in the most effective contexts. This requires promoting awareness of these limitations, seeking out additional tools and methods to fill the gaps, and regularly updating the tools to keep them relevant.

For example, one of the interviewees during validation expressed concerns about the limited timeframe of the Six-Week Look Ahead (SWLA). This tool may not sufficiently account for long-term risks, changes or opportunities that could affect the project beyond the six-week period. Despite a lean expert's view that significant issues can be identified and addressed within the six-week scope, it is important to recognize that, while this limitation might not be significant in traditional lean construction, it could be critical in the context of RM.

Additionally, the framework's use of Weekly Work Plans (WWP) and Daily Meetings tends to narrow the focus to immediate tasks, which, as noted in section 5.2.1, could come at the expense of broader project objectives and risks. Maintaining such a system, especially in a dynamic project environment, requires considerable time and effort to keep plans accurate and relevant. Moreover, there is a risk of meeting fatigue due to the increased number of daily and weekly meetings, which could lead to reduced effectiveness, loss of meaningful discussions, disengagement and a lack of valuable information over time.

Creating Process Maps (PMs) and Work Structures (WSs) presents its own challenges, as many construction processes are interconnected. Without regular updates, these tools can quickly become outdated and lose their value. Additionally, they can be overly prescriptive, leaving little room to

accommodate unexpected changes or unique project conditions. There is a risk that the team may become too focused on adhering to the PMs and WSs, rather than prioritizing desired outcomes and exploring more efficient ways to achieve them. A balance is needed between detailing steps and activities and focusing on key deliverables and outcomes. Furthermore, the effectiveness of PMs and WSs depends heavily on the accuracy and completeness of the information used to create them; if the initial inputs are flawed, these tools can lead to inefficiencies or errors in the project.

5.2.3. Benefits of lean construction tools integration in RM

It is also interesting to understand whether the benefits of lean construction tools integration in RM are only immediate or have a long-term effect.

5.2.3.1. Immediate benefits

As for the immediate results, the use of PMs and WSs ensures that decisions are based on factual data and evidence, rather than subjective opinions or gut feelings, leading to more informed and rational decision-making. Established processes reduce ambiguity in decision-making, minimizing the influence of personal and professional biases due to the clear depiction of processes that can be scaled to fit the entire construction process. This clarity allows for a better understanding of the balance between RM and other project aspects, facilitating a fair evaluation of risks.

The transparency and objectivity added by PMs and WSs make it easier for stakeholders to understand and trust the RM process, fostering confidence in the results and recommendations. Additionally, there is increased accountability, as decisions can be traced back using PMs and WSs, which assists in grounding RM results for external auditors and regulatory compliance. The uniform use of PMs and WSs also increases the consistency of RM across different projects. Clear documentation supporting RM decisions facilitates communication with stakeholders and ensures alignment in understanding.

The use of SWLA, WWP and daily meetings leads to immediate improvements in team coordination. By outlining monthly, weekly, and daily tasks and objectives, these tools promote alignment among team members, ensuring everyone is aware of their responsibilities and how they fit into the broader project goals. Real-time feedback is gathered within this system, allowing for quick responses to emerging risks or changes. With regular assessments, risks can be continuously reassessed as the project progresses, ensuring that RM strategies are updated and relevant to current project conditions.

5.2.3.2. Long term benefits

In the long term, PMs and WSs can be continuously updated and grounded more in real-life practice, thereby enhancing objectivity. After completing several projects with this approach and refining PMs and WSs, cross-process analysis can be conducted at the unit level, contributing to the development and customization of specific instructions for each unit. Over time, using PMs and WSs leads to consistent quality across different units, enhancing client satisfaction and trust.

The established constant feedback loop dedicated to updating PMs and WSs allows unit-level instructions and standards to be continuously refined, fostering a culture of learning, adaptation, knowledge sharing, and the dissemination of best practices throughout the organization. With basic protocols in place, the company's movement towards sustainability can gain more focus, as established processes require less oversight, allowing for faster and more detailed implementation of sustainable practices.

5.3. Research limitations

This section outlines the limitations of the research. Firstly, the study was conducted within a limited timeframe and scope, which restricted the depth of exploration. A huge portion of time was dedicated to administrative tasks, as the chosen topic is closely tied to strategic information. This focus on administration impacted the timing of other research activities, potentially leading to the omission of some information and a less comprehensive analysis than might have been achieved with more time.

5.3.1. Methodology

There are several limitations related to the chosen methodology. For the literature review, the focus was on scientific literature, but access to some sources was restricted. This may have prevented a more detailed exploration of certain topics. Additionally, the review relied on English-language sources, potentially excluding relevant findings available in other languages. Researcher interpretation biases might also be present.

In terms of the interviews conducted during both data gathering, verification, and validation, it is important to note that participants might provide socially desirable responses or may not be entirely truthful, particularly in self-reported data. Their responses were shaped by their personal perspectives and interpretations of the questions, which naturally affects the objectivity of the research. The sample size was also limited to the company's available resources, and although responses became repetitive, this might still not be enough to capture all relevant details. Furthermore, since the interviews were conducted in English, which was not the native language for all participants, some interviewees might have struggled to fully express their thoughts, leading to potential omissions or missing nuances in the analysis. This could impact the reliability of the research conclusions.

To mitigate these challenges, efforts were made to diversify the pool of interview participants. This allowed for a broader range of viewpoints and helped balance individual biases, contributing to a more objective understanding of the issues. Furthermore, open-ended questions were used to encourage elaboration, and follow-up questions were employed to clarify responses and minimize misunderstandings. Although these efforts help mitigate the impact of the limitations, future research involving a larger, more diverse sample and offering the option to conduct interviews in participants' native languages could further improve the reliability and depth of the findings.

5.3.2. Scope

The fact that this research was conducted with representatives from a single company in the Netherlands introduces limitations. The unique organizational culture and national context may influence the generalizability of the findings, making them less applicable to other companies, regions or settings. Additionally, due to the sensitive nature of the topic, certain information may have remained undisclosed, limiting the research's comprehensiveness.

Focusing on lean construction tools may also restrict the effectiveness of the proposed solution, as there could be equally or more effective tools and methodologies outside of lean construction.

While concentrating on operational RM helped uncover issues rooted at the strategic level, but these issues are beyond the scope of what can be addressed within the operational focus. As a result, solving operational-level issues may not add significant long-term value if underlying strategic

problems remain unaddressed. This focus might lead to solutions that enhance short-term efficiency but fail to deliver sustainable benefits over time.

The shift in focus towards knowledge management during data gathering also presents limitations. Codifying tacit knowledge is inherently challenging, both for the interview participants and the researcher. In the process of documenting this knowledge, some nuances and subtleties of expert insight may have been oversimplified or lost.

5.3.3. Research results

Regarding the research results, in addition to the limitations identified in Sections 5.2.1 and 5.2.2, it is important to note that the effectiveness of the proposed framework depends heavily on the availability and accuracy of data — issues that are well-known and complex in the field. Furthermore, the framework was not tested in a real-world setting, which may limit the assessment of its practical applicability.

5.3.4. Researcher biases

To clarify the interpretive nature of this research, a core aspect of qualitative studies, it is important to be transparent about the researcher's background and knowledge of the chosen topic, as well as to reflect on the potential for subjectivity. This allows for the critical evaluation of the trustworthiness of the study by identifying areas where personal biases might influence the findings and explaining the steps taken to limit their influence. This reflection is detailed in the following statement from the researcher:

“My background in structural engineering, which is highly standardized due to safety requirements, along with four years of experience in construction quality control, has undoubtedly shaped my perspective on construction processes. This experience most likely has influenced my focus on maintaining high standards and ensuring consistent quality across projects. During my work, I observed that my team, and myself as well, often made subjective judgments without a solid basis, which led to communication problems with subcontractors and other departments. These experiences convinced me that having an objective foundation in all processes is crucial to avoid misunderstandings as it provides a ground for defending decisions made. This belief likely influenced my research, making me emphasize objectivity in RM. Additionally, my role required me to identify defects, which may have predisposed me to focus more on problems and deficiencies, potentially overlooking positive aspects of the processes I reviewed.

This background may have led me to interpret findings in a way that aligns with quality control, possibly neglecting other important aspects of RM. Furthermore, it might have caused me to undervalue the role of subjective judgment, which is often necessary and unavoidable in complex situations and processes like RM. I might have made specific expectations about what constitutes effective RM, making it influence the way I framed interview questions, selected literature and analyzed responses.

To mitigate these biases, I made a conscious effort to remain open to alternative perspectives and interpretations, consider the positive aspects of RM practices and recognize areas where subjective judgment and experience might actually enhance decision-making, despite my predispositions. I also sought feedback from supervisors and colleagues to ensure that my interpretations were not overly influenced by my biases. In addition, I used multiple data sources, such as literature reviews and interviews with industry practitioners from various roles, to ensure that my interpretations were not overly skewed. I shared preliminary findings with supervisors and colleagues to validate my

conclusions, acknowledging that there is a potential for shared biases and preferences. Nevertheless, the practice of member checking allowed for a more balanced perspective. Furthermore, I shared the rationale behind my choices, providing a ground for others to understand and evaluate the research findings."

6. Conclusion & Recommendations

The aim of this thesis was to identify the RM strategies employed in construction, their weaknesses and strengths, identify lean tools used in construction and evaluate whether they can address the identified RM issues, and illustrate how combining these approaches can potentially lead to improved outcomes. This section presents the answers to the primary research question and sub questions, along with recommendations for practical application and directions for future research.

6.1. Answers to research sub questions

SQ1: Which risk management strategies are used in construction? What are their theoretical deficiencies?

Operational RM is a process that is consistent across industries, but its effectiveness heavily depends on the specific context in which it is applied. Widely accepted standards, such as ISO 31000, PMI and PRINCE2, outline the core steps: risk identification, assessment, mitigation, monitoring and control, coupled with communication and documentation. These standards offer various tools but allow organizations to select those that best fit their needs. While periodic reviews are recommended, the frequency is left to the discretion of each organization. The focus is more on outlining what needs to be done rather than detailing how to achieve it.

Several problems have been identified in the RM process. One issue is the difficulty in grasping project complexity. The abstract nature makes it hard to manage, requiring a deeper understanding and interpretation. Additionally, there is a need for improvements within the organization itself as organizational and managerial factors themselves are significant sources of risk. Another challenge is the need for more effective and collaborative RM strategies to address the interconnected impacts of stakeholders on project outcomes. A gap exists in formal, systematic processes for stakeholder management, with a lack of established strategies and methods for effective collaboration. Enhancing RM approaches during the Front-End Planning (FEP) is crucial, as this stage offers the best opportunity to prevent many potential issues. However, this issue requires a cultural shift within organizations and stronger leadership involvement. Additionally, how construction companies manage project information for RM purposes remains an open question. This highlights a broader conceptual challenge: determining what data is necessary to create, organize and utilize for project success.

Finally, the weakness within the focus of this research, the lack of knowledge management in construction, which could undermine the effectiveness of RM. Much of the industry's expertise is held in the tacit knowledge of industry practitioners, and the challenge lies in capturing and integrating this knowledge into formal processes that can be shared across the industry, improving RM in construction projects.

SQ2: How is risk management done in practice? What works well and what requires improvements in current risk management practice?

The RM process outlined in standards has been acknowledged in practical settings. It is done by requiring practitioners to make professional judgments (PJs) at each step like risk identification, assessment and mitigation. A deep understanding of the project context is essential for effective RM, yet many struggle to balance RM with other project aspects and fully grasp the context. While internal RM guidelines are valued for maintaining consistency, they often lack detail, leading to varied outcomes as operational managers interpret them differently.

