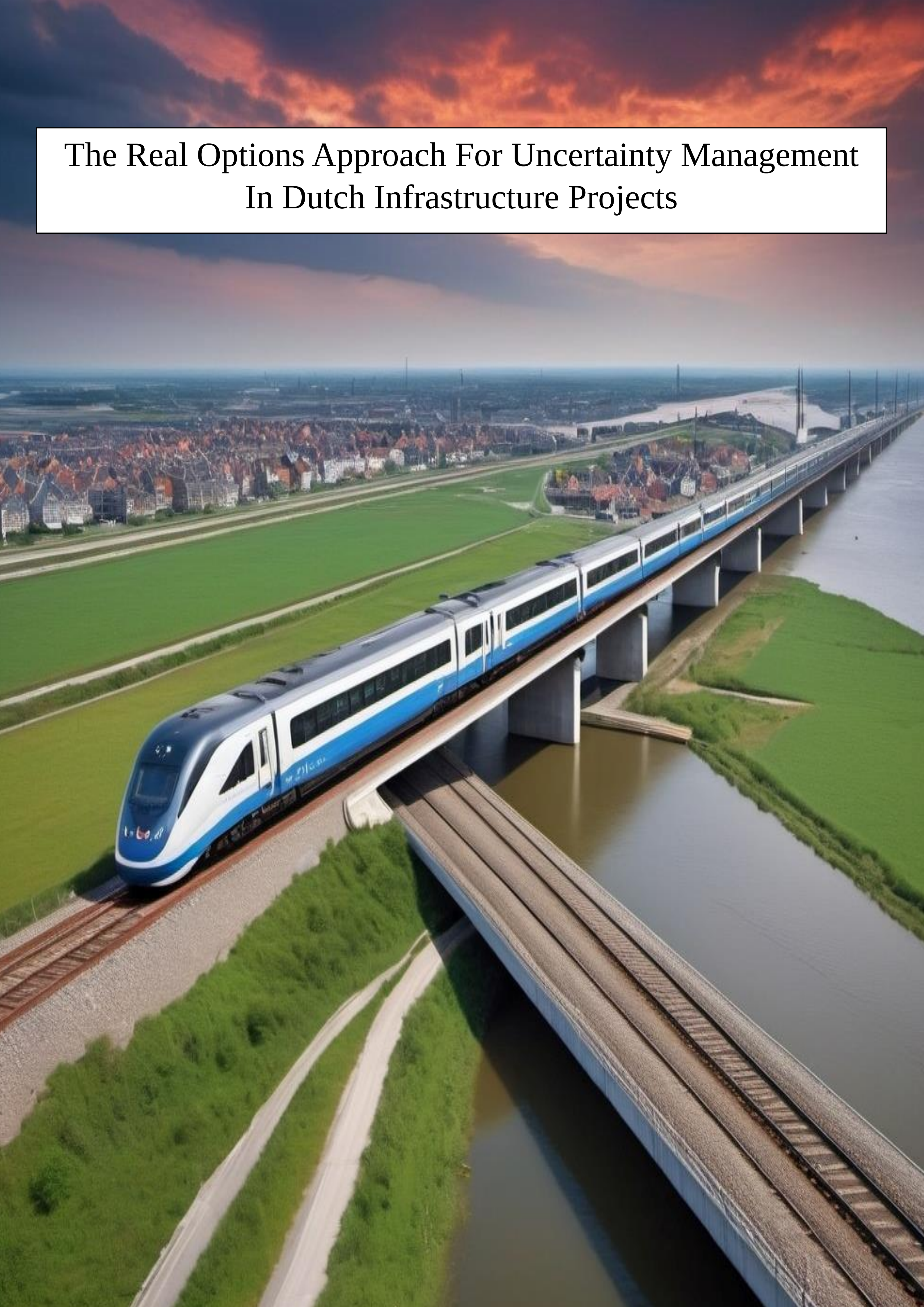
The Real Options Approach For Uncertainty Management In Dutch Infrastructure Projects



The Real Options Approach For Uncertainty Management In Dutch Infrastructure Projects

By

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in fulfilment of the requirements for the degree of

Master of Science

in Construction Management and Engineering

at the Delft University of Technology,

to be defended publicly on October 31st

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Acknowledgements

I would like to express my deepest gratitude to all those who contributed to the completion of this thesis on the application of the Real Options Approach to improve decision-making under uncertainty in the Netherlands.

First and foremost, I extend my heartfelt thanks to my thesis committee. To my chair, Daan Schraven, your critical eye and thoughtful advice have been invaluable throughout the master's journey. To my first supervisor, Martijn Leijten, your inspiration for the topic and insightful feedback have significantly shaped the direction of this research. To my second supervisor, Yara Kharoubi, your encouragement and advice have been essential in refining my work. I am deeply grateful for your collective wisdom and dedication, which have greatly contributed to the success of this thesis Special thanks to the respondents from various sectors in the Dutch infrastructure industry for their time, ideas, and openness. Your contributions were critical to the research and have enriched this thesis immensely.

To my parents, Muna and Abdulaziz, and my parents-in-law, Mariam and Ghassan, your endless support and prayers from abroad have been my strength. To my wife, Batool, and my children, Muna and Abdulaziz, thank you for your unwavering support and encouragement throughout my studies. Your patience and understanding have been a constant source of motivation. Lastly, I would like to thank my friends in Delft for creating an enjoyable and supportive environment. Your companionship has made this journey not only bearable but truly memorable.

Finally, I want to dedicate a special acknowledgement to the Syrian revolution, which has been a profound source of inspiration and motivation throughout this journey. The resilience and courage of the Syrian people, enduring unimaginable hardships, have strengthened my resolve to keep pushing forward. Their struggle serves as a constant reminder of the importance of hope and the dream of building a bright future for a free Syria. This hope continues to fuel my determination to contribute, in whatever way I can, to a better future for my country and its people.

Ahmed Abdulaziz Al Darwish
Delft, October 2024

Preface

In the landscape of decision-making under uncertainty, the process often mirrors an evolving path where initial progress is gradual, requiring thoughtful evaluation and incremental steps. However, as uncertainties grow and become more complex, the need for adaptable, innovative approaches accelerates. This research, therefore, seeks to bridge the gap between traditional decision-making frameworks and the increasing need for flexibility and adaptation. It aims to explore the Real Options Approach (ROA) as a tool to improve decision-making under uncertainty in infrastructure projects.

The research presented in this thesis, titled " *The Real Options Approach For Uncertainty Management In Dutch Infrastructure Projects*," stems from my academic journey in Construction Management and Engineering. It addresses one of the most pressing issues in infrastructure: how to manage uncertainty in a way that enhances long-term project value and adaptability. This thesis not only provides theoretical insights into ROA's potential but also offers practical recommendations for effective applications that can help decision-makers plan more resilient, adaptive infrastructure strategies.

The journey of writing this thesis has been both challenging and rewarding. It reflects my deep interest in improving decision-making under uncertainty, particularly within the Dutch infrastructure sector. ROA has always intrigued me as a method to address the complexities inherent in large-scale infrastructure projects, and through this research, I have aimed to contribute to its practical understanding and application. This thesis is the result of not only academic work but also the collaboration, support, and encouragement of many individuals. The time spent on this project has provided me with valuable insights into the field of infrastructure management and reinforced my belief in the importance of flexibility and innovation in decision-making processes.

Through the findings of this study, I hope to encourage a shift in perspective—one that sees uncertainty not as a barrier, but as a driving force for innovation in infrastructure planning and management in the Netherlands and beyond. My hope is that this thesis will serve as a stepping stone for further research and real-world application of the Real Options Approach in managing uncertainty, improving decision-making processes, and ultimately enhancing the resilience of critical infrastructure projects.

Ahmed Abdulaziz Al Darwish
Delft, October 2024

Executive Summary

Investment decisions in Dutch infrastructure projects are inherently complex due to a wide range of uncertainties, including internal factors like ageing and deterioration, and external influences such as fluctuations in land prices, labour costs, political dynamics, and environmental challenges like climate-related disasters. Traditional evaluation methods, such as Discounted Cash Flow (DCF) and Cost-Benefit Analysis (CBA), though long-standing, are increasingly seen as inadequate for addressing these multifaceted uncertainties. These methods primarily focus on financial returns without capturing the strategic value of flexibility, which is essential for adapting to changing conditions. Consequently, decision-makers risk overlooking critical opportunities that could arise from postponing or adjusting investments as uncertainties evolve.

The Real Options Approach (ROA) presents a more dynamic and promising alternative by emphasizing the value of flexibility, enabling project managers to adjust to new information and uncertainties throughout a project's lifecycle. Despite its theoretical advantages, the practical adoption of ROA in the Dutch infrastructure sector has been limited, with few projects integrating this methodology. Key barriers, as identified in the literature, include the perceived complexity of the approach, a lack of expertise, and the unclear added value in the eyes of decision-makers. Additionally, existing guidelines do not yet fully accommodate ROA, further hindering its widespread implementation. While these barriers have been recognized in previous studies, this research aims to further investigate the underlying reasons for the limited adoption of ROA and provide recommendations to overcome these challenges, with a focus on enhancing investment decision-making under uncertainty. Ultimately, the research addresses the central question:

Why has the Real Options Approach (ROA) not been widely adopted in the Dutch infrastructure sector, and how can it be used to enhance investment decision-making under uncertainty?

To address the research question at hand, the study began with a comprehensive literature review to understand ROA's global application in infrastructure projects, with a focus on the Dutch context. The review traced ROA's origins in financial markets and its adaptation to infrastructure as a strategic framework for managing uncertainty by incorporating flexibility into decision-making. Additionally, it highlighted the types of real options and optimal conditions for ROA application, laying the groundwork for investigating the gap between theory and practice in Dutch infrastructure projects. These insights informed the development of specific research questions, which guided the subsequent empirical investigation. Semi-structured interviews were conducted with sixteen participants from public and private entities, who shared their experiences and perspectives on ROA. The collected data was then coded and analysed to identify common themes. To further validate the findings and ensure their relevance, a focus group discussion with two experts in decision-making and evaluation methods under uncertainty was held.

The study offers valuable insights into Dutch infrastructure decision-making under uncertainty, revealing the overwhelming presence and impact of various uncertainties in infrastructure projects, ranging from political and market fluctuations to environmental and technological factors. These uncertainties complicate long-term planning, rendering traditional evaluation methods, such as CBA and LCA, inadequate. As static methods, they often fail to account for flexibility, which is crucial for adjusting to unforeseen circumstances. Without iterative application, these methods lack the ability to provide a comprehensive analysis, highlighting the need for more dynamic frameworks like ROA, which incorporates adaptability into decision-making. However, addressing all these uncertainties through ROA can result in overly complex models, making it essential to simplify the approach by focusing on the most critical uncertainties. These key uncertainties can be effectively identified through stakeholder consultations, ensuring that the model remains both manageable and relevant to decision-making. A key revelation from the study is that ROA's strength lies in its multidimensional approach to uncertainty. By integrating all possible scenarios into a single decision tree, ROA

simplifies the decision-making process, making it easier for decision-makers to manage complex uncertainties in adaptive paths. Furthermore, ROA shines at identifying and accounting for scenarios that traditional methods might dismiss, uncovering overlooked opportunities and offering considerable strategic benefits. Additionally, the findings demonstrate that ROA applies to a wide range of uncertainties, regardless of their source, challenging the literature that restricts its use primarily to market price uncertainty.