Communication with specialists and stakeholders is the primary source of information for RM. However, when access to experts is limited, critical inputs may be missing, reducing the quality of outcomes. Subjectivity and biases can further skew RM inputs, and in some cases, information may be withheld or misrepresented. Personal experience, project documentation, and past projects are also key information sources, but there are challenges related to data privacy, difficulties in data structuring, the specific nature of projects and data in it, which limit their effectiveness.

The frequency of RM reviews varies, typically ranging from weekly to quarterly, depending on project factors like phase and complexity. However, the effectiveness of these intervals is often only evaluated after project failures. Qualitative risk assessment is commonly used, but poorly defined criteria and reliance on personal judgment led to inconsistent outcomes and complicated risk pricing. The expected risk reserve often does not align with actual needs, causing financial discrepancies. Describing the process of mitigation development is challenging due to its highly context-specific and cause-specific nature. Organizational challenges, such as differences in RM perceptions between management levels, increasing workloads and administration, limited decision-making power and leadership styles further impact RM effectiveness.

On the positive side, RM is valued for promoting communication and teamwork, simplifying complex project environments, and preventing mistakes. It also fosters organizational resilience by helping companies avoid unrealistic contract conditions and benefits from generating ideas and lessons learned.

SQ3: What are the lean tools used in construction?

A wide range of lean tools have been adapted and utilized within the construction industry. Out of the fifty-nine tools identified, 8 were already recommended by existing RM guidelines as risk tools, while others shared similar objectives with RM, such as identifying, understanding and preventing issues that could impact functionality or predicting potential failures and addressing them proactively.

Most of these tools are process-based, which makes them particularly suited for tackling operational-level issues. Their focus on improving workflows and streamlining processes aligns well with the practical needs of construction projects. Additionally, many of these tools incorporate inherent learning features, allowing users to better understand and refine their methods, making them invaluable for gaining an understanding of how to effectively execute tasks.

Of the tools analyzed, fourteen were found to be potentially effective in addressing the RM limitations identified in this research. Furthermore, an additional thirteen tools, 9 of which overlapped with the initial selection, were deemed useful for tackling other challenges highlighted in the study.

SQ4: How can lean construction tools address the deficiencies in risk management?

In addressing the limitations related to the lack of knowledge management, particularly the need for improved context understanding for more accurate professional judgments (PJs), as well as reducing omissions, misjudgments, subjectivity and biases, Construction Process Analysis with Process Maps (PMs) and Work Structures (WSs) has proven to be beneficial. These tools provide a structure of activities, including their sequences, resources, durations, required skill sets and potential bottlenecks, offering a clearer view of the project context. This approach provides an objective foundation for making more accurate PJs and informed decisions. By incorporating feedback loops, WSs and PMs can be continuously updated to reflect the current reality, ensuring that PJs become increasingly accurate over time.

For issues related to the selection of review frequency and ensuring access to key personnel and their judgments in the RM process, tools like Six-Week Look Ahead, Weekly Work Planning and Daily Meetings have been found useful. These tools break down the project's overall scope into manageable parts — six weeks, one week and one day — creating regular touchpoints for team interaction through weekly and daily updates. This structure allows for timely updates and changes, ensuring that all relevant parties can contribute their insights and decisions within the RM process. By focusing on the detailed scope within these selected periods, the team can concentrate on upcoming activities and adjust if needed without affecting the project pace.

The proposed lean RM framework (see Figure 14) illustrates how these five tools might assist in addressing deficiencies in risk management, representing the primary finding of this research.

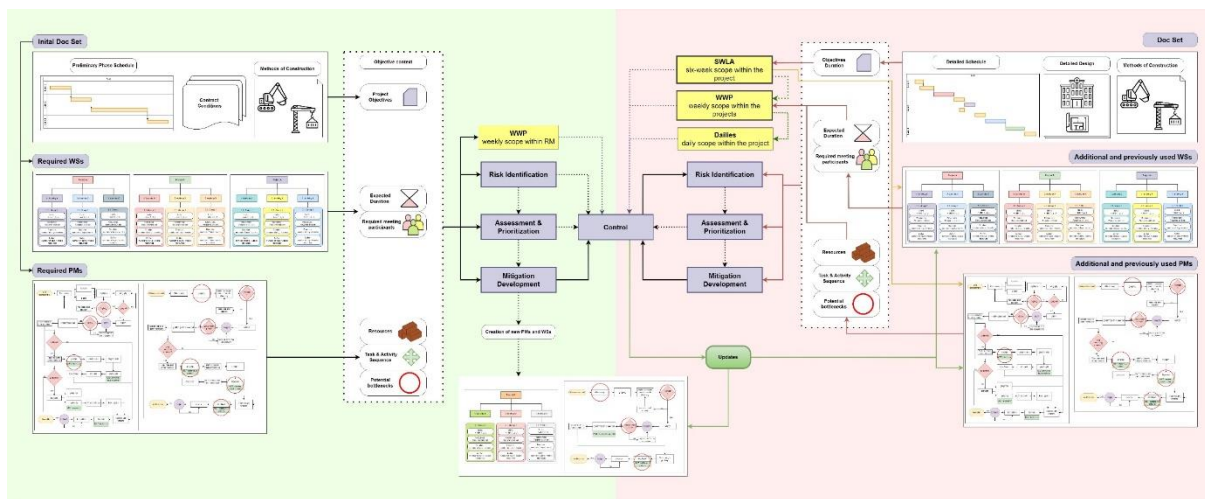


Figure 14 - Lean RM Framework

As for other issues and tools, their potential to aid in resolving RM challenges has been recognized, though not explored in detail. For instance, A3, a problem-solving tool, could assist in managing contributions from various parties for shared decision-making and tracking problem-solving progress due to its concise visual format. 5S, a workplace organization tool, could help in structuring data for the RM database by analyzing, sorting, and systematically storing information. PMs, with their visual representation of sequences and contributions required from different teams, could enhance the understanding of stakeholder interconnectedness, thereby aiding in the development of effective management strategies. These combinations, however, warrant further study.

6.2. Answer to main research question

The main research question was:

"How can lean construction tools improve risk management in construction projects?"

Lean construction tools can significantly enhance RM in construction projects by providing a deeper understanding of the project context, which is crucial for effective RM. These tools are designed to encompass key aspects of the construction process, offering a visual representation that connects various elements of the workflow with scheduling and costs. This system-oriented view helps to simplify the complex nature of construction projects, making it easier for RM professionals to see how different components interact and where potential risks might arise. By doing so, lean tools allow RM practitioners to focus more on their core objective: identifying potential issues early and addressing them proactively. The objective grounding provided by lean tools supports more informed decision-

making, reducing the reliance on assumptions and subjective judgment, making RM outcomes more reliable.

Moreover, lean tools, bonded to the schedule and time, establish regularity in processes, ensuring consistent progress updates and communication within the team. This regularity is vital for RM, as it aligns with the need to identify and address potential risks in a timely manner. By embedding structured routines and checkpoints into the workflow, lean tools help to ensure that risks are monitored continuously and that any emerging issues are dealt with before they escalate.

In addition to improving decision-making and process regularity, lean tools also stimulate continuous learning within RM. They encourage teams to reflect on their work, identify areas for improvement and incorporate lessons learned into future projects. This ongoing learning process is essential for building more resilient and adaptive RM strategies, as it helps teams to evolve and refine their approaches based on real-world experiences.

Overall, lean construction tools not only enhance the efficiency and effectiveness of RM but also contribute to a more proactive, informed and adaptive approach to managing risks in construction projects.

6.3. Recommendations

6.3.1. Recommendations for practice

6.3.1.1. For construction companies

Considering the points outlined in Section 3.3.4, it is important to recognize that operational RM is more complex than it might appear in guidelines or be perceived by higher management. Beyond the basic steps, a significant amount of work is done, much of which currently relies on the experience and knowledge of risk managers. This area asks greater attention and more weight in decision-making to improve outcomes for both projects and the organizations practicing it.

It is advisable to focus on preserving RM knowledge within the organization's memory. Much of the decision-making in RM is based on the knowledge held by individuals, which poses risks to the company's stability and progress. By externalizing and preserving this knowledge, companies can avoid knowledge loss, validate information with various specialists, and build an objective database. This benefits the company by creating a solid foundation for decisions, and it also aids specialists by allowing them to concentrate on RM outcomes rather than the groundwork, thus improving the overall effectiveness of RM.

Given the complexity of construction projects, there is an opportunity to consider how internal guidelines can be further customized. Companies might capitalize on the fact that people rely on internal standards to achieve better outcomes, and ensure these guidelines are flexible enough to be adapted to specific project needs, yet robust enough to maintain consistency across the organization. By refining and tailoring these guidelines, companies can enhance their effectiveness, leading to more precise RM.

To embed RM as a routine practice within the company — rather than as a burdensome obligation — leadership is recommended to actively support this initiative and encourage a cultural shift. RM is better seen as an integral and beneficial part of project management, applied consistently across all projects. Discipline in this approach will be key.

6.3.1.2. For standard developers

Due to the lack of guidance on customization in the general guidelines (sections 3.3.1 and 5.2.1), companies experience inconsistent outcomes in their RM practices. This variability suggests that the standard guidelines may not fully address the unique needs and contexts of different organizations. Therefore, standard developers might further explore how these guidelines can be more effectively tailored. Since organizations and practitioners rely on standards, providing more guidance on customization would support them in improving risk management.

Besides the guidance on customization, it is important to revisit the qualitative scales used in risk assessment. The issues related to the risk assessment were outlined in Section 3.2.1. So, instead of just giving the tools, the elaborated explanations might be more beneficial. These include clear distinctions for each qualitative estimate or instructions on how to define them and ground in objective data such as past projects, lessons learned and statistics. Furthermore, the conversion of qualitative assessments into monetary values might be explored in greater depth, as this will increase trust in the calculations and make them more reliable for both internal and external stakeholders.

6.3.1.3. For operational level employees

Although employees recognize the importance of understanding the project context for qualitative RM, they might seek tools that simplify this process. Process Maps and Work Structures have potential due to their visual and structured approach but exploring other options that might address this challenge is also worthwhile. The result will be more accurate professional judgments (PJs) and informed decision-making throughout the project lifecycle, benefiting both the company and the projects.

Supporting a continuous learning environment is essential. Feedback from completed projects is better systematically integrated into future RM practices through regular post-mortem reviews or ongoing reviews during projects. Encouraging people to share insights and best practices and creating a system for storing and reusing this information will ensure that the knowledge gained is continually applied to improve RM effectiveness.

6.3.2. Recommendations for future research

6.3.2.1. Areas outside the scope of this research

The wide range of RM issues highlighted and supported by industry practitioners underscores the relevance and urgency of finding solutions. This indicates a continued need to delve deeper into understanding project complexity in RM, managing stakeholder interconnectedness and its impact on project risks, improving RM during the Front-End Planning (FEP) phase, and effectively handling the vast amount of information generated during project execution, specifically in filtering, structuring, storing and utilizing this data, for better RM outcomes (see Sections 2.2, 2.3.2 and 3.3.4).

It was found that RM is often influenced by other aspects of project management, such as instances where the risk budget might be intentionally, but unjustifiably, altered by inputs from other departments to meet bid limitations (Section 3.3.1). The problem extends beyond just the RM domain and affects other areas as well, suggesting a need for a comprehensive solution that addresses these interconnected areas. Developing a holistic approach could lead to more integrated and effective project management practices overall.

Besides the lean tools that were used to address issues within the scope of this research, other tools were identified as having potential to assist as well (see Table 36), highlighting a research gap in exploring how these lean tools can improve context understanding, reduce omissions and minimize

subjectivity and biases. Furthermore, there is an opportunity to investigate how the defined lean tools (see Table 37) can address RM deficiencies that fall outside the scope of the research.

While the framework focuses on the technical and operational aspects of construction projects, such as resources and activities, it does not address the broader spectrum of risks that can impact the project. Specifically, the research does not explore the human, organizational, environmental, political, financial and legal elements of RM (Section 5.3.1). This focus means that the framework may miss significant potential problems that arise from non-technical factors, which are just as important to the overall project success. There is an opportunity for further research to explore how these risk factors can be better recognized and integrated into lean RM.

The lean perspective emphasizes the importance of learning from unexpected events and applying those lessons within ongoing projects, rather than just reserving them for future use. The proposed framework currently focuses on understanding the project context and collecting feedback, but it offers limited support for the immediate application of lessons learned. In RM, some insights are only realized after unforeseen issues occur, often forcing the project team to accept the outcomes as they are. However, there remains a research opportunity to explore how insights can be quickly integrated into ongoing projects.

Although the lean RM framework does not specifically include tools for identifying the root causes of issues, it does not restrict users from exploring these areas further and enhancing RM outcomes by incorporating additional tools. RM guidelines do recommend using analytical tools such as the fishbone diagram or Bow-Tie Analysis for this purpose, but the actual implementation of these tools is left to the discretion of the organization. Therefore, there is an opportunity to explore how to encourage users to routinely focus on identifying and addressing repetitive root causes of issues in a way that becomes a natural part of their workflow rather than a forced activity.

6.3.2.2. Areas of the research limitations

The framework developed in this research represents a conceptual first step toward integrating lean into RM within the construction industry. While it has been outlined theoretically, there is an opportunity to test and refine this framework through practical application in pilot projects. This will help in further developing the framework to address the defined problems and assess its effectiveness in real-world scenarios more specifically.

Additionally, there are other knowledge management challenges that affect RM. While this research proposed one approach to addressing these challenges, there is potential for further exploration to develop even more robust and effective strategies. Given that most of the RM decisions rely on professional judgments (PJs), studying how to better capture, externalize and share tacit knowledge within organizations could significantly enhance RM practices.

Exploring the environments of diverse types (e.g., residential, commercial, infrastructure) and sizes (e.g. small, large, complex) of construction projects and contracts could also be beneficial in understanding the limitations and positive impacts of lean integration in RM. This deeper understanding could help identify environmental nuances and contribute to the customization of internal guidelines.

References

- Abdelhamid, T. S. (2003). Six-Sigma in Lean Construction Systems: Opportunities and Challenges. *The 11th Annual Conference for Lean Construction*.
- Aghimien, D., Aigbavboa, C., Oke, A. E., & Setati, M. (2018). Challenges of front-end loading in construction project delivery. *Proceedings of International Structural Engineering and Construction*, 5(2).
- Agile Alliance (2017). Agile practice guide. In *Project Management Institute eBooks*.
- Alashwal, A. M., & Abdul-Rahman, H. (2014). Using PLS-PM to model the process of inter-project learning in construction projects. *Automation in Construction*, 44, 176–182.
- Almeida, F. (2017). Challenges in Migration from Waterfall to Agile Environments. *World Journal of Computer Application and Technology*, 5(3), 39–49.
- Alsaadi, & Norhayatizakuan. (2021). The impact of risk management practices on the performance of construction projects. *Estudios De Economía Aplicada*, 39(4).
- Alshibly, H. H. (2013). The impact of risk management on construction projects success from the employees perspective. *Interdisciplinary Journal of Contemporary Research in Business*, Vol 5, No 4, 12-43.
- Ambrosini, V., & Bowman, C. (2001). Tacit knowledge: Some suggestions for operationalization. *Journal of Management Studies*, 38(6), 811–829.
- Ansah, R. H., Sorooshian, S., Shariman, M., & Duvvuru, G. (2016). Lean Construction Tools. *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA, September 23-25, 2016*.
- Antillón, E. I., Alarcon, L. F., Hallowell, M., & Molenaar, K. R. (2011). A Research Synthesis on the Interface between Lean Construction and Safety Management. *19th Annual Conference of the International Group for Lean Construction 2011, IGLC 2011 - Lima, Peru*
- Aqlan, & Ali. (2014). Integrating lean principles and fuzzy bow-tie analysis for risk assessment in chemical industry. *Journal of Loss Prevention in the Process Industries*, 29, 39–48.
- Arleroth, J., & Kristensson, H. (2011). Waste in Lean Construction – A case study of a PEAB construction site and the development of a Lean Construction Tool.
- Åstedt-Kurki P. & Heikkinen R.-L. (1994) Two approaches to the study of experiences of health and old age: the thematic interview and the narrative method. *Journal of Advanced Nursing* 20, 418–421.
- Aven, T. (2023). On the gap between theory and practice in defining and understanding risk. *Safety Science*, 168, 106325.
- Azmat, Z., & Siddiqui, M. A. (2023). Analyzing project complexity, its dimensions and their impact on project success. *Systems*, 11(8), 417.
- Babaei, A., Locatelli, G., & Sainati, T. (2021). What is wrong with the front-end of infrastructure megaprojects and how to fix it: A systematic literature review. *Project Leadership and Society*, 2, 100032.

- Baccarini, D. (1996). The concept of project complexity—a review. *International Journal of Project Management*, 14(4), 201–204.
- Bahamid, Doh, Khoiry, Kassem, & Al-Sharafi. (2022). The current risk management practices and knowledge in the construction industry. *Buildings*, 12(7), 10-16.
- Ballard, & Howell. (1997a). *Implementing lean construction: Reducing inflow variations*. In L. Alaton (Ed.), *Lean Construction* (pp. 93-100). Rotterdam: A.A. Balkema Publishers.
- Ballard, & Howell. (1997b). *Implementing lean construction: Improving downstream performance*. In L. Alaton (Ed.), *Lean Construction* (pp. 111-125). Rotterdam: A.A. Balkema Publishers.
- Ballard, & Tommelein. (2012). Lean management methods for complex projects. *Engineering Project Organization Journal*, 2(1–2), 85–96.
- Ballard, G. (1997). *Lean Construction and EPC Performance Improvement*. In L. Alaton (Ed.), *Lean Construction* (pp. 79-91). Rotterdam: A.A. Balkema Publishers.
- Ballard, G. (1999) Work structuring. *Lean Construction Institute. White Paper No. 5.*
www.leanconstruction.org
- Ballard, H. G. (2000). *THE LAST PLANNER SYSTEM OF PRODUCTION CONTROL*.
- Banaitienė, & Banaitis. (2012). Risk management in construction projects. In *InTech eBooks*.
- Batzias, D. F. (2012). Transforming incomplete fault tree to Ishikawa diagram as an alternative method for technology transfer. *Nucleation and Atmospheric Aerosols*.
- Beckers, F., & Stegemann, U. (2013). A risk-management approach to a successful infrastructure project. In *McKinsey & Company*. <https://www.mckinsey.com/capabilities/operations/our-insights/a-risk-management-approach-to-a-successful-infrastructure-project#/>
- Bertelsen, S. (2003) Complexity-Construction in a New Perspective. IGLC-11, Blacksburg, Virginia.
- Bhosale, S. D., & Khose, L. P. (2016). Evaluation of process performance using control charts and histogram in manufacturing industry. *GE-International Journal of Management Research*.
- Bilgin, G. M., Erol, H., Atasoy, G., Dikmen, İ., & Birgönül, M. T. (2022). Exploring pattern of complexity in mega construction projects. *International Journal of Managing Projects in Business*, 15(7), 1064–1090.
- Biotto, C., Mota, B., Araújo, L. O. C., Barbosa, G., & Andrade, F. M. (2014). Adapted use of Andon in a horizontal residential construction project. *22nd Annual Conference of the International Group for Lean Construction*, 1295–1305.
- Bo, Z., Niu, Z., & Liu, C. (2020). Lean Tools, knowledge Management, and Lean Sustainability: The Moderating Effects of study Conventions. *Sustainability*, 12(3), 956.
- Bollinger. (2010). Lean risk management. *PMI® Global Congress 2010 - North America, Washington, DC*. Newtown Square, PA: Project Management Institute.
- Brown, M. L., & Kros, J. (2003). The impact of missing data on data mining. In *IGI Global eBooks*, 174–198.
- BS ISO 31000:2018 Risk management — Guidelines*. (2018). ISO, Switzerland.

- Çetin, N. (2023). Identifying bottlenecks and optimizing the production line using bottleneck analysis. *Multidisciplinary Perspectives in Educational and Social Sciences VI*, 155–181.
- Chao-Duivis, M. a. B. (2012). *Het bouwteam model: een studie naar de juridische vormgeving en het functioneren in de praktijk*. Instituut voor Bouwrecht.
- Chapman, C. and Ward, S. (2003) *Project Risk Management: Processes, Techniques and Insights*. John Wiley & Sons Ltd., Chichester.
- Chauhan, G., & Singh, T. P. (2012). Measuring parameters of lean manufacturing realization. *Measuring Business Excellence*, 16(3), 57–71.
- Choi, H. R., & Mahadevan, S. (2008). Construction project risk assessment using existing database and Project-Specific information. *Journal of the Construction Division and Management*, 134(11), 894–903.
- Covello, V. T., & Mumpower, J. (1985). Risk Analysis and Risk Management: An Historical perspective. *Risk Analysis*, 5(2), 103–120.
- Crema, & Verbano. (2015). Mapping lean experiences and emerging connections with clinical risk management in Italian context. *Business Process Management Journal*, 21(5), 1091–1116.
- Cristóbal, J., Carral, L., Díaz, E., Fraguera, J., & Iglesias, G. (2018). Complexity and Project Management: A General Overview. *Complexity*, 2018, 1–10.
- Crute, V., Ward, Y., Brown, S., & Graves, A. (2003). Implementing Lean in aerospace—challenging the assumptions and understanding the challenges. *Technovation*, 23(12), 917–928.
- Cruz, A., Alves, A. C., & Tereso, A. (2020). Traditional, Agile and Lean Project Management - A systematic literature review. *Journal of Modern Project Management*, 8(2).
- Davies, K., McMeel, D., & Wilkinson, S. (2017). Making friends with Frankenstein: hybrid practice in BIM. *Engineering, Construction and Architectural Management*, 24(1), 78–93.
- De Almeida Parizotto, L., Tonso, A., & De Carvalho, M. M. (2020). The challenges of project management in small and medium-sized enterprises: a literature review based on bibliometric software and content analysis. *Gestão & Produção*, 27(1).
- De Bruijn, J. A., De Bruijn, H., & Heuvelhof, E. T. (2008). *Management in networks: On Multi-actor Decision Making*. Routledge.
- Deep, S., Bhoola, V., Verma, S. K., & Ranasinghe, U. (2021). Identifying the risk factors in real estate construction projects: an analytical study to propose a control structure for decision-making. *Journal of Financial Management of Property and Construction*, 27(2), 220–238.
- Dikmen, I., Birgonul, M. T., Anac, C., Tah, J. H. M., & Aouad, G. (2008). Learning from risks: A tool for post-project risk assessment. *Automation in Construction*, 18(1), 42–50.
- Dimitrieska, S., Stankovska, A., & Efremova, T. (2018). The Fourth Industrial Revolution: Advantages and Disadvantages. *Economics and Management*, 14(2), 182–187.
- Do, D., Chen, C., Ballard, G., & Tommelein, I. D. (2014). Target value design as a method for controlling project cost overruns. *22nd Annual Conference of the International Group for Lean Construction*, 171–181.