Despite its recognized benefits, ROA practical implementations face various challenges. The study further casts light on key barriers to ROA adoption in Dutch infrastructure. These barriers stem from institutional inertia, the perceived complexity of the methodology, and a lack of expertise and understanding among decision-makers. Political influences exacerbate the issue, as the short-term focus of political agendas often outweighs the long-term benefits of adopting more flexible, strategic approaches like ROA. Additionally, resistance to change and unfamiliarity with the practical application of ROA, combined with the absence of supportive policy frameworks, further hinder its implementation. Additionally, the study also highlights the psychological aspects of ROA implementation, an issue that has been largely overlooked in previous research. Practitioners often exhibit a general dislike of uncertainty, driven by concerns over accountability for uncertain outcomes and a perceived loss of control over project direction. The findings suggest that ROA implementation is more challenging than anticipated, emphasizing the need to address both psychological and technical barriers to its effective adoption. Despite these challenges, the study identifies several key enablers that can drive broader adoption of ROA. Simplifying the methodology and standardizing processes can make ROA more accessible, while targeted training programs can equip stakeholders with the necessary skills and knowledge. Enhancing communication through clear, engaging strategies that effectively highlight ROA's benefits can address resistance and build support. Furthermore, practical tools such as user-friendly software and detailed, real-world case studies can demonstrate the tangible advantages of ROA in managing long-term uncertainties, thereby increasing confidence in its application. Moreover, differentiating enablers for organizations and ROA promoters is essential—organizations should focus on internal strategies and fostering a supportive culture, while promoters should prioritize advocacy and stakeholder engagement to ensure successful integration.

The study concludes by providing vital recommendations for optimal use of ROA. It stresses the importance of adopting ROA as a strategic mindset, rather than relying solely on complex quantifications. While quantification can offer valuable insights, it should support—not replace—the strategic approach. ROA is particularly effective during the pre-implementation phase of large-scale projects characterized by high uncertainty and significant financial commitments, as it allows projects to be segmented into manageable components for adaptability and optimization. This makes ROA especially valuable for public entities dealing with dynamic political environments and the need for long-term planning. Key options such as phase, expansion, defer, and pre-invest strategies were highlighted for their ability to enable flexible, incremental investments, ensuring infrastructure development remains resilient and adaptive to uncertainty. While various option valuation techniques were explored, practitioners favour simplified decision tree analysis for its transparency, applicability, and ease of integration with CBA, making it ideal for ROA. This simplicity fosters clear communication and stakeholder engagement, which are often more critical to successful decision-making than the decisions themselves.

Keywords: infrastructure decision-making, uncertainty, flexibility, Dutch infrastructure sector, evaluation methods, Real Options Approach (ROA), barriers, enablers.

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Nomenclature

Abbreviation	Definition
ROA	Real Options Approach
NPV	Net-Present Value
CBA	Costs-Benefits Analysis
LCA	Life-Cycle Analysis
MCA	Multi-Criteria Analysis
TCO	Total Cost Of Ownership
VE	Value Engineering
DCF	Discounted Cash Flows
PPP	Public-Private Partnership

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1. Introduction

1.1 The Context

1.1.1 Uncertainty in Decision-Making for Dutch Infrastructure Projects

Infrastructure forms the foundation of modern human life, facilitating the movement of people, goods, resources, energy, water, and waste (Bergsma et al., 2017). Investment decisions in this sector, however, are characterized by irreversibility and significant uncertainties with large sunk costs (Zhao & Tseng, 2003; Salet et al., 2015; Martins et al., 2015), characteristics that inevitably affect the decision-making process. The lengthy development period for such projects, often spanning years or decades from conception to actual use, is susceptible to the ever-changing demands and requirements (Rhee et al., 2008; Zhao et al., 2004). Moreover, both mobility suppliers and government entities grapple with unpredictable outcomes and face significant levels of uncertainty regarding the future implications associated with the implementation of innovative solutions during their development and execution stages (Akse et al., 2023).

The complexity of these decisions is further compounded by a myriad of uncertainties arising from dynamic political, social, and environmental landscapes that infrastructure projects are not immune to (Zhao et al., 2004; van der Pol et al., 2016; Salet et al., 2015; Dotti, 2018). These uncertainties are multifaceted, encompassing both internal uncertainties, such as ageing and deterioration, and external uncertainties, including fluctuations in land price, labour costs, demand, political and socio-economic conditions, land availability, technological advancements, regulatory changes, environmental considerations, and natural disasters and climate-related challenges like earthquakes, hurricanes, floods, and water level rises. Additionally, factors such as the government's financial position, the intricacies of political decision-making, and the intentions and actions of various actors further intensify these challenges (Akse et al., 2023; van der Pol et al., 2016; Herder et al., 2011; Arts et al., 2008; Zhao et al., 2004; Rhee et al., 2008; Martins et al., 2015). Successfully managing these uncertainties is critical to enhancing a project's value and feasibility, as it requires both the anticipation of potential challenges and the strategic adaptation to changing conditions (Rhee et al., 2008).

1.1.2 Traditional Decision-Making Approaches

Traditional investment appraisal methods, wh once deemed effective for the sector, are becoming obsolete and no longer adequate since they overlook and often fail to capture the inherent value of flexibility and the strategic advantages of deferring, expanding, or abandoning investment projects in response to uncertain conditions(Dixit & Pindyck, 1994; Trigeorgis, 1996; Frayer & Uludere, 2001). These conventional approaches capture the value of a project’s future cash flow but exclude the possible value brought by future uncertainties and flexibility (Zhao & Tseng, 2003). Specifically, while simple Discounted Cash Flow (DCF) techniques consider the costs of building this flexibility into projects, they do not adequately value the benefits of exercising this flexibility at opportune moments (Martins et al., 2015). Consequently, they ignore the potential upside of investments that can be realized through managerial flexibility and innovation (Yeo & Fasheng, 2003).

Due to the uncertainty over future circumstances, it can be judicious to keep certain options open until there is more clarity (Herder et al., 2011). The significant impact of uncertainties on the future value of decisions necessitates a reevaluation of the timing and extent of investments. In scenarios where uncertainties are expected to significantly influence outcomes, deferring certain investments may be more beneficial than proceeding immediately. Such delays allow for strategic flexibility, affording decision-makers the opportunity to act under more favourable conditions and with a clearer understanding of the situation, thereby enhancing the potential value and feasibility of the investment (Rhee et al., 2008; Zhao & Tseng, 2003).

1.1.3 The Value of Flexibility

Flexibility pertains to the capacity to adjust to unpredictable, uncertain and evolving circumstances by either rendering irreversible decisions more reversible or by deferring such decisions when feasible. This adaptability consequently enhances the overall value of a project.

The significance of integrating flexibility into transportation infrastructure decision-making is well-recognized in academic literature (Zhao & Tseng, 2003). Incorporating flexibility can significantly enhance the system's adaptability and optimal responsiveness to future changes, thereby improving expected value. Relying solely on Net Present Value (NPV) calculations, without accommodating flexibility, may lead to suboptimal decisions by undervaluing certain strategic alternatives. Despite the acknowledged importance, traditional Cost-Benefit Analysis (CBA), a prevalent methodology in infrastructure evaluation, does not typically mandate the inclusion of flexibility value (Eijgenraam et al., 2000). This oversight is particularly critical for infrastructure projects characterized by long lifespans, high levels of uncertainty, and susceptibility to macroeconomic shifts (Martins et al., 2015). Therefore, a recalibration of evaluation methods to incorporate flexibility is essential for more accurate and beneficial infrastructure decision-making.

1.1.4 Real Option Approach (ROA)

Efficient resource allocation in Dutch infrastructure projects is paramount for the sustainable evolution of transportation networks. Despite a reputation for efficiency and reliability, the Dutch infrastructure system confronts challenges in adapting to evolving market dynamics and meeting future demands (Mannaerts et al., 2013; Reporting, n.d.). In light of these uncertainties, there is an urgent need for innovative decision-making tools that can incorporate flexibility and navigate the complexities of infrastructure management. As noted by Martins et al. (2015), ROA arose due to the need for a new approach to infrastructure management and valuation, since the DCF method does not allow for capturing the value of flexibility, which preferably should be incorporated into any infrastructure project.

Originating from financial economics, ROA has been recognized as a promising solution for valuing and managing strategic investments in uncertain environments (Martins et al., 2015; Dixit & Pindyck, 1994). It specifically focuses on quantifying how flexibility within systems can influence and augment the overall value of a project. By acknowledging that flexibility holds intrinsic value, ROA posits that increasing the flexibility of an investment project may increase its total value substantially, providing a strategic advantage in dynamic and uncertain investment landscapes. In contrast, Overlooking the intrinsic value of flexibility can lead to the misjudgment of preferring less adaptable investment projects over those that offer greater flexibility, potentially leading to suboptimal investment decisions (Bos & Zwaneveld, 2014; Trigeorgis, 2005). This flexibility is expressed in real options and can be defined as opportunities to respond to changing circumstances of a project by the management (Yeo & Fasheng, 2003).

The Real Options Approach (ROA) offers an alternative approach in which real options – relating to real assets – are valued throughout the decision-making process, so decision-makers can adapt to future changes by exercising the options they hold. The principle is that the project should have the necessary flexibility to adapt to future changes; i.e., at the design stage, it is necessary to incorporate flexible options (real options) that allow the infrastructure to be adapted to a certain change (Wang and de Neufville 2005). In recent years, ROA has gained increasing attention, with extensive research aimed at enhancing the understanding of its application in transportation infrastructure management (Garvin & Ford, 2012; Kashani, 2012). The growing interest in ROA over the past two decades reflects the demand for innovative methodologies in project valuation (Frayer & Uludere, 2001).

1.1.5 ROA Application in the Dutch Infrastructure Sector

Over the last two decades, real options thinking has emerged as a new approach for addressing uncertainty in investment decision-making processes (Herder et al., 2011; Dixit & Pindyck, 1994). ROA has been advocated as a more fitting valuation method for investment decisions in scenarios characterized by: (1) uncertain future investment cash flows, (2) irrevocable decisions, and (3) flexibility in the timing of decision-making (Dixit & Pindyck, 1994). Research and studies have demonstrated how real options can enhance project value by managing uncertainty through investment, structuring, and design decisions, particularly in the context of infrastructure development and construction project management (Garvin & Ford, 2012).

Despite the proven benefits, the growing body of literature supporting its efficacy, and the confirmed need by policymakers of the Dutch Ministry of Transport, Public Works and Water Management makers, the application of the real options approach in infrastructure investment decision-making in the Dutch context remains limited and in its infancy (Bos & Zwaneveld, 2014; Rhee et al., 2008). This underutilization is notable given the approach's potential to significantly improve the strategic management of large-scale, complex projects in the face of uncertainty (Garvin & Ford, 2012; Herder et al., 2011). While there have been some exploratory case studies in the Netherlands investigating the potential and application of ROA in infrastructure project evaluation (van der Pol et al., 2016; Bos & Zwaneveld, 2014; Gijsen,2016) these studies indicate that the adoption and effectiveness of ROA in the Dutch transportation infrastructure remain under-researched. The reticence towards the widespread application of ROA can largely be ascribed to its inherent complexity, the unclear added value perceived by decision-makers, and most significantly, the lack of expertise and detailed guidelines for its proper implementation, as highlighted by Garvin & Ford (2012) and Lander & Pinches (1998). According to the new Dutch guidelines for societal cost-benefit analysis (MKBA), the real-option approach is promising in theory, but its practical applicability is still a problem (Bos & Zwaneveld, 2014).

This study aims to address this gap by focusing on elucidating how the Dutch infrastructure sector can specifically benefit from the implementation of ROA, increasing the experience regarding the use of ROA in infrastructure projects and providing actionable advice for its future applications. By doing so, it seeks to bridge the divide between the theoretical potential of ROA and its practical application, thereby contributing to the strategic enhancement of infrastructure development and management in the face of evolving uncertainties, especially in contexts like the Netherlands where infrastructure projects are critical to economic and social well-being.