- DOE G 413.3-7A, Risk Management Guide. (2015).
- Dunn J. & Leibovici F. (2023, August 07) Supply Chain Disruptions and Inventory Dynamics. *Federal Reserve Bank of St. Louis*. <https://www.stlouisfed.org/on-the-economy/2023/aug/supply-chain-disruptions-inventory-dynamics>
- Ebekozien, A., Aigbavboa, C., & Ramotshela, M. (2023). A qualitative approach to investigate stakeholders' engagement in construction projects. *Benchmarking: An International Journal*.
- Erol, H., Dikmen, I., Atasoy, G., & Birgonul, M. T. (2020). Exploring the Relationship between Complexity and Risk in Megaconstruction Projects. *Journal of Construction Engineering and Management*, 146(12).
- Essaber, Benmoussa, DeGuio, & Dubois. (2021). A Hybrid Supply chain Risk management Approach for lean Green Performance based on AHP, RCA and TRIZ: A case study. *Sustainability*, 13(15), 84-92.
- Etges, B. M., Saurin, T. A., & Bulhões, I. R. (2012). Identifying lean construction categories of practices in the IGLC proceedings. *20th Annual Conference of the International Group for Lean Construction*.
- Fan, Z.-P., Li, Y.-H., & Zhang, Y. (2015). Generating project risk response strategies based on CBR: A case study. *Expert Systems with Applications*, 42(6), 2870–2883.
- Feld, W. M. (2000). *Lean manufacturing: Tools, Techniques, and How to Use Them*. CRC Press.
- Fidel, R. (1984). The case study method: A case study. *Library and Information Science Research*, 6(3), 273-288.
- Florice, S., Michela, J. L., & Piperca, S. (2016). Complexity, uncertainty-reduction strategies, and project performance. *International Journal of Project Management*, 34(7), 1360–1383.
- Flyvbjerg, B. (2013). Quality control and due diligence in project management: Getting decisions right by taking the outside view. *International Journal of Project Management*, 31(5), 760–774.
- Flyvbjerg, B. (2014). What you Should Know about Megaprojects and Why: An Overview. *Project Management Journal*, 45(2), 6–19.
- Formoso, C. T., & Moura, C. B. (2009). Evaluation of the Impact of the Last Planner System on the Performance of Construction Projects. *Proceedings for the 17th Annual Conference of the International Group for Lean Construction*, 153–164.
- Franz, B., Leicht, R., Molenaar, K. R., & Messner, J. (2017). Impact of team integration and group cohesion on project delivery performance. *Journal of the Construction Division and Management*, 143(1).
- Galli, B. J. (2019). Barriers to effective communication and stakeholder management in project environments and how to overcome these barriers. *International Journal of Applied Logistics*, 9(2), 39–57.
- Gibb, A. G. (1999). *Off-site fabrication: Prefabrication, Pre-assembly and Modularisation*. John Wiley & Sons.

- Gibson, G.E., Wang, Y.R., Cho, C.S., & Pappas, M.P. (2006). What is pre project planning anyway? *Journal of Management in Engineering*, 22(1), 35-42.
- Goh, Y. M., & Chua, D. K. H. (2010). Case-Based Reasoning Approach to Construction Safety Hazard Identification: Adaptation and Utilization. *Journal of Construction Engineering and Management*, 136(2), 170–178.
- Gomes Miron L., Kaushik, A. & Koskela, L. (2015) *Target Value Design: The Challenge of Value Generation*. In: Proceedings of the 23rd Annual Conference of the International Group for Lean Construction. IGLC (23). IGLC.net, Perth, Australia, pp. 815-825.
- Grabher, G. (2002). Cool Projects, Boring institutions: Temporary collaboration in social context. *Regional Studies*, 36(3), 205–214.
- Haddad, T. (2021). Quality assessment of concrete production using Statistical Process Control (SPC) techniques. *Proceedings on Engineering Sciences*, 03(2).
- Hansen, S., Too, E., & Le, T. (2015). Retrospective look on front-end planning in the construction industry: A literature review of 30 years of research. *International Journal of Construction Supply Chain Management*, 8(1), 19–42.
- Hartono, B. (2018). From project risk to complexity analysis: a systematic classification. *International Journal of Managing Projects in Business*, 11(3), 734–760.
- Hooper, M., & Ekholm, A. (2010). A Pilot Study: Towards BIM Integration - An Analysis of Design Information Exchange & Coordination. *Proceedings of the CIB W78 2010: 27th International Conference –Cairo, Egypt, 16-18 November*.
- Hugo-Burrows, M. (2002). Converting tacit knowledge into explicit knowledge in organisations : a communication challenge : research article. *Communicare; Journal for Communication Sciences in Southern Africa*, 21(1), 61–81.
- Husin, S., Mubarak, M., & Fachrurrazi, F. (2019). The significance risk for factors of labor, material, and equipment on construction project quality. *Aceh International Journal of Science and Technology*.
- IEC/ISO 31010:2019 Risk management - Risk assessment techniques* (2nd ed.). (2019). ISO.
- Ilie, G., & Ciocoiu, C. N. (2010). Application of fishbone diagram to determine the risk of an event with multiple causes. *Management Research and Practice*, 2(1), 1–20.
- Institute, P. M. I. P. M. (2022). *The Standard for Risk Management in Portfolios, Programs, and Projects*. Project Management Institute.
- Issa. (2013). Implementation of lean construction techniques for minimizing the risks effect on project construction time. *Alexandria Engineering Journal*, 52(4), 697–704.
- Johansen, & Walter. (2007). Lean Construction: Prospects for the German construction industry. *Lean Construction Journal*, 3(1), 19-32.
- Jung, Y. (2008). Automated Front-End Planning for Cost and Schedule: Variables for Theory and Implementation. *AEI 2008: Building Integration Solutions*.

- Jung, Y., Lee, Y. H., Woo, S., Yang, J., An, S., Oh, Y., & Lee, B. N. (2009). Automated CPM Schedule Generation for early Project Planning: Methodology and case study. *Construction Research Congress 2009*.
- Kaizen Institute Consulting Group. (2013). <https://in.kaizen.com/blog/post/2013/10/21/go-to-gemba-muda-walk>
- Kallio, H., Pietilä, A., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, 72(12), 2954–2965.
- Kaoud, M. (2017). Investigation of customer knowledge management. *International Journal of Service Science, Management, Engineering and Technology*, 8(2), 12–22.
- Karlsen, J. T. (2002). Project stakeholder management. *Engineering Management Journal*, 14(4), 19–24.
- Keçi, & Mustafaraj. (2013). Practices, Barriers and Challenges of Risk Management Implementation in Albanian Construction Industry. *ATINER'S Conference Paper Series, No: CIV2013-0639*. Athens.
- Kim, D. H. (1998). The Link between Individual and Organizational Learning. In *Elsevier eBooks*, 41–62.
- Kivrak, S., Arslan, G., Dikmen, I., & Birgonul, M. T. (2008). Capturing Knowledge in construction Projects: Knowledge Platform for Contractors. *Journal of Management in Engineering*, 24(2), 87–95.
- Klakegg, O. J. (2009). Pursuing relevance and sustainability. *International Journal of Managing Projects in Business*, 2(4), 499–518.
- Ko, C.-H., & Tsai, P.-Ch. (2013). Applying Lean Production A3 to Enhance Construction Work Flow. *Life Science Journal*, 10(2), 2409–2416.
- Koppes, Laura L. 2014. *Historical Perspectives in Industrial and Organizational Psychology*. London: Psychology Press.
- Koskenvesa, A. & Koskela, L. (2005) Introducing last planner : Finnish experiences. In: Understanding the construction business and companies in the new millennium. *VTT – Technical Research Centre of Finland*, 95-107. ISBN 952-5004-62-7
- Krauss S.E., Hamzah A., Omar Z., Suandi T., Ismail I.A. & Zahari M.Z. (2009) Preliminary investigation and interview guide development for studying how Malaysian farmers form their mental models of farming. *The Qualitative Report* 14(2), 245–260.
- Kroll, K. M. (2007). Small projects, big results. *PM Network*, 21(7), 28–33.
- Lai, I. K. W., & Lam, F. K. (2010). Perception of various performance criteria by stakeholders in the construction sector in Hong Kong. *Construction Management and Economics*, 28(4), 377–391
- Laidoune, A., Zid, C., & Sahraoui, N. (2021). Innovate and overcome resistance to change to improve the resilience of systems and organizations. *Journal of the Knowledge Economy*, 13(4), 2986–3001.
- Lasa, I. S., Laburu, C. O., & De Castro Vila, R. (2008). An evaluation of the value stream mapping tool. *Business Process Management Journal*, 14(1), 39–52

- Lean Construction Institute (LCI). (2024, January 26). *Lean Kanban* | *Lean Construction Institute*. Lean Construction Institute. <https://leanconstruction.org/lean-topics/lean-kanban/>
- Leavengood, S., & Reeb, J. (2002). *Statistical Process Control*. Oregon State University.
- Lee, J. Y., Kim, S., Noh, S., Jang, S. H., & Lee, S. Y. (2023). Paradoxical organizational culture, authoritarian leadership, and international firm performance: evidence from international firms in China. *Journal of International Management*, 101117.
- Leedy, P. D., & Ormrod, J. E. (2001). *Practical research planning and design*, 7th Ed., Prentice-Hall, Upper Saddle River, N.J.
- Leung, M., & Olomolaiye, P. (2009). Risk and Construction Stakeholder Management. *Construction Stakeholder Management*, 75–98.
- Liker, J. K. (2003). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw Hill Professional.
- Losonci, D., Demeter, K., & Jenei, I. (2011). Factors influencing employee perceptions in lean transformations. *International Journal of Production Economics*, 131(1), 30–43.
- Lozano, R., & Garcia, I. (2020). Scrutinizing sustainability change and its institutionalization in organizations. *Frontiers in Sustainability*, 1:1.
- Lucko, G., & Rojas, E. M. (2010). Research Validation: Challenges and opportunities in the construction domain. *Journal of Construction Engineering and Management*, 136(1), 127–135.
- Manson, S. M. (2001). Simplifying complexity: a review of complexity theory. *Geoforum*, 32(3), 405–414.
- Marnewick, C., & Marnewick, A. L. (2023). Project managers' ability to explore and exploit predictive and iterative best practices. *International Journal of Managing Projects in Business*, 16(8), 126–151.
- Martin B. (2021, November 15) Supply Chain Disruptions: The Risks and Consequences. *RAND*. <https://www.rand.org/pubs/commentary/2021/11/supply-chain-disruptions-the-risks-and-consequences.html>
- McLaughlin, S., Paton, R. A., & Macbeth, D. K. (2008). Barrier impact on organizational learning within complex organizations. *Journal of Knowledge Management*, 12(2), 107–123.
- Meier, S. R. (2008). Best project management and systems engineering practices in the preacquisition phase for federal intelligence and defense agencies. *Project Management Journal (Online)*, 39(1), 59–71.
- Miller, R., & Hobbs, B. (2009). The Complexity of Decision-Making in Large Projects with Multiple Partners: Be Prepared to Change. In *Making Essential Choices with Scant Information*. Palgrave Macmillan, London. 375–389.
- Mills, A. (2001). A systematic approach to risk management for construction. *Structural Survey*, 19(5), 245–252.
- Monden, Y. (2011). *Toyota Production System: An Integrated Approach to Just-In-Time*, 4th Edition. CRC Press.

- Monden, Y. (1983). *Toyota Production System: Practical Approach to Production Management*. Industrial Engineering and Management Press, Institute of Industrial Engineers: Norcross, GA, USA
- Nahmens, & Ikuma. (2009). An Empirical Examination of the Relationship between Lean Construction and Safety in the Industrialized Housing Industry. *Lean Construction Journal*, 1-12.
- Namada, J. M. (2018). Organizational learning and competitive advantage. In *Advances in human resources management and organizational development (book series)*, 86–104.
- Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science*, 5(1), 14–37.
- Okudan, O., Budayan, C., & Dikmen, İ. (2021). A knowledge-based risk management tool for construction projects using case-based reasoning. *Expert Systems With Applications*, 173, 114776.
- Papachatzi, D., & Xenidis, Y. (2019). Risk management in construction projects using building information modelling. *Proceedings of the 2019 European Conference on computing in construction – Chania, Crete, Greece, 10-12 July*.
- Pasquire, C., & Connolly, G. E. (2002). *Leaner Construction Through Off-Site Manufacturing. Proceedings IGLC-10*. Gramado, Brazil.
- Patel, J. S., & Patange, G. S. (2017). A Review on Benefits of Implementing Lean Manufacturing. *International Journal of Scientific Research in Science and Technology IJSRST*, 3(1), 249–252.
- PeopleCert. (2023). *PRINCE2® 7 Managing Successful Projects*. PeopleCert International Ltd.
- Phillips, J., & Klein, J. D. (2022). Change Management: From theory to practice. *TechTrends*, 67(1), 189–197.
- Pitagorsky, G. (2008). *Managing project management knowledge*. Paper presented at PMI® Global Congress 2008 — North America, Denver, CO. Newtown Square, PA: Project Management Institute.
- Pizzolitto, E., Verna, I., & Venditti, M. (2022). Authoritarian leadership styles and performance: a systematic literature review and research agenda. *Management Review Quarterly*, 73(2), 841–871.
- PMBOK® Guide (2021).
- Process Groups: A Practice Guide (2022).
- Projectbureau RISMAN. (2002). *Risicomanagement: Praktijkervaringen aan de hand van de grote infrastructuurprojecten in Nederland*. RWS Bouwdienst
- Qazi, A., Quigley, J. M., Dickson, A., & Kirytopoulos, K. (2016). Project Complexity and Risk Management (ProCRiM): Towards modelling project complexity driven risk paths in construction projects. *International Journal of Project Management*, 34(7), 1183–1198.
- Qazi, A., Shamayleh, A., El-Sayegh, S., & Formanek, S. (2021). Prioritizing risks in sustainable construction projects using a risk matrix-based Monte Carlo Simulation approach. *Sustainable Cities and Society*, 65, 102576.

- Rahman, M. M., Yap, Y. H., Ramli, N., Dullah, M. A., & Shamsuddin, M. S. W. (2017). Causes of shortage and delay in material supply: a preliminary study. *IOP Conference Series*, 271, 012037
- Rahmandad, H., & Repenning, N. (2015). Capability erosion dynamics. *Strategic Management Journal*, 37(4), 649–672.
- Rewers P., Trojanowska J., Chabowski P. (2016). Tools and methods of Lean Manufacturing - a literature review, *proceedings of 7th International Technical Conference TECHNOLOGICAL FORUM 2016*, Czech Republic, 28-30.06.2016, pp.135-139
- Rigby, B. P., Dodd-Reynolds, C. J., & Oliver, E. J. (2022). The understanding, application and influence of complexity in national physical activity policy-making. *Health Research Policy and Systems*, 20(1).
- Sabini, L., Muzio, D., & Alderman, N. (2019). 25 years of ‘sustainable projects’. What we know and what the literature says. *International Journal of Project Management*, 37(6), 820–838.
- Salem, O. M., Solomon, J., Genaidy, A. M., & Luegring, M. (2005). Site implementation and assessment of lean construction techniques. *Lean Construction Journal (LCJ)* 2(2)
- Samari, Godrati, Esmaeilifar, Olfat, & Shafiei. (2013). The investigation of the barriers in developing green building in Malaysia. *Modern Applied Science*, 7(2).
- Samset, K., & Volden, G. H. (2016). Front-end definition of projects: Ten paradoxes and some reflections regarding project management and project governance. *International Journal of Project Management*, 34(2), 297–313.
- Santos, A. D., & Powell, J. A. (1999). Potential of Poka-Yoke Devices to Reduce Variability in Construction. *Proceedings IGLC-7 Seventh Conference of the International Group for Lean Construction, USA, 1999*, 51–62.
- Sarhan, & Fox. (2013a). Barriers to implementing lean construction in the UK construction industry. *The Built & Human Environment Review*, 6.
- Sarhan, & Fox. (2013b). Performance measurement in the UK construction industry and its role in supporting the application of lean construction concepts. *Construction Economics and Building*, 13(1), 23–35.
- Senge, P. M. (1990). The fifth discipline, the art and practice of the learning organization. *New York: Currency Doubleday*, 371p
- Shah, R., & Ward, P. T. (2003). Lean manufacturing: Context, practice bundles, and performance. *Journal of operations management*, 21 (2), 129–149.
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333–339.
- Solihin, W., Dimyadi, J., Lee, Y., Eastman, C. M., & Amor, R. (2017). The Critical Role of Accessible Data for BIM-Based Automated Rule Checking Systems. *Lean and Computing in Construction Congress (LC3): Volume I & Proceedings of the Joint Conference on Computing in Construction (JC3), July 4-7, 2017, Heraklion, Greece, p. 53-60.*

- Son, J. (2022). Complexity and dynamics in construction project organizations. *Sustainability*, 14(20), 13599.
- Sopelana, A., Kunc, M., & Hernáez, O. R. (2012). Towards a dynamic model of organisational flexibility. *Systemic Practice and Action Research*, 27(2), 165–183.
- Sowmya, K., & Chetan, N. (2016). A review on effective utilization of resources using overall equipment effectiveness by reducing six big losses. *International Journal of Scientific Research in Science, Engineering and Technology*, 2(1), 556–562.
- Stone J. (2018, June 1) Fragile Antibiotic Supply Chain Causes Shortages And Is A National Security Threat. *Forbes*. <https://www.forbes.com/sites/judystone/2018/06/01/fragile-antibiotic-supply-chain-causes-shortages-and-is-a-national-security-threat/>
- Sunder, M. V. (2016). Lean six sigma project management – a stakeholder management perspective. *The Tqm Journal*, 28(1), 132–150.
- Tanga, O., Akinradewo, O., Aigbavboa, C., Oke, A. E., & Adekunle, S. A. (2022). Data Management Risks: a bane of construction project performance. *Sustainability*, 14(19), 12793.
- Tanga, O., Akinradewo, O., Aigbavboa, C., & Thwala, W. D. (2021). Usage of cloud storage for data management in the built environment. In *Lecture notes in networks and systems*, pp. 465–471.
- Thamhain, H. J. (2013). Managing risks in complex projects. *Project Management Journal*, 44(2), 20–35.
- Thomas, G., & Thomas, M. (2005). Construction Partnering & Integrated Teamworking. In *Blackwell Publishing Ltd eBooks*.
- Thomé, A. M. T., Scavarda, L. F., Scavarda, A., & De Souza Thomé, F. E. S. (2016). Similarities and contrasts of complexity, uncertainty, risks, and resilience in supply chains and temporary multi-organization projects. *International Journal of Project Management*, 34(7), 1328–1346.
- Tokola, H., Niemi, E., & Kyrenius, P. (2017). How Lean transformation affects scheduling. *Robotics and Computer-Integrated Manufacturing*, 43, 171–178.
- Underwood, J., & Khosrowshahi, F. (2005). Academe—Industry Collaboration through the Experience of a Construction IT Membership-Based Network. *Industry and Higher Education*, 19(5), 375–383.
- Van De Ven, A. H., & Johnson, P. E. (2006). Knowledge for theory and practice. *The Academy of Management Review*, 31(4), 802–821.
- Vilasini, N., & Gamage, J. R. (2010). Implementing Value Stream Mapping Tool in the Construction Industry. *Conference: International Research Conference on Sustainability in Built Environment*.
- Wang, Z., Liu, Y., & Liu, S. (2019). Authoritarian leadership and task performance: the effects of leader-member exchange and dependence on leader. *Frontiers of Business Research in China*, 13(1).
- Ward, S., & Chapman, C. (2008). Stakeholders and uncertainty management in projects. *Construction Management and Economics*, 26(6), 563–577.

- Wengraf T. (2001) *Qualitative Research Interviewing: Biographic Narrative and Semi-structured Methods*. SAGE, London.
- Wettenbank. Aanbestedingswet 2012 (Accessed on 28-05-2024)
<https://wetten.overheid.nl/BWBR0032203/2022-03-02/0>
- Whetsell, T. A., Kroll, A., & DeHart-Davis, L. (2021). Formal hierarchies and informal networks: How organizational structure shapes information search in local government. *Journal of Public Administration Research and Theory*, 31(4), 653–669.
- Williams, T., Samset, K. (2010). Issues in front-end decision making. *Project management journal*. 41 (2), 38–49.
- Willumsen, Oehmen, Rossi, & Welo. (2017). Applying lean thinking to risk management in product development. *21st International Conference on Engineering Design (ICED 17), Design Processes, Design Organisation and Management*, 2, 269–278.
- Womack, J., Jones, D. & Roos, D. (1990) *The Machine That Changed the World: The Story of Lean Production, Toyota's Secret Weapon in the Global Car Wars That Is Now Revolutionizing World Industry*. Free Press, New York.
- Wu, L., Ji, W., Feng, B., Hermann, U., & AbouRizk, S. M. (2021). Intelligent data-driven approach for enhancing preliminary resource planning in industrial construction. *Automation in Construction*, 130, 103846.
- Xia, N., Zou, P. X., Griffin, M., Wang, X., & Zhong, R. (2018). Towards integrating construction risk management and stakeholder management: A systematic literature review and future research agendas. *International Journal of Project Management*, 36(5), 701–715.
- Yang, R. J., Shen, G. Q., Ho, C. M. F., Drew, D. S., & Xue, X. (2011). Stakeholder management in construction: An empirical study to address research gaps in previous studies. *International Journal of Project Management*, 29(7), 900–910.
- Yang, R. J., Zou, P. X., & Wang, J. (2016). Modelling stakeholder-associated risk networks in green building projects. *International Journal of Project Management*, 34(1), 66–81.
- Yildiz, A. E., Dikmen, İ., Birgönül, M. T., Ercoskun, K., & Alten, S. (2014). A knowledge-based risk mapping tool for cost estimation of international construction projects. *Automation in Construction*, 43, 144–155.
- Zhou, Y., Hu, Z., Lin, J., & Zhang, J. (2019). A review on 3D Spatial Data Analytics for building information Models. *Archives of Computational Methods in Engineering*, 27(5), 1449–1463.
- Zouaghi, I. (2011). Tacit knowledge Generation and Inter-Organizational memory development in a supply chain context. *Journal of Systemics Cybernetics and Informatics* 9(5), 77-85.