1.2 Problem Statement

The Dutch infrastructure sector faces significant challenges in making investment decisions under uncertainty (Zhao & Tseng, 2003; Salet et al., 2015; Martins et al., 2015). Despite the Real Options Approach (ROA) being recognized for its potential to enhance decision-making under such conditions in various industries, including infrastructure projects and the energy sector, there is a notable gap in both awareness and understanding of its applicability and implementation within the infrastructure sector (Bos & Zwaneveld, 2014; Rhee et al., 2008). This gap is particularly evident in the Dutch context, where there is a scarcity of literature and empirical studies exploring the adoption of ROA (Bos & Zwaneveld; 2008; van der Pol et al., 2016; Gijsen,2016). Additionally, there is a lack of sufficient experience in applying ROA within Dutch infrastructure decision-making, further hindering its adoption and effective utilization. Consequently, the industry is at a crossroads, seeking effective methodologies to navigate investment uncertainties but lacking a clear path to harness the benefits of ROA (Bos & Zwaneveld, 2014; Frayer & Uludere, 2001).

1.3 Research Objectives

The primary objective of this research is to enhance investment decision-making under uncertainty in the Dutch infrastructure sector by incorporating the Real Options Approach (ROA). The study aims to investigate the reasons behind the limited adoption of ROA, despite its recognized potential, and to offer recommendations that will facilitate its integration into the decision-making process. By addressing the barriers to adoption and providing actionable strategies, this research seeks to promote the effective use of ROA in managing uncertainties within infrastructure projects.

1.4 Research Questions

Based on the research objective, the following main research question was formulated:

The Main Research Question: **Why has the Real Options Approach (ROA) not been widely adopted in the Dutch Infrastructure Sector, and how can it be used to enhance investment decision-making under uncertainty?**

The following four sub-questions will be used to answer the main research question:

SQ1: What is currently known about the real option approach and its applicability & application in infrastructure projects?

SQ2: What types of uncertainties are prevalent in Dutch infrastructure decision-making, and how do existing evaluation methods address these uncertainties?

SQ3: What are the key reasons and barriers that have prevented the widespread adoption of ROA in the Dutch infrastructure sector?

SQ4: What recommendations can be provided to facilitate the adoption and implementation of ROA in the Dutch Infrastructure Sector?

1.5 Research Design

The main research question will be addressed through a structured three-stage process as outlined in Figure 1: beginning with a Literature Study, followed by Empirical Research, and concluding with a Synthesis Stage.

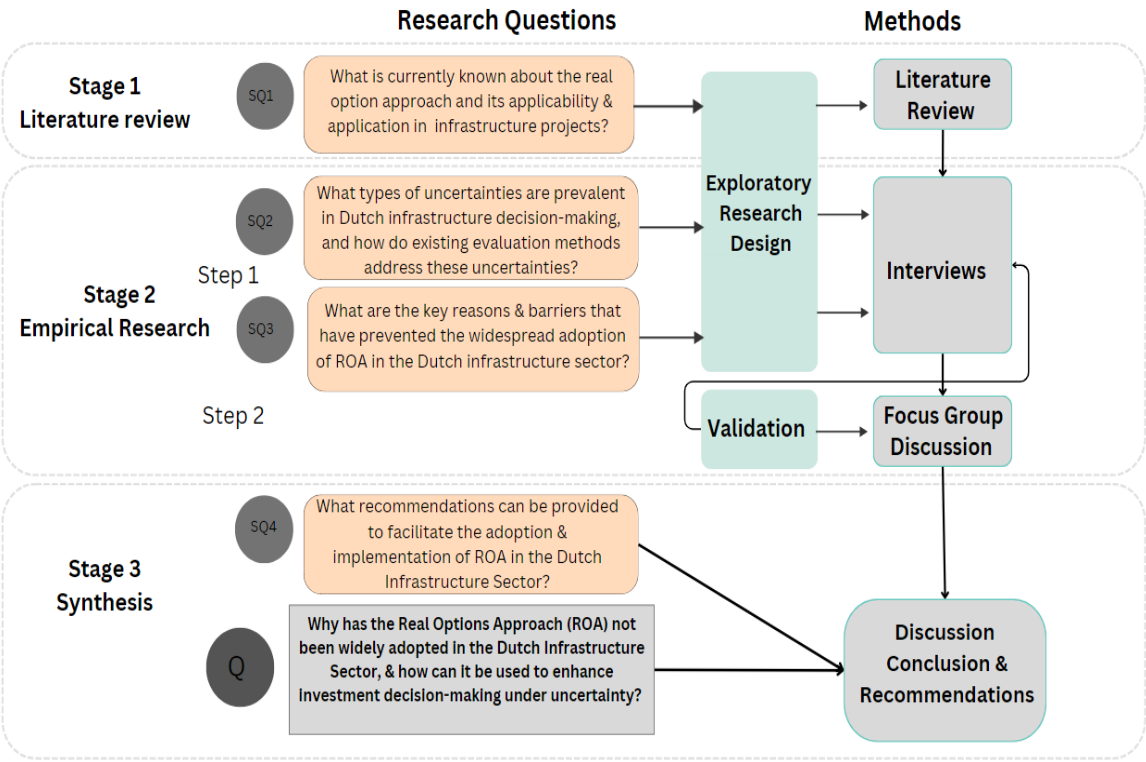

***Figure 1**: Research Design*

Stage 1. Literature Study

This initial phase aims to build a comprehensive foundation on the Real Options Approach (ROA) and its application in infrastructure projects. Scheduled for Chapter 2, this stage addresses (SQ1) by delving into existing scholarly works. A detailed literature review will be conducted, sourcing materials from reputable academic databases such as Scopus, Google Scholar, Web of Science, and the TU Delft online library. The search will employ specific keywords including 'real option' alongside terms like 'infrastructure', and 'infrastructure projects', and detailed infrastructural elements such as 'transport', 'road', 'rail', 'port', and 'airport infrastructure'.

The objective of the literature review is to thoroughly assess the current understanding and implementation of ROA in infrastructure projects, with a particular emphasis on the context within the Netherlands. It will explore the historical application of ROA, identify the predominant options utilized in infrastructure projects, and examine the significance of flexibility. Additionally, the review will evaluate the applicability of ROA, outlining its advantages, limitations, and potential obstacles to its adoption. By integrating a diverse array of academic sources, the review aims to provide valuable insights that will guide the development of interview questions. This approach ensures a well-informed foundation on ROA's global application and its specific impact on decision-making processes within the Dutch infrastructure sector.

Stage 2. Empirical Research

This stage marks the transition from theoretical analysis, as detailed in the literature review, to practical, empirical investigation. Chapter 3 outlines the methodology for conducting empirical research, establishing a framework for the analysis that follows. In Chapter 4, the research progresses through interviews that not only enhance the insights gained from the literature review but also contribute to the findings. These interviews are crucial in addressing Sub-questions 2 and 3 by identifying the main uncertainties, dominant evaluation methods, and key barriers to ROA implementation in the Dutch infrastructure sector. Chapter 5 focuses on the validation process, ensuring the reliability and accuracy of the findings through a focus group discussion. This approach ensures a seamless transition from theoretical grounding to empirical validation, enriching the research with practical insights into ROA implementation within infrastructure projects.

Stage 3. Synthesis

This final stage synthesizes the insights derived from both the literature review and the empirical research. Chapter 6 integrates the findings from the theoretical exploration and the subsequent empirical investigation, critically analyzing and comparing these results with existing literature. This discussion thoroughly addresses Sub-question 4 and lays the groundwork for Chapter 7. In Chapter 7, the overarching research findings are presented, summarizing the study's outcomes and addressing the main research question. This chapter also offers recommendations for future research and practical applications in the field. This stage not only ties together the theoretical and empirical insights but also illuminates the path forward, suggesting practical applications and areas for future investigation.

1.6 Report Structure

In this section, it is shown which chapters are used in this research and what will be discussed in those chapters, as described in Figure 2:

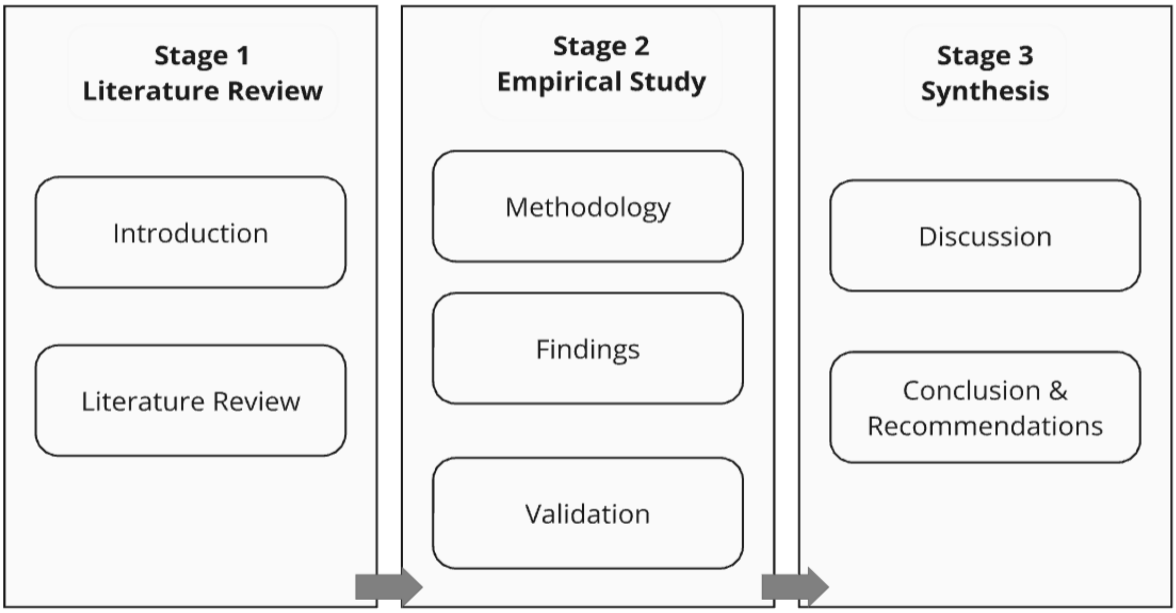

***Figure 2**: Chapter-Wise Outline of The Thesis Report*

Chapter 1: Introduction: This chapter provides an overview of the research, explaining the rationale and significance of the study. It introduces the main research question and sub-questions and defines the study's scope. The introduction aims to engage the reader's interest, encouraging them to explore the entire study.

Chapter 2: A Literature Study: This chapter reviews previous studies related to the research topics. It summarizes key findings and establishes the foundation for the research. Sub-question 1 is addressed here, and the insights gained serve as a critical foundation for the subsequent chapters, aiding in the preparation for the interviews.

Chapter 3: Research Methodology: This chapter details the methods employed for data collection and analysis. It describes the approach taken for both the literature review and empirical research, setting the framework for conducting the interviews and ensuring a systematic and rigorous research process.

Chapter 4: Findings: This chapter presents the results of the empirical research conducted through interviews. It outlines the key insights gained from these discussions and systematically presents the collected data, highlighting key themes and patterns that emerged.

Chapter 5: Validation: This chapter validates the research findings, ensuring their reliability and accuracy through a focus group discussion.

Chapter 6: Discussion: This chapter critically analyzes the research findings, comparing them with existing literature. It explores the implications of the findings, addresses the research sub-questions, and provides a comprehensive understanding of the study's outcomes.

Chapter 7: Conclusion & Recommendations: This chapter summarizes the research outcomes and draws conclusions based on the study's findings. It offers recommendations for future research and practical applications in the field, providing a clear direction for further investigation and implementation.

2. ROA & its Application in Infrastructure Project: A Literature Study

This chapter addresses Research Question 1: **What is currently known about the real options approach and its applicability & application in infrastructure projects?** Using a literature review methodology, relevant research on ROA in the infrastructure context was systematically collected, reviewed, and synthesized. The primary databases used were Scopus, Google Scholar, and Web of Science, with keywords such as ‘real option’, ‘infrastructure projects’, and specific sectors like ‘road’, ‘rail’, ‘port’, and ‘airport infrastructure’.

The review begins by outlining the foundational concepts of ROA, including its theoretical basis and strategic importance for decision-making under uncertainty. It then covers the classification of real options, valuation techniques, and the integration of ROA into infrastructure project frameworks. The current status of ROA's application in Dutch infrastructure projects is examined, along with a discussion of its benefits, disadvantages, and barriers to implementation, providing a thorough understanding of its impact.

The following sub-questions were used to guide the review:

2.1 What is ROA (ROA background?

- ROA on projects vs ROA in projects
- Different ways of using ROA
- What types of real options exist?
- What are the different techniques to value options?
- When ROA can be applied?
- The role of flexibility

2.2 What is the current status of using ROA in infrastructure decision-making?

- Current status of using ROA within the infrastructure project decision-making (worldwide).
- Current status of using ROA within the Dutch infrastructure project decision-making.

2.3 What are the benefits and barriers to the implementation of ROA in practice within the infrastructure sector?

- ROA benefits
- ROA disadvantages
- ROA barriers

2.1 Real Options Approach Background (ROA)

This section delves into ROA's origins, differentiates its application "on" versus "in" projects, explores varied usage methodologies, and categorizes key real options types. Further, it investigates ROA's optimal applicability conditions and discusses the critical role of flexibility in infrastructure investments, illustrating how incorporating ROA can lead to more nuanced and informed project evaluations.

ROA originates from financial markets, where the fundamental theory was first developed to value options on financial assets (Rhee et al., 2008). The theoretical foundations were laid by Louis Bachelier in 1900 and matured in the 1970s through the Nobel Prize-winning work of Merton Black and Scholes (Merton 1973; Black and Scholes 1973; Fernandes et al., 2011). The concept was later applied to value options on tangible assets, leading to the term "real options" (Chiara et al., 2007).

Myers (1977) is credited with introducing the term "real option" and initiating its study in this context (Fernandes et al., 2011; Myers, 1977). Since then, real options have been extensively applied across various sectors, including oil and gas, pharmaceuticals, manufacturing, airlines, mining, and real estate (Chiara et al., 2007; Zhao et al., 2004).

An option is defined by Black and Scholes (1973) as a security granting the right, but not the obligation, to buy or sell an asset under specific conditions within a predetermined timeframe. Chiara et al. (2007) expand on this by describing an option as the opportunity to undertake a beneficial action within a limited period when favourable conditions arise. Essentially, an option offers decision-makers the chance to act once uncertainties are revealed, thereby mitigating some risks (Zhao & Tseng, 2003). The value of financial options can be perceived as the cost incurred to eliminate uncertainty and gain flexibility. When this concept is applied to tangible assets, it is referred to as a real option (Rhee et al., 2008; Zhao & Tseng, 2003).

Similar to financial options, real options provide the right, but not the obligation, to acquire and utilize an asset, such as making an investment (Boyadzhiev, 2023). Real options are embedded within operational processes, activities, or investment opportunities that are not financial instruments, affording the holder the flexibility to take specific actions beyond merely purchasing something in the future (Fernandes et al., 2011; Trigeorgis, 1996; Zhao et al., 2004; De Neufville et al., 2008; Rhee et al., 2008). Since options represent rights, the return on an option can never be negative, regardless of the underlying asset's performance (Black & Scholes, 1973). The option holder has the flexibility to exercise or kill it by deciding to proceed with the investment or postpone it, awaiting further information that clarifies uncertainties and potentially alters the investment's timing (Machiels et al., 2020). Marques et al. (2023) explain that the right to purchase an asset constitutes a call option, while the right to sell an asset defines a put option. They further distinguish between European options, which can only be exercised on their maturity date, and American options, which can be exercised at any point until expiration.

Building on the foundational understanding of options as instruments that confer rights without obligatory action, ROA advances the application of option theory to tangible assets, emphasizing investment decisions marked by uncertainty, the value of future managerial discretion, and the significance of irreversibility (Kogut & Kulatilaka, 2001). Copeland and Antikarov define a real option as "the right, but not the obligation, to take an action (e.g., deferring, expanding, contracting or abandoning) at a predetermined cost, called exercise price, for a predetermined period of time—the life of the option" (Fernandes et al., 2011). Therefore, options theory studies how to model and price this "opportunity," which is typically either a contractual right (e.g., financial options, flexible commodity contracts) or system flexibility (e.g., expansion or delay options) (Chiara et al., 2007). This perspective highlights the strategic flexibility and decision-making empowerment that ROA offers to managers, enabling them to navigate the complexities and uncertainties inherent in investment opportunities (Fernandes et al., 2011).

ROA is recognized in both academic and industrial contexts as a viable capital budgeting method, serving as either an alternative or a complement to traditional tools for resource allocation under uncertainty (Driouchi et al., 2009). It provides managers with proactive skills to cope with uncertainty and acts as a tool to value flexibility and risk in infrastructure projects. ROA assumes that decision-makers can alter the sequence of a project or strategic plan by holding the right, but not the obligation, to make the considered commitment (Driouchi et al., 2009; Rhee et al., 2008). This approach is grounded in the principle that the future is uncertain, and investment opportunities can be viewed as options that might be exercised in the future based on how uncertainties unfold (Dixit & Pindyck, 1994). ROA not only calculates the value of holding options but also determines the optimal timing to exercise them (Machiels et al., 2020).

Unlike the static nature of NPV calculations, which often view investment decisions as now-or-never propositions, ROA values management's flexibility to adapt investments in response to market changes, offering a strategic tool for evaluating investments with uncertain outcomes (Boyadzhiev, 2023; Fernandes et al., 2011; Zhao et al., 2004). ROA highlights that many initial investments grant firms opportunities, but not the commitment, to undertake future investments (Di Maddaloni et al., 2024). In the context of transportation projects, "a real options approach shifts the decision-making process from simply choosing whether to invest in a transportation project to a management approach that considers a range of possible decisions, with the potential value of each decision measured in terms of its option-creating value" (Brand, Mehndiratta, & Parody, 2000, p. 57).

As highlighted, ROA neither substitutes nor excludes traditional DCF and NPV analyses within CBA but rather complements them. It builds on their foundational principles to create a new valuation paradigm, enriching both the application and depth of financial and strategic analysis (Brach, 2003; Bos & Zwaneveld, 2014). ROA enhances decision-making by comparing investment projects with and without additional flexibility options, aiming to identify the most beneficial investment strategy (Bos & Zwaneveld, 2014). This method, according to Bos & Zwaneveld (2014), proves advantageous even when traditional NPV calculations are positive, as it demonstrates the potential for higher returns through the strategic inclusion of flexibility. The project's value can thus be viewed as a combination of its NPV and the added value of flexibility. According to Rhee et al. (2008), ROA can address two major shortcomings of CBA: the use of a discount rate that does not account for project- or alternative-specific risks, and the failure to recognize the value of adapting to future conditions. Furthermore, Real Options provide additional insights and strategic guidance, enabling management to make informed and optimal decisions throughout the project's lifetime (Rhee et al., 2008).

2.1.1 ROA "in" & "on" Projects

Real Options are classified as either "on" projects or "in" projects, with the latter representing the latest expansion of ROA into physical systems design as depicted in Figure 3 (Wang & De Neufville, 2005).

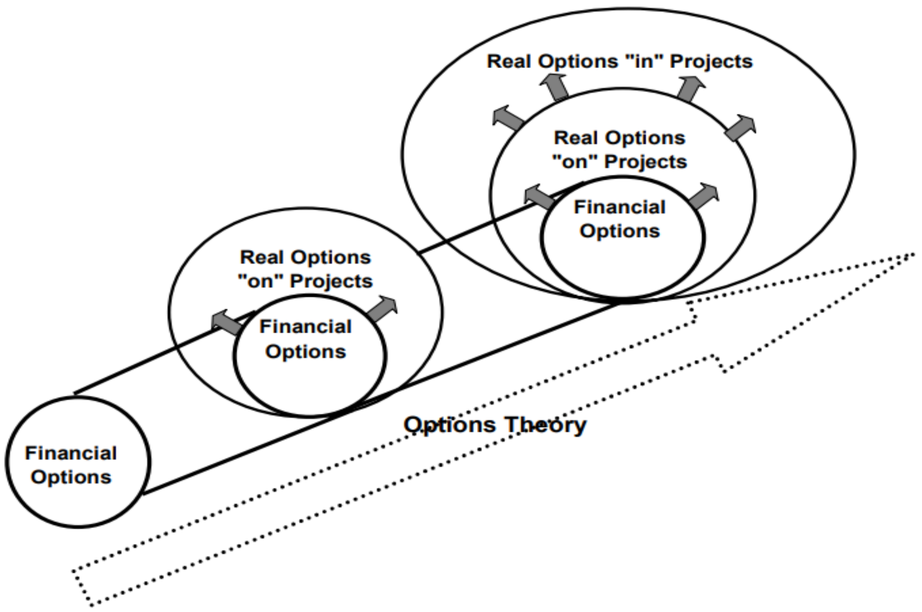

Figure 3: *Development of Options Theory*
(Wang and de Neufville 2005, p17)

Real Options "on" projects treat technology as a black box, focusing on the value of investment opportunities without modifying the system's design. They are financial options applied to technical systems (Wang & De Neufville, 2006; De Neufville et al., 2008). This approach operates at a macro level and serves as a powerful tool for strategic investment analysis, focusing on project selection and portfolio management, particularly in response to market uncertainties such as demand fluctuations (Trigeorgis, 1996). This is especially relevant in Public-Private Partnerships (PPPs), where flexibility, risk allocation, and adaptability are critical (Martins et al., 2015). Real options "on" projects allow owners to defer, expand, or close projects based on evolving market conditions, capturing the value of managerial flexibility in uncertain environments (Greden et al., 2005; Trigeorgis, 1996; De Neufville et al., 2008).

In contrast, options that emerge from alterations in a system's design are classified as Real Options "in" projects (Wang & De Neufville, 2006; Greden et al., 2005; De Neufville et al., 2008). ROA "in" projects embed flexibility within a project's design and operations, enabling managers to adapt to uncertainties, avoid obsolescence, and seize future opportunities while mitigating risks (Greden et al., 2005). This approach is especially valuable in infrastructure projects, where technological and operational adjustments can profoundly impact outcomes. Unlike real options "on" projects, which treat the infrastructure as a single system, real options "in" projects apply options within subsystems, enhancing adaptability and value (Martins et al., 2015). The analysis of real options "in" projects faces two main challenges: the complexity of identifying options due to numerous design variables and path dependencies, and the need for a specialized framework beyond standard options theory (Wang & De Neufville, 2006; Wang and de Neufville 2005). Additionally, the available data for these options is less accurate than for real options "on" projects, and they require project managers to have both technical expertise and strategic foresight to effectively manage risks and uncertainties (Wang & De Neufville, 2005; Greden et al., 2005). Table 4 summarizes the main differences between Real Options ‘on’ and ‘in’ projects:

Table 1: Real Options on & in Projects (Wang and de Neufville, 2005)

Real options “on” projects	Real options “in” projects
Value opportunities	Design flexibility
Valuation important	Decision important (go or no go)
Relatively easy to define	Difficult to define
Interdependency/Path-dependency is less of an issue.	Interdependency/Path-dependency is an important issue.

This distinction is key to understanding ROA's application, as it shows that while ROA principles apply universally, their implementation varies by project type and uncertainty. Options "in" projects handle uncertainties by embedding flexibility within design and engineering to adapt to market and technical changes, while options "on" projects focus on strategic investment decisions (Greden et al., 2005; Garvin & Ford, 2012). Both perspectives are complementary, offering a holistic framework that allows organizations to harness the full potential ROA to effectively manage uncertainties, seize opportunities, and improve project outcomes.

2.1.2 ROA Utilization Approaches

ROA stands out as a valuable tool in scenarios where information is scarce, functioning both as a way of thinking and an analytical tool, with its applicability varies per project. (Herder et al., 2011; Triantis and Borison, 2001). Wang and de Neufville (2005) emphasize that ROA transcends traditional analysis by offering a structured way to understand, organize, and quantify flexibility, making it an indispensable asset in decision-making processes. The literature outlines various approaches to employing ROA, as detailed by Wang and de Neufville (2005), Gijsen (2016), Rhee et al. (2008), and Machiels et al. (2020). These studies demonstrate the application of ROA to case studies to showcase its benefits through numerical examples in various distinct ways. Figure 4 demonstrates these methodologies, underlining the multifaceted utility of ROA in enhancing decision-making for investments.