Appendix A: Risk Management tools & techniques

No	Tools & Techniques	Meaning	Risk Management Process					
			preparation	Identification	analysis (qualitative)	analysis (quantitative)	mitigation	monitoring
1	Assumption and constraint analysis	a tool where all potential assumptions and constraints are listed, tested and proceeded to determine risk impact		PMI (C)	PMI (S)			PMI (S)
2	Brainstorming	a technique to generate potential risk events, either individually or from a group of people	ISO	PMI (C), ISO			PMI (S)	
3	Cause and effect diagrams / Ishikawa diagram	a tool to display root causes of risk visually, allowing deeper understanding of the source and likelihood of potential problems		PMI (C), ISO, PRINCE2	PMI (S), PRINCE2		PMI (S), PRINCE2	
4	Cindynic approach	an approach used to identify situations vulnerability to reduce it beforehand and limit the risks possibility		ISO				
5	Checklists	developed based on historical information, can be in the form of breakdown structure. Should be reviewed to improve it for use in the future		PMI (C), ISO	PMI (S)		PMI (S)	PMI (S)
6	Delphi technique	anonymous polling of subject matter experts to identify risks in their area of expertise	ISO	PMI (C)	PMI (S)		PMI (S)	

7	Bow-Tie	a visual tool that unites FTA and ETA in one system; is used to design proactive and reactive risk responses, calculate probabilities and impacts, prioritize measures and causes			ISO		ISO	
8	Hazard Analysis and Critical Control Points (HACCP)	an analysis of risks in the process and procedures for controlling these risks (is usually used for food safety from biological, chemical, physical hazards)		ISO	ISO	ISO	ISO	
9	Layer of protection analysis (LOPA)	a tool for estimating frequency, probability and severity of an incident scenario;			ISO	ISO		
10	Causal mapping	a technique used to analyze and present issues and links between them (like cause and effect)		ISO	ISO			
11	Cross impact analysis	a technique used to connect relationships between events and variables, categorize these relationships (positive/negative), determine which events or scenarios are most probable within a given time frame		ISO	ISO			
12	Doc review	a structured review of docs like plans, assumptions, prior portfolio, program, project files. Other info		PMI (C)				
13	Expert Judgement	a contribution provided to risk identification based on expertise in a subject area, industry segment, org processes, etc.		PMI (C), ISO	PMI (C)	PMI (S), ISO	PMI (S)	PMI (S)

14	Historical info	use of data from past projects, programs, portfolios to identify common risks and prevent repeating mistakes		PMI (C)	PMI (C)	PMI (C)	PMI (C)	PMI (S)
15	Interviews	interviewing experienced project, program, portfolio participants, stakeholders, subject matter experts to identify risks	ISO	PMI (C)				PMI (C)
16	Prompt lists	tools enumerating risk categories with the purpose of detecting the most relevant to the project, program, portfolio		PMI (C), PRINCE2			PMI (S)	
17	<i>PESTLE</i>	political, economic, social, technological, legal, environmental		PMI (C), PRINCE2			PMI (S)	
18	<i>TECOP</i>	Technical, environmental, commercial, operational, political		PMI (C)			PMI (S)	
19	<i>SPECTRUM</i>	socio-cultural, political, economic, competitive, technology, regulatory/legal, uncertainty/risk, market		PMI (C)			PMI (S)	
20	Questionnaire	a quality question list to encourage broad thinking to identify risks	ISO	PMI (C)	PMI (S)			
21	Root-Cause Analysis	to identify additional dependent risks		PMI (C), ISO	PMI (S), ISO	PMI (S)	PMI (C)	
22	SWOT	a technique to increase the breadth of considered risks		PMI (C), PRINCE2	PMI (S)		PMI (S)	
23	Failure modes, effects, and criticality analysis (FMECA)	a technique used to identify potential failures in systems and equipment (like FMEA)		ISO				

24	Hazard and Operability (HAZOP)	a tool to determine potential problems in safety of design, existing processes and operations (used in chemical, pharmaceutical, oil, gas, nuclear industries)		ISO				
25	Structured What-If Technique (SWIFT)	techniques aim to identify hazards and evaluate their potential impact; used brainstorming with "what if?"; allows to look at the system response to problem besides examining the consequences		ISO	ISO			
26	Nominal group technique	brainstorming technique; used to identify problems and generate solutions; ideas are generated, collected, discussed and ranked	ISO	ISO				
27	Affinity diagram	a tool to organize specific ideas or factors that contribute to a risk; helps to sort risks by similarities or generic risk categories			PMI (S)		PMI (S)	
28	Analytic hierarchy process	a matrix technique used to support a multicriteria decision-making process, can be used to identify risks			PMI (C)	PMI (S)		
29	Influence diagram	diagrammatic representation of a situation showing the main entities, decision points, uncertainties, outcomes, indicating relationships (influences) between them		PMI (C)	PMI (C), ISO		PMI (S)	

30	Nominal group technique	an adaptation of brainstorming where participants share and discuss all issues before evaluation, with each participant participating equally in evaluation		PMI (S)	PMI (C)			
31	Probability and impact matrix	a tool to prioritize risks for further analysis or responses			PMI (C)		PMI (S)	PMI (S)
32	Risk data quality analysis	to evaluate the information used in risk analysis to ensure data accuracy, validate sources, conduct regular audit			PMI (C)			
33	System dynamics	a particular application of influence diagrams that can be used to further identify risks within a given situation		PMI (C)	PMI (C)		PMI (S)	
34	Contingency reserve estimation	to determine the amounts of time and costs needed to be set aside for all conditional response plans and residual risks				PMI (C)	PMI (S)	PMI (S)
35	Decision tree analysis	to determine partial and global probabilities of occurrence and expected monetary values			PMI (S), ISO	PMI (C), ISO	PMI (C)	
36	Expected monetary value	statistical technique that is used to quantify risks, which in turn assists in calculating the contingency reserve (weighted average/ expected cost/ benefit)				PMI (C), PRINCE2		

37	Failure Mode and Effects Analysis (FMEA)	a model structured to identify the various elements that can cause system failure by themselves or in combination with others based on the logic of the system		PMI (C), ISO	ISO	PMI (C), ISO	PMI (S)	
38	FTA	is used to identify how risk impacts might arise, the probability of failure of overall system, where the system can be made more reliable		PMI (C)	ISO	PMI (C)		PMI (S)
39	Monte Carlo simulation	a technique to simulate distribution for a risk of an objective, statistical method to understand the average behavior of a system				PMI (C), ISO, PRINCE2	PMI (S)	
40	PERT (project/program evaluation and review technique)	a time-based technique that can be used to quantify risks at a given point in the development of a project or program				PMI (C)	PMI (S)	
41	Bayesian analysis	a statistical paradigm that answers research questions about unknown parameters using probability statements; a parameter is summarized by an entire distribution of values instead of one fixed value as in classical frequentist analysis				ISO		

42	Bayesian network	a probabilistic graphical model for representing knowledge about an uncertain domain where each node corresponds to a random variable and each edge represents the conditional probability for the corresponding random variables				ISO		
43	Business impact analysis (BIA)	a technique used to identify and evaluate the potential effects of an interruption to critical business operations because of an uncertain event; helps to prioritize processes			ISO	ISO		
44	Cause-consequence analysis (CCA)	quantitative analysis of reliability theory; can qualitatively analyze the cause of the accident and the possible consequences of the incident				ISO		
45	Event tree analysis (eta)	visual tool to analyze and assess the probability and impact of mitigation measures for a certain risk event			ISO			
46	Human reliability analysis HRA	an analysis used to identify potential human failure events and estimate the probability of these errors using data, models or expert judgement		ISO	ISO	ISO		
47	Markov analysis	a method used to forecast the value of a variable whose predicted value is influenced only by its current state and not by any prior activity				ISO		

48	Privacy impact analysis PIA	an analysis used to assess impacts of potential privacy risks before data processing (e.g. new projects, initiatives, strategies, policies); review the processes to define how they may compromise the privacy of the individuals/organizations whose data it holds, collects, processes			ISO	ISO		
49	Data protection impact analysis DPIA	the same as PIA, but for personal data, sensitive data, when use a modern technology			ISO	ISO		
50	Toxicological risk analysis	an analysis to evaluate a safety of a product based on its composition and intended uses (for materials, food, etc.)				ISO		
51	Value at risk (var)	a parameter that quantifies the extent of possible financial losses within a firm, portfolio, position over a specific time frame; use statistical data, variance method, Monte Carlo			ISO	ISO		
52	Conditional value at risk (cvar) / Expected shortfall (ES)	a measure that quantifies the amount of tail risk an investment portfolio has; a weighted average of the "extreme" losses in the tail of the distribution of returns, beyond the value at risk (VaR) cutoff point; used for portfolio optimizations				ISO		

54	As low as reasonably practicable ALARP / as far as is reasonably practicable SFAIRP	weighing a risk against the trouble, time and money needed to control it; describes the level to which we expect to see workplace risks controlled			ISO	ISO	ISO	
55	Frequency-number diagram F-N	a graph representing the level of a risk generated by a technology, activity or a project; vertical - frequency of the event, horizontal - number of fatalities; lower = safer situation; use historical records				ISO		
56	Pareto charts	a chart representing individual values in descending order and cumulative value; helps to set priorities within a given problem				ISO	ISO	
57	Reliability centered maintenance RCM	a method to identify problems that compromise functionality; use systematic studies to assess how each failure compromises functionality, why, the consequences, how to prevent or predict them		ISO	ISO	ISO	ISO	
58	Risk index	a dataset that uses available data for various risks (e.g. disasters, crises) to support decisions about prevention measures			ISO	ISO	ISO	
59	Contingency planning	response planning as if the risk had genuinely happened (for high impact risks)			PMI (S)	PMI (S)	PMI (C)	

60	Force field analysis	used in change management context, is used in risk response planning by identifying driving forces and restraining forces which currently affect achievement of an objective		PMI (C)	PMI (S)		PMI (S)	
61	Multicriteria selection technique / MCA	criteria for deciding whether to choose a specific risk response from among several options include costs, schedule, tech requirements, risk attributes			PMI (S)	ISO	PMI (C)	
62	Scenario planning	a technique used to identify several plausible alternative scenarios with different responses that can describe and evaluate their cost and effectiveness, alternatives are compared, results in contingency planning		PMI (C), ISO, PRINCE2	PMI (S), ISO, PRINCE2	PMI (S)	PMI (C), PRINCE2	
63	Simulations	a technique to estimate the benefits and implications of different response plans vs the efforts and costs required to implement them		PMI (S)		PMI (C)	PMI (S)	
64	CBA	a systematic analysis for decision making; sums potential rewards expected from a situation or action and then subtracts the total costs associated with taking that action			ISO	ISO	ISO	

65	Game theory	analysis of strategies in competitive contexts, where the outcome of someone's choice always depends on the actions of others; an approach used to capture any available opportunity and turn risk into possibility; use historical data			ISO	ISO	ISO	
66	Data analytics	a technique used to explore known risk types by analyzing related docs and data for applicability to a specific portfolio, program, project		PMI (S)		PMI (S)		PMI (C)
67	Reserve analysis	an analytical technique to determine the essential features and relationships of components in the work management plan to establish a reserve for the schedule duration, budget, estimated cost, funds			PMI (C)	PMI (C)	PMI (C)	PMI (S)
68	Residual impact analysis	a technique used to identify side effects of implementing a response plan		PMI (C)			PMI (S)	PMI (S)
69	Risk audit	to evaluate that RM rules are being carried out as specified, are adequate for controlling the work		PMI (S)				PMI (C)
70	RBS (Risk Breakdown Structure)	a hierarchical framework of potential sources of risk, helps to identify risks in relation to its category and offers a framework for other risk identification techniques, ensure coverage of all types of risk and tests for blind spots		PMI (C), PRINCE2	PMI (S)	PMI (S)	PMI (S)	PMI (S)