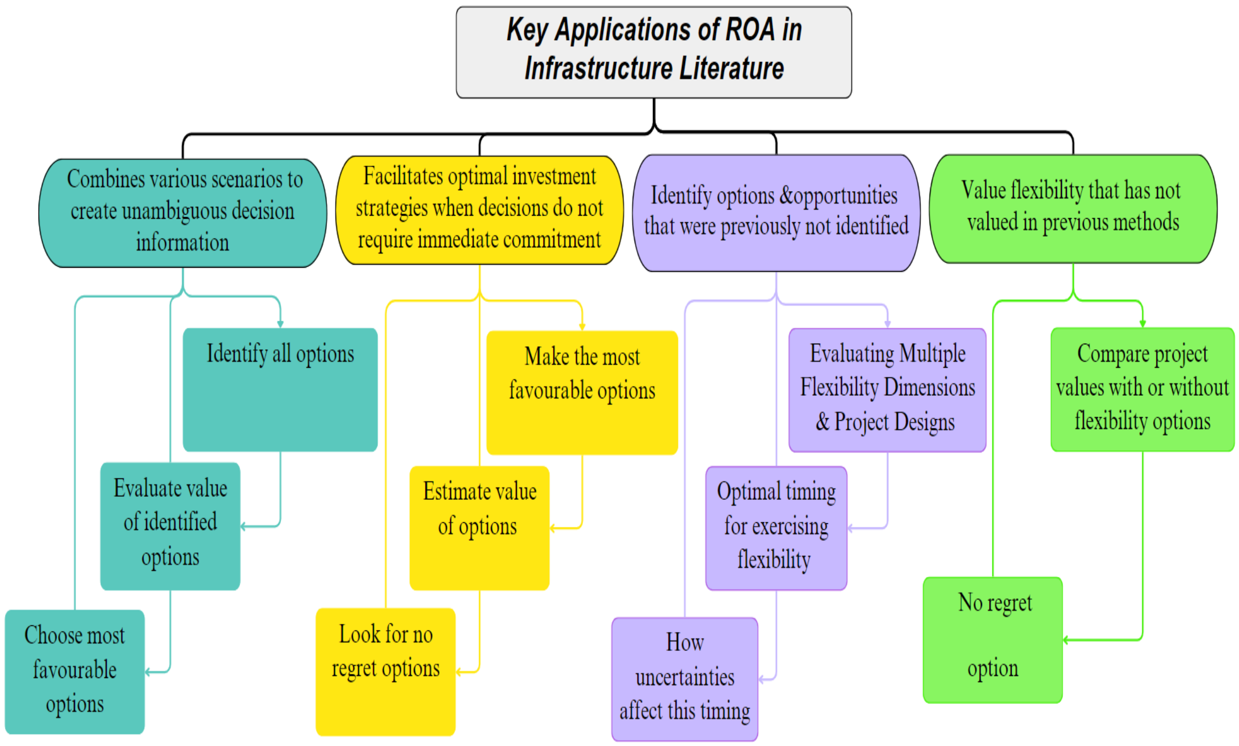

***Figure 4**: Key Applications of ROA in Infrastructure Literature*
Wang and de Neufville (2005), Gijsen (2016), Rhee et al. (2008) & Machiels et al. (2020)

2.1.3 Real Options Types

Real options can be categorized into several distinct types, each providing unique opportunities for organizations to navigate uncertainty, leverage potential future advantages adapt to evolving business landscapes, and meet varied strategic demands. Understanding differences among these options is essential, as that can impact option values in diverse ways. The options listed in Table 2 have been widely acknowledged by various authors, including Trigeorgis (1996), van Trigeorgis (2005), Rhee et al. (2008), Herder et al. (2010), Martins et al. (2015), and Machiels et al. (2020):

Table 2: Common Types of Real Options (Trigeorgis (1996); van Trigeorgis (2005); Rhee et al. (2008); Herder et al. (2010); Martins et al. (2015); Machiels et al. (2020)):

Option types	Explanations
Defer	Allows to postpone project initiation or investment to gather more information, reducing uncertainty. Or to delay actions until the circumstances turn favourable. It is particularly valuable in volatile markets when investment capital is extremely high, expensive, or scarce.
Expand	Provides the flexibility to increase project scale or scope, and system capacity, in response to favorable market conditions when a trend of higher system demand is formed. Expand options can capture additional upside potential, making them critical for projects with uncertain demand.
Abandon	Offers the possibility to exit a project or investment partially or entirely, or discontinuing an ongoing operation before its projected completion. It helps mitigate losses when projects underperform or external conditions deteriorate. Abandon options play an important role in preserving capital and redirecting resources to more profitable ventures.
Grow	Often present in R&D projects. This option exists when early investments create the opportunity for future revenue. Growth options provide a means to use initial projects as platforms for future expansion, strategically aiming to take advantage of subsequent investment opportunities.
Switch	Allows the system operators to switch different technologies or resources in industries with fluctuating input costs or product prices. Switch options enable projects to alternate between different operational modes or outputs in response to changing market conditions, enhancing adaptability, for example, by allowing a change from road lanes to railroad infrastructure in the design.
Phase	Allows projects to be developed in stages creating growth and abandonment options, with each phase contingent on the success of the previous one, thus spreading risk and investment over time. It serves as a means to respond to evolving market and technological information.
Contract	Provides flexibility to operate below capacity or even reduce the scale of operations, safeguarding against adverse developments.

Among these options, the Defer, Expand and Abandon options are particularly prevalent in infrastructure projects (Machiels et al., 2020; Marques et al., 2023). In contrast, less frequently used are the growth, switch, and stage options(Machiels et al., 2020). The literature also identifies other types of options, such as the option to shut down and subsequently restart operations, allowing projects to halt when operational costs exceed benefits and resume when conditions improve (Machiels et al., 2020; Herder et al., 2011). Additionally, in infrastructure concession projects, guarantee options and collar options have been recognized, with guarantee options being the most prevalent (Machiels et al., 2020).

2.1.4 Real Options Valuation Methods

This section will provide an overview of common methods for valuing options, focusing on their applicability to infrastructure projects within the scope of this research, rather than detailing each technique. It will briefly describe the various valuation approaches and highlight the most practical methods for assessing infrastructure projects. It is important to note that the suitability of these methods varies depending on the specific characteristics of the project. The primary methodologies for valuing options, as identified by Martins et al. (2015) and Machiels et al. (2020), are outlined below:

Table 3: Options Valuation Techniques

Valuation Methods	Description	References
Black-Scholes Model	One of the most widely used methods. It provides a closed-form solution to estimate the price of European call and put options. The model considers factors such as the underlying asset's price, the option's strike price, time to expiration, risk-free interest rate, and the asset's volatility.	Martins et al. (2015); Machiels et al. (2020)
Binomial Model	A discrete-time model for valuing options involves constructing a binomial tree to represent possible future prices of the underlying asset over time. At each node, the model assumes two possible price movements (up or down), and the option value is calculated through a backward induction process.	Martins et al. (2015); Machiels et al. (2020)
Monte Carlo Simulation	A flexible technique that uses random sampling to simulate the potential future paths of the underlying asset's price. This method can handle a wide range of complex option pricing scenarios, including those with path-dependent features. The option's value is estimated by averaging the payoffs from a large number of simulated paths. However, the method can be resource-intensive and may be deemed cumbersome for many applications. It is most beneficial in situations where detailed insights into interdependencies are necessary.	Martins et al. (2015); Machiels et al. (2020)
Risk-Adjusted Decision Tree	It integrates risk assessments into the decision-making process by breaking down complex decisions into manageable steps, each with associated probabilities and outcomes. This method enables the structured evaluation of various scenarios, accounting for uncertainties and risks at each stage. It is particularly effective for valuing options in uncertain environments, providing a clear visual representation of potential outcomes and their associated risks.	Martins et al. (2015); Machiels et al. (2020)

In Dutch infrastructure decision-making, Decision Tree methodologies are recognized as effective and promising tools, despite some debate regarding their accuracy. Although Decision Tree analysis may be considered simplistic and straightforward, its ease of application is essential for encouraging decision-makers to engage with and understand the benefits of ROA. The Netherlands Bureau for Economic Policy Analysis (CPB) advocates for the Simplified Decision Tree method due to its transparency, applicability, alignment with CBA, feasibility of implementation, and realism (van der Pol et al., 2016). Additionally, Brandão et al. (2005) assert that decision Tree analysis, when applied to real-option valuation, is suitable because Decision Trees effectively model project flexibility and produce results comparable to option pricing theory when properly applied.

2.1.5 ROA Applicability

The value of incorporating ROA depends on the project's specific context, indicating that its applicability is conditional rather than universal. This section explores the critical conditions that determine when ROA is most suitable for investment decision-making. Literature advocates ROA as a more appropriate valuation method for investment decisions in scenarios characterized by (Dixit & Pindyck, 1994; Trigeorgis, 1996; Huang & Lin, 2023; Brach, 2003; Adner & Levinthal, 2004; Machiels et al., 2020):

1. **Uncertainty**
2. **Irreversibility**
3. **Managerial flexibility**
4. **Asymmetric payoffs**

Uncertainty is essential for applying ROA (Bos & Romijn, 2017). Without uncertainty, flexibility has no value, making ROA ineffective (Bos & Zwaneveld, 2014). Uncertain investment outcomes and cash flows substantially influence valuation and decision-making. Dixit and Pindyck (1994) and Huang and Lin (2023) highlight that ROA is valuable in environments where the future is unpredictable and subject to changes affecting project viability and profitability. De Neufville et al. (2008) explain that uncertainty creates options whose values increase as uncertainty grows. Thus, ROA is especially beneficial for large-scale, innovative, long-term projects where future unpredictability enhances value flexibility and where project benefits and costs are susceptible to external trends and developments (Rhee et al., 2008). Essentially, the more uncertain the future, the greater the premium on the ability to adapt, and the higher the real option’s relevance becomes (Couto et al., 2012; Bos & Zwaneveld, 2014; Bos & Romijn, 2017). Van Den Boomen et al. (2018) recommend using ROA for projects with major, quantifiable market price uncertainties where managerial flexibility can adapt to changes. However, they advise against using ROA for projects with minimal market uncertainties or when critical market variables are difficult to estimate, suggesting alternative valuation methods instead.

The irreversibility of investments, which leads to sunk costs if a project is abandoned, highlights the importance of ROA. Infrastructure projects typically involve substantial upfront costs that cannot be recovered upon discontinuation. Huang and Lin (2023) emphasize that ROA accounts for this irreversibility, providing a framework to evaluate investments considering potential sunk costs. Uncertainty and irreversibility are particularly prevalent in infrastructure investment decisions, as noted by De Neufville et al. (2008), Herder et al. (2011), Huang and Lin (2023), and Di Maddaloni et al. (2024). These investments are characterized by significant initial outlays that exceed any possible resale value, rendering the price differential sunk costs. Additionally, the long duration of infrastructure projects increases their exposure to uncertainty (Huang & Lin, 2023; Di Maddaloni et al., 2024). Figure 5 illustrates that ROA is a more suitable valuation method than traditional NPV calculations in scenarios with high uncertainty and irreversibility (Adner & Levinthal, 2004).