71	Risk Reassessment	a technique that requires the activities (identify new risks, evaluate current risks, evaluate RM processes, closing risks) to be estimated and validated again to assure effective control					PMI (S)	PMI (C)
72	Sensitivity analysis	a technique to evaluate the effect on a variable by one or more influencing variables				PMI (C)	PMI (S)	PMI (S)
73	Status meetings	meetings including the review of all open risks and trigger conditions that have occurred, leading to risks becoming issues		PMI (S)				PMI (C)
74	Trend analysis	a technique to evaluate how the risk profile changes over time, whether the previous actions resulted in the expected effect, whether additional actions are required		PMI (S)				PMI (C)
75	Variance analysis	a technique that compares planned and actual results; increased variance = increased uncertainty and risk; used to forecast any potential for future deviations from the baseline plan prior to completion		PMI (S)				PMI (C)
76	S-curve	a graph that depicts relevant cumulative data for a project plotted against time; is used to determine dangers of any given course of action			ISO	ISO		ISO

77	Horizon scanning	to understand the complexity, challenge assumptions; used to spot potential causes of uncertainty, ensure adequate preparation, exploit opportunities and survive threats; can include driver mapping (prompt lists), trend analysis, scenario planning, stress testing;		PRINCE2				
78	Pre-mortem analysis	a technique to look ahead to the end of a project and imagine it has failed; working backwards from the point of failure; used to identify and prevent project risks		PRINCE2	PRINCE2		PRINCE2	
79	Swiss cheese model	a technique that demonstrates how a failure cannot be traced back to a single root cause, accidents are often the result of a combination of factors; used to help organizations understand why accidents occur despite their best efforts to prevent them; inform decision-making that will prevent accidents from occurring					PRINCE2	
80	Use of data	an analytical tool based on data sets containing e.g. similar projects, products, tasks; used to understand the risks, relationships between them, most appropriate controls and mitigations		PRINCE2	PRINCE2	PRINCE2	PRINCE2	PRINCE2

Appendix B: Interview questions

Table X - Main Interview questions & prompts

No	Main question	Prompts	Purpose
1	Can you tell me how your company plans for project control in the execution phase?	Can you provide examples where professional judgement (PJ), and objective knowledge (OK) played key roles in identifying new and secondary risks in the execution phase?	KM in risk identification
		How do you decide which identified potential problems are the most important to focus on in a project? What do you draw on more when making that decision (PJ/OK)? (example)	KM in risk analysis & priorities
		How often do you monitor the identified risks and their status? What do you look at when monitoring risk status? What helps you decide how often to check? Can you describe what influences your choice? How do you decide whether to adjust current RM status based on PJ or OK?	KM in monitoring & control + frequency
		Can you tell me about a time when OK or PJ influenced the choice of mitigation measures in a project? How did you figure out what to do? How did you choose the best way to handle it? How did professional experiences and OK influence the detailed development of this strategy?	KM in risk mitigation
2	How has the balance between PJ and OK been done in managing risks and decision-making in projects?	How do you advise on handling situations where PJ and OK suggest different courses of action? (example)	PJ and OK interplay
3	How does the RM process that you have described work out for you?	What do you like about it? What works well?	Effectiveness, advantages & disadvantages
		Is there something that is not working as well as you hoped? What needs to be improved?	

Appendix C: Lean tools & techniques used in construction

№	Tools & Techniques	Meaning	Application (level, phase, process if specific)	Source	Potential for RM (hypothetical)	
					Primary contribution	Secondary contribution
1	Fail Safe for Quality and Safety (Poka-yoke)	tool to generate ideas that alert for potential defects; design and implement mechanisms, processes, or systems that prevent errors or defects from occurring , e.g. forcing functions	Operational level: control (construction)	Salem et al. (2005); Santos & Powell (1999)	4	
2	Construction Process Analysis	a tool making use of process charts and top-view flow diagrams to describe the flow of processes and make it possible to quickly determine where the problem exists in the process (looks like threat diagram in logistics)	Organizational level: construction	Lee et al. (1999)	2	6.2, 7.2, 1
3	The 5S Process (Visual Workplace)	"a place for everything and everything in its place"; 5S - Seiri, Seiso, seiton, Seiketsu and Shitsuke, (meaning Sort, Straighten, Shine, Standardize, and Sustain): sort (separate needed tools and remove unneeded), straighten (arrange tools for ease of use), shine (clean up), standardize (maintain first 3S), sustain (create a habit); e.g. material layout	Operational level: construction	Salem et al. (2005)	8.1	3

4	Work Structuring	a technique for production system design, is used for overall construction production system design and guide the design and execution of interacting pieces of impending work; includes practices like constructability analysis, value engineering, productivity improvement studies	Organizational level: construction	Tsao et al. (2004)		1, 2
5	Single-Minute Exchange of dies (SMED)	a process control tool focusing on segregation of activities, their recategorization and reduction of steps in a process	Organizational level: construction	Feld (2000)		
6	Statistical Process Control (SPC)	a set of tools that is used to analyze, manage, control and improve processes to enhance the quality of production; employs statistical methods to detect and monitor special cause events; helps to achieve process stability; has a capability to reduce process variability by identifying and eliminating special causes	Organizational level: control (planning, construction)	Haddad (2021)		7.1, 9.1, 9.2
7	check sheets	a tool to collect nonconformities in a list with the number of occurrences for each cause of nonconformity	Operational level: construction	Leavengood & Reeb (2002)	RM tool	
8	histogram	a graphical tool demonstrating the shape of data set; it is used to break out the process data into regions for determined frequencies of certain events or categories of data; any notable change or anomaly indicates that there is something going on in the process, which is causing the quality problem	Organizational level: control (planning)	Bhosale & Khose (2016)		

9	Pareto chart / analysis	a graphical tool that displays the relative importance of problems in a format that is easy to interpret; make use of check sheets	Organizational level: control (planning, construction)	Leavengood & Reeb (2002)	RM tool	
10	cause and effect diagram / Ishikawa diagram / fishbone diagram	a graphical tool for organizing and displaying interrelationships of various theories of the root cause of a problem	Organizational level: project lifecycle, planning and construction phases	Leavengood & Reeb (2002)	RM tool	
11	control charts	a statistical tool used to distinguish between variations in a process resulting from common causes and variations resulting from special causes;	Organizational level: control (planning, construction)	Bhosale & Khose (2016)		
12	Concurrent Engineering	methodology involves the various tasks parallelly executed by multi-disciplinary teams with the aim of optimizing engineering cycles of products for efficiency, quality, and functionality	Operational (?) level: planning, design	Ansah et al. (2016)		
13	Muda Walk	an activity of continuous watching of the process with the aim to identify production problems/constraints	operational level: construction phase	Kaizen Institute Consulting Group (2013)	9.3	
14	5 Whys	a quality management technique of problem solving that tries to find the root cause of a problem; means to ask and answer why it occurred at least five times until an actionable root cause is identified	Organizational level: project lifecycle, planning, design and construction phases	Tsao et al. (2004)		

15	Synchronize/Line Balancing	a technique that involves leveling of workload across all processes in a value stream to remove excess capacity and bottlenecks	organizational level: construction phase	Ansah et al. (2016)		
16	Heijunka (Level Scheduling)	a technique of evenly spreading of production for orders by looking at the average demand and combining them into a production schedule that takes into consideration the volume and mix	organizational level: construction phase	Ansah et al. (2016)		
17	Failure Mode and Effects Analysis (FMEA)	a step-by-step approach for identifying potential failures in product or service, design, and manufacturing, etc.; the failures are further ranked to determine the seriousness of their consequences to take actions to eliminate them, starting with the highest ranked ones	Organizational level: control (planning, construction)	Ansah et al. (2016)	RM tool	
18	SMART Goals	a technique of setting goals that are Specific, Measurable, Attainable, Relevant, and Time-Specific	Organizational (?) level: planning	Ansah et al. (2016)	6.1	
19	Total Productive Maintenance (TPM)	a machine management technique, which includes preventive maintenance (prevent breakdown), corrective maintenance (improve repaired equipment) and maintenance prevention (daily monitoring);	Organizational & Operational levels: construction phase	Feld (2000)		
20	Time and Motion Study	A procedure for evaluating industrial or other operational efficiency based on the taken or needed time for an operation or production	Organizational level: construction phase	Ansah et al. (2016)		

21	Value Stream Mapping (VSM)	tool used to lay out the material and information flows required to know the activities performed to deliver the result; used to identify wastes and opportunities to use other lean techniques; has two states maps - current and future state maps - to stimulate the process improvement	Organizational level: construction	Patel & Patange (2017)	2	
22	Just-In-Time (JIT)	a production system which aims to produce the necessary items in the necessary quantity at the necessary time to reduce costs, increase quality, improve lead time;	Organizational & Operational level: construction	Antillón et al. (2011), Monden (2011)		
23	Continuous Flow	an approach aiming to constantly provide or process and produce units through a progressive system of uninterrupted steps in the process	Organizational level: construction	Ansah et al. (2016)		
24	Last Planner System (LPS)	a technique that shapes workflow and addresses project variability in construction; includes operational planning and production unit control; includes seven points below; sets up a framework through a pull technique	Organizational level: project lifecycle, planning and construction	Salem et al. (2005)		
25	master schedule (MS)	an overall project schedule with milestones; used for a bid package	Organizational level: project lifecycle, planning and construction	Salem et al. (2005)		

26	reverse phase schedules (RPS)	a schedule that works backwards from the completion date; based on MS; the goal is to produce a plan for the integration and coordination of various operations; closer to reality than MS	Operational level: construction	Salem et al. (2005)	2, 4	
27	six-week lookahead (SWLA)	a workflow control tool, a detailed plan for a certain period or time (e.g. 3-12 weeks); based on the results of RPS	Operational level: construction	Salem et al. (2005)	1, 2, 8.1	6.2
28	weekly work plan (WWP)	the actual schedule produced based on SWLA and the field condition before the weekly meeting; covers weekly schedule, safety issues, quality issues, material needs, workforce, construction methods, backlog of ready work, problems that can occur in the field; includes CA and VA	Operational level: construction	Salem et al. (2005)	1, 2	6.1
29	percent plan complete (PPC)	the measurement metric: number of activities that are completed as planned divided by the total number of planned activities, the higher - the better	Operational level: control (construction)	Salem et al. (2005)		
30	Constraint analysis	a tool to determine the activities that must be completed (and other stuff) so that each assignment can be executed	Operational level: planning & construction	Antillón et al. (2011)	RM tool	
31	variances analysis	performed based on the work performance plan from the previous week	Operational level: construction	Salem et al. (2005)	RM tool	