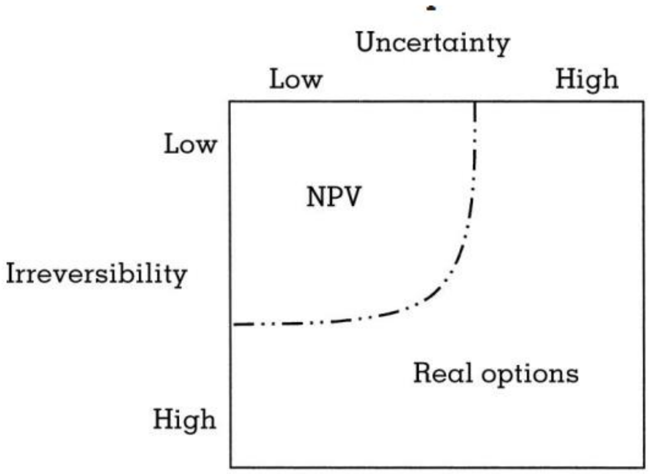

Figure 5*: Boundaries of Applicability For ROA & NPV*
(Adner and Levinthal, 2004, p 245)

Managerial flexibility, the ability to postpone, expand, contract, defer, or abandon actions combined with a pay-off contingent on such circumstances, renders ROA not only relevant but advantageous (Dixit & Pindyck, 1994; Trigeorgis, 1996). This flexibility allows management to adapt strategies in response to market shifts, And refers to what extent dealing with flexibility could affect future value (Van Den Boomen et al., 2018). Trigeorgis (1996) highlights that big investment value lies in the strategic options available to management, enabling dynamic responses to uncertainty. Brach (2003) underlines that calculating option value is meaningful only when managerial flexibility can influence project outcomes and mitigate risks. Without such flexibility, determining real option value is unnecessary, and traditional NPV-based appraisal is appropriate under uncertainty. Conversely, the ROA framework is applicable when management can respond to uncertainty and evolving competitive landscapes, effectively influencing future conditions. In the absence of flexibility, ROA and NPV yield identical results, assuming both methods properly account for relevant risks. Moreover, Rhee et al. (2008) assert that ROA provides greater value when information affecting the project's benefits and costs becomes available during its lifetime.

Asymmetric payoffs, where outcomes can vary widely based on future uncertainty, are crucial for the application of ROA. Asymmetric payoffs refer to the scenario where the potential upside gains from an investment significantly outweigh the downside risks. Unlike symmetric payoffs, where gains and losses are mirrored, asymmetric payoffs capture the essence of ROA by emphasizing the non-linear relationship between investment outcomes and underlying uncertainties. Dixit and Pindyck (1994) explain that ROA effectively values investments with payoffs that are highly dependent on uncertain future events, enabling more accurate assessments of projects with high return potential. ROA is especially valuable in situations where future revenues and costs exhibit high volatility due to environmental uncertainties, and where managerial flexibility can effectively mitigate or capitalize on these uncertainties (Rhee et al., 2008).

Furthermore, Van der Pol et al. (2016) and Gijsen (2016) highlight that applying ROA to evaluate different project alternatives is particularly beneficial when no no-regret option exists—that is when no single alternative is preferred across all future scenarios. ROA is also valuable when additional flexibility, such as delaying or phasing investments, provides clear benefits despite major additional costs. Additionally, ROA is advantageous in situations with a wide range of possible outcomes.

However, non-monetary costs and benefits that cannot be quantified have limited impact on the evaluation, as these elements cannot be incorporated into the real options framework.

In summary, ROA is not a one-size-fits-all solution and requires customization based on the specific problem, circumstances, investment alternatives, and flexibility options (Bos & Zwaneveld, 2014). The degree to which these conditions must be present for ROA to be relevant is not universally defined, emphasising the need for a nuanced understanding of how uncertainty affects future revenues in infrastructure decision-making. Although more complex and time-consuming than traditional NPV, ROA is particularly valuable for projects when the benefits to the project's business case outweigh the costs of introducing options (Rhee et al., 2008; Bos & Zwaneveld, 2014). ROA enhances value creation, mitigates risk, and increases flexibility, especially in scenarios with considerable payoff asymmetry. In such cases, the added value from ROA justifies the extra effort. Consequently, the variation between minimum and maximum cash flows is a crucial factor in the evaluation process. On the other hand, Rhee et al. (2008) indicate that NPV is sufficient for projects with short timeframes and limited outcome variability, where options provide no additional value. Additionally, NPV is appropriate when no new information emerges during the project's lifecycle and when the same decision is consistently made under all conditions. Table 4 offers a comprehensive summary of ROA's conditions applicability in comparison to NPV.

Table 4: Applicability Conditions for ROA vs. NPV

Condition	ROA Offers More Added Value	NPV Suffices	References
Timeframe of Decisions	Decisions affect long timeframes, allowing for strategic flexibility and adaptation over extended periods.	Projects have short timeframes where immediate outcomes are more critical and long-term flexibility is limited.	Rhee et al., 2008; De Neufville et al. 2008; Huang & Lin, 2023; Di Maddaloni et al., 2024
Uncertainty/ Volatility	High volatility or uncertainty in costs and revenues, enables ROA to capture the value of flexibility and adaptability.	Low volatility with a narrow range of possible outcomes, making NPV sufficient for valuation.	Bos & Romijn, 2017; Bos & Zwaneveld, 2014; Dixit & Pindyck, 1994; Huang & Lin, 2023; De Neufville et al., 2008; Couto et al., 2012; Machiels et al., 2020; Van Den Boomen et al. 2018; Rhee et al., 2008;Trigeorgis, 1996; Brach, 2003; Adner & Levinthal, 2004
Irreversibility	Investments are irreversible with significant upfront costs that cannot be recovered if the project is abandoned, making ROA essential for evaluating sunk costs.	Investments are reversible or have minimal sunk costs, reducing the need for ROA's flexibility features.	Huang & Lin, 2023; De Neufville et al., 2008; Herder et al., 2011; Di Maddaloni et al., 2024; Adner & Levinthal, 2004;Dixit & Pindyck, 1994; Trigeorgis, 1996; Brach, 2003; Machiels et al., 2020
Managerial Flexibility	High managerial flexibility to postpone, expand, contract, defer, or abandon actions based on evolving circumstances, enhancing strategic decision-making.	Limited or no managerial flexibility, making traditional NPV static and adequate for evaluation.	Dixit & Pindyck, 1994; Trigeorgis, 1996; Brach, 2003; Van Den Boomen et al., 2018

Condition	ROA Offers More Added Value	NPV Suffices	References
Asymmetric Payoffs	Potential upside gains significantly outweigh downside risks, allowing ROA to effectively value projects with high return potential dependent on uncertain future events.	Payoffs are symmetric with balanced gains and losses, where NPV adequately captures the investment's value.	Dixit & Pindyck, 1994; Rhee et al., 2008; Bos & Zwaneveld, 2014
No No-Regret Alternative	No single alternative project is preferred across all future scenarios, ensuring ROA provides unique strategic benefits.	A preferred alternative exists in all future scenarios, making NPV a sufficient valuation method.	van der Pol et al., 2016; Gijsen (2016)
Flexibility Costs vs. Benefits	Additional flexibility (e.g., delaying or phasing) offers clear benefits despite non-negligible additional costs, justifying the use of ROA.	Options to introduce flexibility have no added value or benefits do not outweigh the costs, making NPV adequate.	van der Pol et al., 2016; Gijsen (2016); Bos & Zwaneveld, 2014
Outcome Variability (Wide Spread)	A large spread of possible outcomes enhances ROA's value by capturing and exploiting a broad range of future states.	Limited variability in outcomes, where NPV can sufficiently evaluate the project without needing ROA's flexibility.	van der Pol et al., 2016; Gijsen (2016)
Information Availability	New information that affects project benefits and costs becomes available during the project's lifetime, allowing ROA to adapt to changing conditions.	No new information becomes available during the project's life, making NPV a straightforward and sufficient method.	Rhee et al., 2008
External Trends/Developments	Project benefits and costs are susceptible to external trends and developments, enabling ROA to leverage strategic options in response to these changes.	External trends have minimal impact, and the same decision will be made regardless of changing external conditions.	Rhee et al., 2008
Non-Monetary Factors	Non-monetary costs and benefits have a limited impact on the evaluation outcome, as they cannot be incorporated into ROA.	Significant non-monetary factors influence the evaluation, necessitating methods beyond ROA to capture their effects.	van der Pol et al., 2016; Gijsen (2016)

2.1.5.1 The Role of Flexibility

To effectively explore ROA's application and relevance in infrastructure projects, it is essential to first understand the concept and value of flexibility, which underlines the importance of integrating ROA into decision-making processes.

Flexibility in infrastructure investments is highly valuable in an increasingly uncertain future, as it allows for savings on potentially unnecessary investments and enables better responses to developments in the economy, demography, climate, technology, and politics (Bos & Romijn, 2017). A flexible system is defined as one "characterized by a ready capability to adapt to new, different, or changing requirements," and capable of coping with uncertainties associated with changing needs (Zhao & Tseng, 2003). Systems with inherent flexibility often yield higher expected value than those rigidly planned around specific future scenarios (De Neufville et al., 2008). CPB states that "flexibility in design and phasing of a project makes it easier to adapt to future developments and reduce risks resulting from incorrect decisions." Therefore, in an uncertain future, a flexible investment strategy that adapts to changing conditions offers significant advantages (Bos & Romijn, 2017).

Integrating flexibility into project designs to navigate future uncertainties, thereby enhancing project resilience and performance (De Neufville and Scholtes, 2011). By acknowledging the unpredictability of the future and adopting adaptable design principles, project teams can improve outcomes, seize new opportunities, and avoid losses. The value of flexibility arises from uncertainties in future needs or conditions; in a predictable system, flexibility would be unnecessary. Thus, modelling uncertainty is crucial for accurately valuing flexibility. As uncertainty increases, the importance of flexibility correspondingly grows. Ignoring flexibility's value can lead to the dismissal of viable alternatives. When properly valued, flexibility often results in more ambitious optimal designs (Zhao & Tseng, 2003).

Incorporating flexibility into infrastructure decision-making is well-recognized in academic literature (Zhao & Tseng, 2003). Ford et al. (2002) discuss how flexibility leads to improved outcomes by allowing adjustments aligned with evolving market demands and technological trends, avoiding obsolescence and enhancing utility. However, traditional CBA, commonly used in infrastructure evaluation, typically does not mandate the inclusion of flexibility's value (Eijgenraam et al., 2000). This oversight is critical for projects with long lifespans, high uncertainty, and susceptibility to macroeconomic shifts (Martins, Marques, & Cruz, 2015). Therefore, evaluation methods must be recalibrated to incorporate flexibility for more accurate and beneficial decision-making.