32	Increased visualization / Visual Management	communication tool to deliver information effectively via various signs and labels around the construction site	Operational level: construction	Salem et al. (2005)	6.1, 6.2., 9.3	2
33	Daily Huddle Meetings / Tool-box meetings	tool of employee involvement to increase awareness of the project, stimulate collaborative problem solving; part of the improvement cycle	Organizational & Operational levels: planning, design, construction	Salem et al. (2005)	6.1, 6.2, 8.1, 8.2	1
34	First run Studies	tool to redesign critical assignments, part of a continuous improvement; includes productivity studies and review work methods by redesigning and streamlining the distinct functions	Organizational level: planning, construction	Salem et al. (2005)		
35	Backlog of ready work	a checklist of activities that have gone through constraint analysis and are ready to be performed with the assurance that everything is indeed workable	Operational level: construction	Antillón et al. (2011)		4
36	Kaizen (Continuous improvement)	a technique for the cultural change in the workplace (to define e.g. habitual causes of inefficiencies in production)	Strategic level: planning, design, construction	Patel & Patange (2017)		
37	FIFO line (First In, First Out)	a technique that is used to prioritize activities to produce a low flow time variation; it forces the activities to be processed in the order they arrive in (end of A1 = start of A2, they match by endings)	Organizational level: scheduling (planning, construction)	Tokola et al. (2017)		

38	Set up reduction	a technique that is used to minimize machine downtime and losses of production capacity aiming to deal with the time taken between the production of the last good piece to the completion of the first good piece of the following run; use SMED as concept; use standardization of external actions, of necessary actions, use quick fasteners, supplementary tools, parallel operations, mechanical set-up systems as implementation	Organizational level: construction	Monden (2011)		
39	Bottleneck Analysis	a technique which aims to eliminate bottlenecks and constraints (areas that are causing the workflow to back up or be slower than it should be) to improve the efficiency of a production system, a process, or an activity; can use different tools (fishbone, brainstorming, 5 whys, process planning, kanban)	Organizational level: construction	Çetin (2023)		
40	Suggestion schemes	a formal mechanism which allows and encourages employees to actively contribute productive ideas for product and process improvements	Organizational & Operational levels: planning, design, construction	Ansah et al. (2016)	2	8.2, 9.3
41	Multi Process Handling	a technique of assigning operators' tasks in multiple processes in an oriented layout of a product flow	Operational level: construction	Ansah et al. (2016)		

42	Check Points & Control Points	mechanisms used to regulate and determine the levels of improvement in the activities of managers occupying various levels of positions	Organizational level: control (?)	Ansah et al. (2016)		
43	Kanban (Pull System)	a "signboard" tool to control levels, production and supply by allowing work to start exactly where and exactly when it is needed	Organizational level: planning, construction	Patel & Patange (2017); Lean Construction Institute (LCI) (2024)		8.2
44	Work Standardization	using stable repeatable methods everywhere to maintain the predictability, regular timing, regular output of process	Organizational level: planning, design, construction	Antillón et al. (2011)	2, 3, 7.2, 8.1, 9.1, 9.2	
45	Takt Time	a technique which is defined as frequency of a part or component must be produced to meet the demand, need to be measured to identify costs and inefficiency factors (producing ahead, storage)	Operational level: construction	Patel & Patange (2017)		

46	Six Sigma	an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and scientific methods to make a significant reduction in defined defect rates; focuses on defect rates which are caused by product/process variability; framework - DMAIC (define the problem, measure data, analyze with tools, improve the process, control the process)	Organizational level: planning, design, construction	Abdelhamid (2003)		
47	Root Cause Analysis	a tool used to track and analyze causes of nonconformance to develop a future plan and prevent it from happening in the future, so that improvements can be made	Organizational level: planning, design, construction	Antillón et al. (2011)	RM tool	
48	PDCA (Plan, Do, Check, Act)	tool used for studies: plan - select work process to study, assemble ppl, analyze process steps, brainstorm how to eliminate steps, check for safety, quality and productivity; do - try out ideas; check - describe and measure what actually happens; act - reconvene the team, communicate the improvement method and performance as the standard to meet	Organizational & Operational levels: planning, design, construction	Salem et al. (2005)		
49	Jidoka/Automation	a technique consists of never letting a defect pass into the next station allowing machines or workers to stop production whenever something unusual is detected	Operational level: construction	Antillón et al. (2011)		

50	Quality Function Development (QFD)	the use of stakeholders and different organization functions and units for final engineering specification of a product	Organizational & Operational levels: preparation, planning & design	Ansah et al. (2016)	6.1	
51	Off-Site Manufacturing	an approach that incorporates prefabrication and preassembly, includes the design and manufacture of units or modules, remote from the work site, and their installation in place with only the min of on-site work needed before they are fit for use	Organizational level: design & construction	Gibb (1999); Pasquire & Connolly (2002)		
52	Target Value Design	an approach that aims to maximize value with a pre-established cost target; tool for managing costs and development of new products that aims to reduce costs, ensure quality, reliability and other attributes that will add value to the customers; 'design-to-cost' method	Organizational & Operational levels: preparation, planning & design	Gomes Miron et al. (2015); Do et al. (2014)		
53	Kamishibai	a visual set of sheet lists which are designed to control the work, identify mistakes and defects in the quality of products, tutor the person controlling find possible improvements to the process of position	Organizational level: planning, construction	Rewers et al. (2016)		

54	Andon System	a technology (machine) of visual control that shows the operation status in a workstation; it provides workers the autonomy to send a signal seeking help from their supervisors and stopping the production flow when there is a problem in their workstation	Operational level: construction	Biotto et al. (2014)		
55	Overall Equipment Effectiveness	a technique to measure the gap between the actual performance and the potential performance of a manufacturing unit (machine); 3 metrics - availability, performance, quality; availability takes into account any downtime losses (6 big losses): break down losses, setup and adjustment, idling and minor stoppage, reduced speed, quality defects and rework, startup;	Operational level: construction	Sowmya & Chetan (2016)		
56	Gemba walk	an activity focusing on understanding of the current condition of the value stream and generating to-do improvement lists	Operational level: construction phase	Kaizen Institute Consulting Group (2013)	9.3	

57	A3 problem solving	a graphical tool demonstrating the problems and solutions, is used for sharing important info, requesting assistance and suggestions, achieving consensus; 3 parts: proposal story (defined problem - VSM is used here usually, plan), states report story (latest info on improvement progress in reference to milestones), final report (process deliverables, waste removed, goals achieved, success factors)	Organizational level: planning, design, construction phases	Ko & Tsai (2013)	4, 8.2, 9.3	
58	Shojinka	a technique of attaining flexibility in the number of workers at a workshop to adapt to demand changes; alter (increase / decrease) the number of workers when the production demand has changed	Operational level: construction phase	Monden (2011)		

Appendix D: Detailed lean RM framework

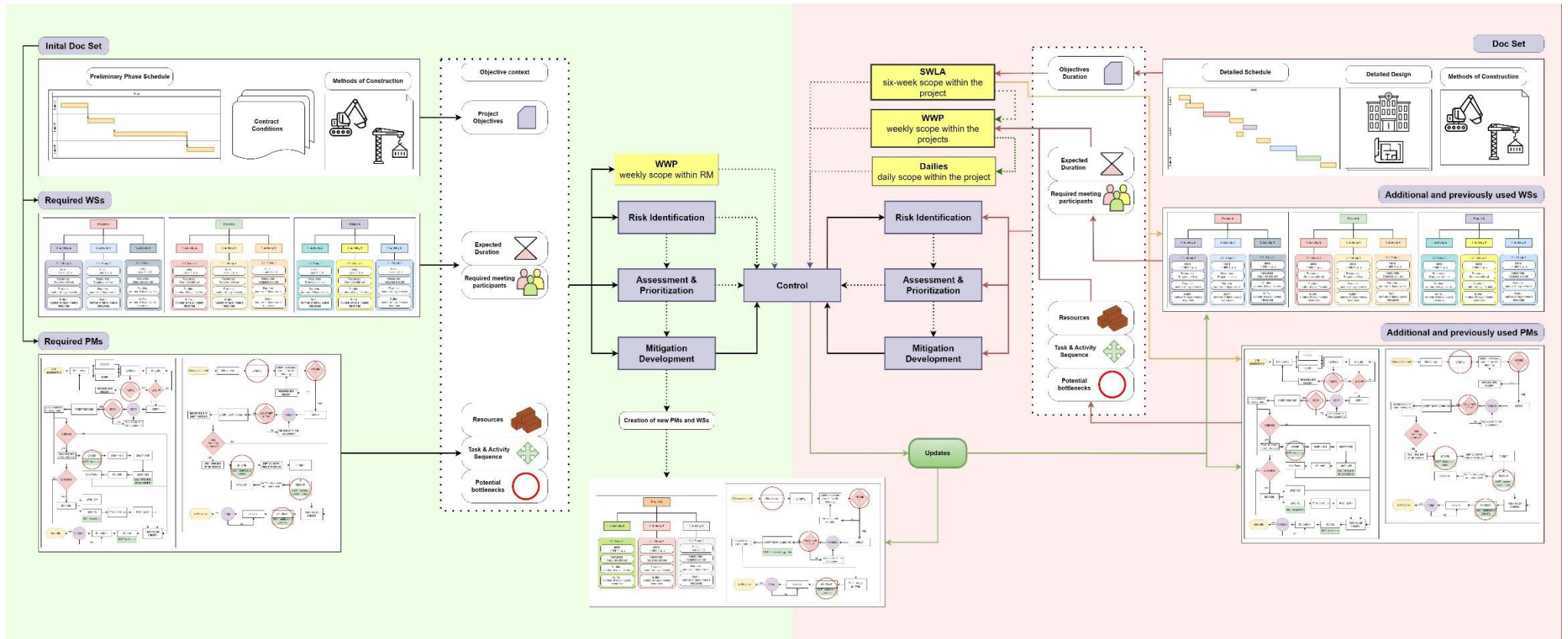


Figure 15 - Lean RM Framework (extended version)

Appendix E: Expert Review Guidance

Question and evaluation form

No	Evaluation criteria	Strongly Disagree	Slightly Disagree	Neither Disagree not Agree	Slightly Agree	Strongly Agree
1	The framework adequately reflects the following requirements:					
1.A	It can be seamlessly integrated into the existing system					
1.B	It provides objective input					
1.C	It facilitates regular team meetings and the formation of cross-functional teams					
1.D	It helps in a deep understanding of the project context					
1.E	It promotes a proactive approach to RM					
1.F	It facilitates regular reviews, data gathering and refinement, ensuring learning within the process					
2	The framework is adequately addressing the following gaps:					
2.A	It establishes an approach to the selection of the review frequency					
2.B	It helps to assess the effectiveness of the review frequency selection					
2.C	It ensures the access to people and their PJs in RM process					
2.D	It assists in customization of the internal RM guideline					
2.E	It helps to understand the context to make accurate PJs					

2.F	It helps to deal with misjudgments and omissions in PJs					
2.G	It helps to deal with subjectivity and biases					
3	The framework can improve the effectiveness of RM process					
4	The framework fits for lean purposes					
5	The framework is complete enough for the application					
6	The framework is easy to understand and use					

Evaluation questions

№	Question	Respond	
		Agree	Disagree. Please give explanations / reasons.
1	Is the proposed framework feasible?	Agree	Disagree. Please give explanations / reasons.
2	Could it help the company to plan for risks in its projects? How and to what extent? / Why not help?	-	-
3	Do you feel that this framework is applicable and useful in the company?	Yes	No. Please give explanations / reasons.
4	What can make it more useful? How?	-	-
5	What can make it more practical? How?	-	-
6	What obstacles do you see in the implementation process? How do you think they can be solved?	-	-
7	What other issues in RM process which were not outlined in the requirements and needs do you think it helps to resolve?	-	-