ROA offers a systematic method to value flexibility by treating investment decisions as options exercisable in the future (Marques et al., 2023). It provides a framework for quantifying and incorporating flexibility into project evaluation and decision-making. A key characteristic of ROA is that it explicitly accounts for the value of flexibility (Bos & Romijn, 2017). Van Den Boomen et al. (2018) state that managerial flexibility in infrastructure investment and replacement decisions adds value, which ROA captures under uncertain market conditions. ROA assumes that flexibility has value; increasing a project's flexibility can substantially increase its total value (De Neufville et al., 2008; Trigeorgis, 2005). Flexibility is expressed through real options, defined as "the right, but not the obligation, to exercise an option that creates flexibility" (Yeo & Fasheng, 2003). This contrasts with traditional valuation methods like NPV, which consider only information known at the initial moment and may not fully capture the value of managerial flexibility to alter a project's course in response to new information, thus ignoring the market's dynamic environment (Marques et al., 2023). Trigeorgis (1996) articulated how ROA can evaluate various real options, such as the options to defer, expand, contract, or abandon projects, providing a more accurate reflection of project value under uncertainty. De Neufville et al. (2008) explain that incorporating ROA into system design makes the system adaptable to future technological innovations and changing stakeholder needs, as designers require real options, and the flexibility to alter development trajectories as needed. Figure 6 illustrates how ROA accounts for the value of flexibility embedded within projects:

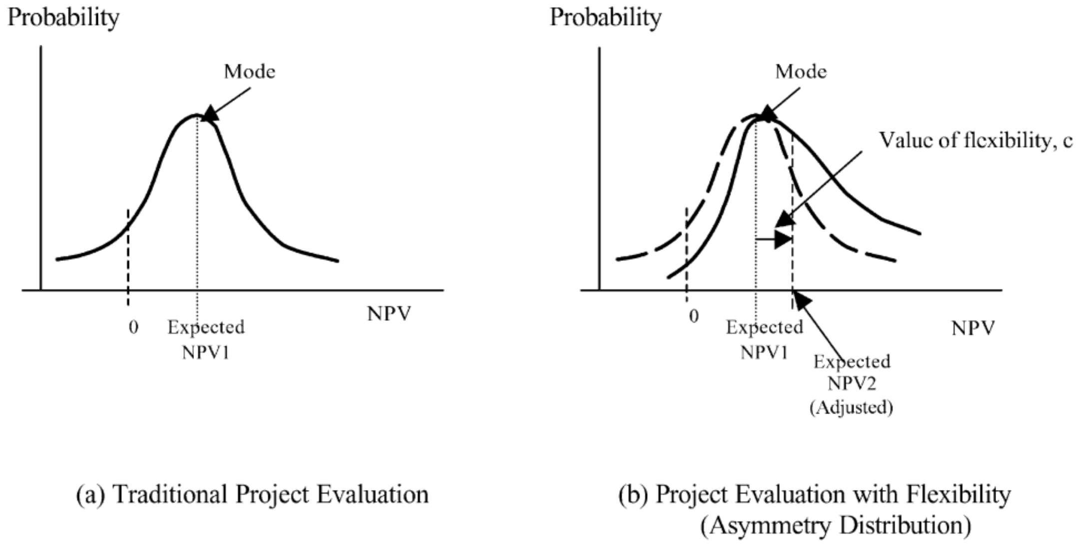

***Figure 6**: Value of Management Flexibility*
(Yeo and Fasheng 2003, p 245)

Based on the fact flexibility has a value, which can be captured in real options, the new total value of a project would be (Trigeorgis, 2005; Gijsen, 2016):

- $NPV\ active = NPV\ passive + f\ (value\ of\ real\ options\ embedded\ in\ the\ project)$

However, flexible solutions are not without cost (Bos & Romijn, 2017). And real options may involve some up-front costs. Therefore, the flexibility must be valued to compare it with these costs (De Neufville et al., 2008). In this case, there are additional costs and the formula will be as follows:

- $NPV\ active = NPV\ passive + value\ of\ option - cost\ of\ option$

If the value weighs out the costs of an option, the NPV will increase. Hence, the value of an option is the difference between the values of the underlying asset (e.g. the project) with and without the option (Garvin & Ford, 2012).

2.2 ROA Application in Infrastructure Decision-making

This introduction sets the stage for a detailed examination of ROA's application globally, highlighting its benefits in enhancing project value and adaptability, and specifically investigates its use and challenges within the Netherlands, providing an overview of the approach's impact on infrastructure development.

2.2.1 ROA Application Worldwide

In infrastructure decision-making, ROA is particularly relevant due to the large scale, long lifespans, irreversible investments, significant uncertainties, and economic impact of such projects (Zhao & Tseng, 2003; Zhao et al., 2004; Cheah & Liu, 2006; Rhee et al., 2008; Herder et al., 2011). Dixit & Pindyck (1994) categorize uncertainties into three types: market, technological, and policy. Market uncertainty involves fluctuating project costs and benefits, such as transport infrastructure demand. Technological uncertainty relates to project completion challenges or the effectiveness of new technologies. Policy uncertainty involves unpredictable regulations. In transportation projects, Machiels et al. (2020) identify market uncertainty, particularly transport demand, as the most common, reinforcing the importance of ROA in managing these uncertainties (Van Den Boomen et al., 2018).

Cheah and Liu (2006) argue that incorporating flexibility in infrastructure project design and execution is essential due to uncertainties and economic irreversibility. ROA has emerged as a tool for combating uncertainty and harnessing flexibility within project management, particularly in infrastructure sectors (Machiels et al., 2020; Marques et al., 2023). ROA allows managers to treat investment decisions as options, enabling them to defer, expand, or abandon projects based on evolving conditions (Cheah & Liu, 2006; Miller & Park, 2002). The presence of economic competition, space constraints, and the need for future expansion further emphasize the importance of using ROA in decision-making (Zhao & Tseng, 2003). Herder et al. (2011) highlight that ROA views infrastructure projects as evolving processes, allowing for strategic adjustments over time, and accommodating unforeseen challenges and opportunities. This flexibility, referred to as "options on projects," enables scalable, adaptive decision-making.

Martins et al. (2015) trace the inception of ROA in infrastructure to a 1991 theoretical case study on Sydney Airport by de Neufville and note a rise in its application since the early 2000s. Their review of 80 studies from 2003 to 2013 reveals that airports and toll roads are the primary sectors for ROA application. While contractual real options in PPPs were emphasized for flexibility in contracts, other options like switching, growth, and contraction were also noted for managing operational flexibility and adapting to market conditions. The authors highlight ROA's ability to incorporate flexibility from design and operations and its strength in addressing market uncertainties, advocating it as a transformative tool for strategic infrastructure planning.

Zhao et al. (2004), as reviewed by Martins et al. (2015), applied a real options model to a hypothetical 50-mile U.S. highway, showing how ROA optimizes decisions by addressing uncertainties in traffic demand, land pricing, and highway conditions. Similarly, Cheah & Liu (2006) demonstrated the value of ROA in the Malaysia-Singapore Second Crossing project by incorporating flexibility to manage uncertainties like traffic forecasts and advocating for phased construction to improve financial and operational outcomes. Expanding on this, Zhao and Tseng (2003) emphasized the economic benefits of embedding flexibility in infrastructure, demonstrated through a public parking garage case in Washington, D.C. They showed that neglecting flexibility, especially under uncertain demand, leads to economic drawbacks. Using ROA, the study revealed how upfront investments, like reinforcing the foundation for potential expansion, yield long-term advantages. Likewise, the George Washington Bridge exemplifies ROA in engineering, designed for future expansion without immediate action (De Neufville et al., 2008), underlining the value of flexibility in the design phase.

Additionally, Martins et al. (2015) highlight the limited research on the interplay of multiple embedded real options in infrastructure projects. A key contribution in this area is Bowe and Lee's (2004) ex-post evaluation of the Taiwan High-Speed Rail (THSR) project, which examined real options such as postponing construction, early abandonment, and adapting scale or functionality. Using actual data, they demonstrated how traditional NPV analyses fail to fully capture the value of complex investments, stressing the importance of managerial flexibility in navigating market changes.

Similarly, Rose's (1998) study of the Melbourne CityLink Project pointed out the strategic value of real options in PPPs, particularly in toll road infrastructure. Rose showed that options like termination rights and payment deferrals substantially enhance project value by reducing risks and protecting investor returns, cautioning that neglecting these components can lead to undervaluing the project. Likewise, De Neufville et al. (2008) demonstrated how ROA enhances infrastructure project value through a case study on Intelligent Transportation Systems (ITS) for crash avoidance at highway intersections. By incorporating ROA to account for both potential gains and the option to abandon the project, the expected value tripled compared to standard CBA estimates.

In their review, Machiels et al. (2020) analysed 42 articles, with over half published between 2014 and 2019, providing fresh insights into ROA's application in transport infrastructure projects. Their review highlighted road infrastructure, particularly toll roads, as the primary focus, along with railways, airports, car parks, and ports. The authors emphasized ROA's potential in managing uncertainties in large-scale projects, identifying and communicating risks, and quantitatively valuing flexibility. They also demonstrated its effectiveness in PPP transportation projects, particularly in managing risk distribution between public and private partners, which contributes to project success. ROA was presented as a flexible alternative to the rigid 'predict and control' approach, which often overlooks risks, leaving megaprojects vulnerable to unforeseen changes. The authors concluded that integrating ROA overcomes the limitations of traditional methods like CBA, which may be suitable for passive investments but fall short in strategic planning by not accounting for active management and market adaptation. The 2017 study by Martins et al, Referenced in Machiels et al.'s (2020) literature review, examined the Container Terminal of Ferrol (CTF) in Spain to highlight the benefits of using ROA in infrastructure projects facing uncertainty. The study assessed CTF's phased expansion strategy through an ex-post evaluation using actual data. Unlike traditional NPV analyses, which deemed the project economically unfeasible due to high costs, ROA revealed that incorporating flexibility improved its NPV. This demonstrated how adaptable planning can turn an unattractive project into a viable investment, showing how ROA fosters realistic planning by embracing uncertainties and supporting adaptable strategies for better decision-making.

Furthermore, a recent literature review by Marques et al. (2023) examined the application of ROA in infrastructure concession projects, analyzing 111 articles from 2000 to 2022. The review confirmed previous findings on ROA's effectiveness in handling uncertainty and valuing managerial flexibility. It highlighted a predominant focus on road projects, with growing interest in sanitation, rail, airports, and ports, aligning with earlier research. Despite the increased use of ROA in infrastructure, its application in transportation remains limited, with DCF analysis still the by far dominant investment evaluation method (Di Maddaloni et al., 2024). Additionally, most studies on ROA are theoretical or ex-post evaluations, lacking direct, practical applications in real-world projects (Machiels et al., 2020; Martins et al., 2015). While these studies illustrate ROA's benefits, they fall short of offering empirical evidence to substantiate their findings.

Despite advances in methodology and the conceptual shift toward incorporating flexibility in project planning, Machiels et al. (2020), Martins et al. (2015), and Marques et al. (2023) stress the need for further empirical research to validate ROA's theoretical benefits in infrastructure development. They call for more case studies across diverse sectors to better understand ROA’s practical application. Furthermore, these authors note that most studies focus on a single type of real option, typically expansion options, with limited exploration of interactions between multiple options. Moreover, studies often address only one source of uncertainty, such as traffic flow, while overlooking others like project value, revenue, and demand, as highlighted by Van Den Boomen et al. (2018).

Additionally, the predominantly cited case studies centred on PPPs, have limited relevance for a comprehensive review as they focus more on contractual nuances rather than the projects themselves. However, they still provide useful insights into the methodologies and calculations used. Much of the literature emphasizes the potential benefits of ROA without addressing the operational and contractual complexities involved (Machiels et al., 2020). On top of that, the literature tends to feature articles rather than detailed calculations, likely because these are used privately and based on assumptions that are not always transparent. As a result, ROA knowledge remains largely within academic circles, and accessing actual evaluation processes in infrastructure decision-making is challenging due to limited public availability. Table 5 summarizes the key findings of this section.

Table 5: Current Status Of ROA Application Worldwide

Aspect	Details	References
ROA Applicability in Infrastructure Projects	ROA is particularly suited for infrastructure projects due to their large scale, long lifespans, significant irreversible investments, and inherent uncertainties. These characteristics make ROA an effective tool for managing the economic impact and strategic decisions associated with such projects.	Zhao & Tseng, 2003; Zhao et al., 2004; Cheah & Liu, 2006; Rhee et al., 2008; Herder et al., 2011; Van Den Boomen et al., 2018.
ROA Application in Infrastructure Projects	ROA is utilized across various infrastructure sectors to adaptively manage projects amidst uncertainties like market demand fluctuations, technological advancements, and policy changes. It provides options to defer, expand, or abandon projects based on evolving conditions, thereby enhancing flexible project management. This adaptability is crucial for addressing challenges such as economic competition, space constraints, and the need for future expansion.	Cheah & Liu, 2006; Machiels et al., 2020; Marques et al., 2023; Miller & Park, 2002; Herder et al., 2011; Zhao & Tseng, 2003.
Summary of Previous Studies	Studies have highlighted ROA's growing importance in infrastructure, especially in sectors like airports, toll roads, and rail projects. These studies emphasize the benefits of incorporating flexibility early in planning, enabling effective navigation of market uncertainties. Key applications demonstrate ROA's utility in enhancing project outcomes through adaptable designs, phased construction, and strategic decision-making. Examples include the Sydney Airport case study, the Malaysia-Singapore Second Crossing project, and the George Washington Bridge.	Martins et al., 2015; Zhao et al., 2004; Cheah & Liu, 2006; Zhao & Tseng, 2003; De Neufville et al., 2008; Bowe & Lee, 2004; Rose, 1998; Rhee et al., 2008; Machiels et al. 2020; Martins et al 2017; Marques et al. (2023).
Nature of Studies	Most studies on ROA in infrastructure are theoretical or ex-post evaluations rather than direct, practical applications. This highlights a gap between theoretical modelling and real-world applicability, indicating the need for studies that bridge this divide through empirical research and practical case analyses.	Martins et al., 2015; Machiels et al., 2020; Marques et al., 2023.

Identified Gaps or Future Directions	Despite ROA's theoretical advantages, its practical implementation remains limited. There is a need for more empirical research, diverse case studies, and exploration of interactions among various real options to better understand ROA's benefits. Additionally, most studies focus on single types of real options and specific sources of uncertainty, such as traffic flow, while overlooking others like project value, revenue, and demand. Enhancing empirical evidence and addressing multiple uncertainties is critical for advancing ROA's practical application in strategic infrastructure planning and execution.	Machiels et al., 2020; Martins et al., 2015; Marques et al., 2023; Van Den Boomen et al., 2018; Di Maddaloni et al., 2024.

2.2.2 ROA Application in the Dutch Context

In the Dutch context, despite the proven benefits, the growing body of literature supporting its efficacy, and the confirmed need by policymakers of the Dutch Ministry of Transport, Public Works and Water Management makers, the application of the ROA in infrastructure investment decision-making remains limited and in its infancy, particularly within the railway sector (Rhee et al., 2008; Bos & Zwaneveld, 2014; Gijsen, 2016; Van Den Boomen et al. 2018). This underutilization is notable given the approach's potential to improve the strategic management of large-scale, complex projects in the face of uncertainty (Garvin & Ford, 2012; Herder et al., 2011). According to the new Dutch guidelines for societal cost-benefit analysis, the real-option approach is promising in theory, but its practical application remains challenging (Bos & Zwaneveld, 2014).

In the Netherlands, public studies by van der Pol et al. (2016), Gijsen (2016), and Bos & Zwaneveld (2014) explore the application of ROA in evaluating infrastructure projects. These exploratory case studies highlight ROA's relevance while acknowledging certain limitations. For instance, Gijsen (2016) examined the A27 highway widening and Kaagbrug A44 bridge replacement, demonstrating ROA's advantages over traditional NPV methods. In the A27 highway case, ROA recommended deferring and phasing construction to adapt investments to actual traffic growth, flexibility not captured by NPV. Similarly, for the Kaagbrug A44 bridge replacement, ROA advocated postponing the project to better align with future traffic patterns and highway plans, allowing for expansion based on demand forecasts.

Likewise, Rhee et al. (2008) demonstrated ROA's effectiveness in managing uncertain infrastructure investments through the 'Zuiderzeelijn' project. Initially rejected due to high NPV costs, ROA proposed a phased construction approach, starting with the Schiphol to Almere section and expanding to Groningen based on passenger growth. This strategy revealed strategic benefits and cost savings, highlighting NPV's limitations and the importance of flexibility in infrastructure planning. Incorporating ROA could have enabled the 'Zuiderzeelijn' project to adapt to future changes, enhancing its economic and strategic viability. This theoretical study reflects the missed opportunity in the 'Zuiderzeelijn' project by not using ROA to enhance investment decisions and improve the project's economic viability. In another study, Van Den Boomen et al. (2018) applied ROA to the replacement of an ageing bridge in the Netherlands, addressing structural integrity, political decisions affecting urban traffic, and fluctuating construction costs. ROA facilitated a phased decision-making strategy, allowing the project to be deferred until more information or favourable conditions emerged, such as changes in traffic flow or construction costs.

Furthermore, Van der Pol et al. (2016) applied ROA in the Netherlands through three case studies: the Meppelerdiepsluis replacement, the Ramspolbrug replacement, and a hypothetical highway expansion with a tunnel. Utilizing decision tree analysis, these studies demonstrated ROA's ability to incorporate flexibility in infrastructure projects, allowing for adjustments, replacements, or expansions based on evolving needs and uncertainties. In the Meppelerdiepsluis and Ramspolbrug replacements, ROA emphasized the benefits of deferring or modifying projects in response to changing conditions, rather than committing to immediate, inflexible solutions. The hypothetical highway expansion illustrated how phased investments aligned with actual demand and future developments can enhance project value by preventing premature overinvestment and enabling scalable responses. Collectively, these examples underline the importance of integrating ROA into infrastructure project evaluations to effectively manage the complexities and uncertainties of long-term investments, fostering more resilient and adaptable decision-making strategies, and providing a more dynamic alternative to conventional CBA assessments.

Contrary to the predominantly theoretical and retrospective research on ROA, the Port of Rotterdam serves as a key example of its practical application The Port Authority, tasked with the development of Maasvlakte 2, is spearheading a substantial port expansion initiative aimed at constructing new territory in the North Sea. To facilitate this, a dedicated project group has been established within the port's administrative framework. This team has adopted a phased approach to the construction process, allowing for the option to abandon subsequent phases if market conditions become unfavourable. This strategic decision-making mitigates capital expenditure risks and exemplifies ROA in action, illustrating the adaptability and forward-thinking investment strategies of modern organizations (Herder et al., 2011).

To sum up, despite the acknowledged potential, ROA is not widely adopted within Dutch infrastructure projects, where CBA remains the dominant method of evaluation. The reluctance to implement ROA in the Netherlands is attributed to several factors beyond investment policy considerations. These include the complexity of ROA methodologies, the significant time and effort required for their implementation, and the challenges posed by existing standardized decision-making frameworks. Additionally, the need for swift decision-making, political pressures, and the demand for tangible results further hinder its application (Gijsen, 2016; Herder et al., 2011; Rhee et al., 2008). Gijsen (2016) emphasizes the necessity of weighing ROA’s benefits against the required effort. Nonetheless, Rhee et al. (2008) note that the option to grow is being implicitly applied in the construction of new highways in the Netherlands, indicating some level of ROA integration despite its limited formal use. The table below summarizes the current status of ROA application in Dutch infrastructure decision-making:

Table 6: The State of ROA in Dutch Infrastructure Decision-Making

Aspect	Details	References
Context & Challenges	ROA's application in Dutch infrastructure, particularly in the railway sector, remains limited and is in its early stages. Despite its potential to improve the strategic management of large, complex projects, challenges in practical implementation persist.	Rhee et al. (2008); Bos & Zwaneveld (2014); Gijsen (2016); Van Den Boomen et al. (2018); Garvin & Ford, 2012; Herder et al., 2011
Dutch Guidelines	New societal cost-benefit analysis (SCBA) guidelines recognize ROA's theoretical benefits but emphasize the challenges associated with practical application, particularly within standardized decision-making frameworks.	Bos & Zwaneveld (2014)
Studies & Findings	Exploratory case studies, such as the A27 highway widening, Kaagbrug A44 replacement, Meppelerdiepsluis replacement, the Ramspolbrug replacement, and a hypothetical highway expansion with a tunnel, showcase ROA's advantages over NPV, recommending deferral and phased construction strategies. The Zuiderzeelijn project and an ageing bridge replacement study also highlight ROA's value in managing uncertainty.	Gijsen (2016); Van der Pol et al. (2016); Rhee et al. (2008); Van Den Boomen et al. (2018); Bos & Zwaneveld (2014)
Practical Application Example	The Port of Rotterdam's Maasvlakte 2 expansion project demonstrates ROA's practical utility, utilizing a phased construction approach in combination with the option to abandon subsequent phases if market conditions become unfavourable, to manage capital expenditure risks and adapt to market conditions.	Herder et al. (2011)
Barriers to ROA Adoption	<u>Key barriers include:</u> • the complexity of ROA methodologies, • the time and effort required for their application, • the political pressures, • the demand for swift decision-making, and • the challenges posed by existing standardized decision-making frameworks. These obstacles hinder ROA's widespread adoption in Dutch infrastructure projects.	Gijsen (2016); Herder et al. (2011); Rhee et al. (2008)
Implicit Use of ROA	Despite limited formal adoption, implicit use of ROA can be seen in the construction of new highway projects in the Netherlands, such as options to grow (expand), signalling gradual recognition of its value in infrastructure planning.	Rhee et al. (2008)

2.3 ROA Benefits, Disadvantages, & Barriers to Implementation

This section of the literature review explores the benefits, disadvantages, and barriers to the implementation of ROA in practice within the infrastructure sector.

2.3.1 ROA Benefits

The table below illustrates ROA's main benefits in the context of infrastructure projects:

Table 7: ROA Benefits In Infrastructure Projects

ROA Benefits	Explanation	Guide to literature
Enhancing System Design with ROA: Strategic Reconfiguration for Optimal Performance	ROA enhances system design by allowing operators to strategically reconfigure, seizing opportunities through successful research and development or mitigating risks by curtailing losses when experiments falter	De Neufville et al. (2008), Lander and Pinches (1998); Lyons and Davidson (2016)
Objective Evaluation	By referencing comparable market-traded assets, ROA minimizes subjective appraisal, allowing for more objective comparison and evaluation of projects.	Herder et al. (2011)
Promotes Strategic Insight	ROA enhances strategic decision-making by providing a framework for evaluating investments with a focus on future flexibility and strategic value.	Herder et al. (2011); Rhee et al. (2008)
Concrete Value Proposition providing a quantitative valuation of flexibility	ROA translates abstract strategic benefits into tangible value by linking project valuation to established financial valuation theories (translating the strategic advantages and flexibility that ROA offers into explicit financial terms).	Herder et al. (2011); Machiels et al. (2020)
ROA improves the accuracy of the calculation of future investment outcomes	The calculation of ROA employs the Black-Scholes model, fundamental in current financial theory, which utilizes a stochastic equation to forecast the future value of capital investments, incorporating the influences of time and assorted risk factors.	Di Maddaloni et al. (2024)
ROA allows for better uncertainty management, enabling better risk assessment	ROA eliminates the need for immediate decision-making at a project's inception, introducing built-in flexibilities that enable decision-makers to effectively navigate uncertainties and adapt to changes.	Machiels et al. (2020); Couto et al. (2012); Lyons and Davidson (2016); Rhee et al. (2008)

ROA Benefits	Explanation	Guide to literature
ROA is a tool for more transparent and explicit identification and communication of risks and uncertainties	Through the process of recognizing, describing, and modelling uncertainties, ROA not only provides quantitative outcomes but also enriches understanding and awareness of potential future scenarios, thereby facilitating more informed decision-making.	Machiels et al. (2020); Ford et al. (2002)
ROA Emphasises the Value of Flexibility	This includes the option to postpone, stop or expand irreversible investments in real assets.	Di Maddaloni et al. (2024); Dixit & Pindyck (1994); Lyons and Davidson (2016); Van der Pol et al. (2016)
No Fixed Formation	As ROA does not work with a fixed format, the method can be customised for each project.	Lander & Pinches, 1998

2.3.2 ROA Disadvantages

Table 8 illustrates ROA disadvantages in the context of infrastructure projects:

Table 8: ROA Disadvantages In Infrastructure Projects

ROA Disadvantages	Explanation	Guide to literature
Incomplete Picture of Megaproject Complexity	ROA applications typically concentrate on a narrow range of uncertainties and flexibility options, yielding an incomplete view of megaproject complexities leading to underestimating crucial risks and uncertainties (focusing on evaluating one option or one type of uncertainty, whereas, real-life projects are often more complex in that they involve a collection of multiple real options, whose values may interact). Furthermore, infrastructure assets are subject to other types of uncertainties, defined here as asset uncertainties, uncertainties specifically associated with the physical and operational characteristics of the infrastructure itself such as the asset's lifespan and maintenance requirements.	Machiels et al. (2020); Trigeorgis (1996); Van Den Boomen et al. (2018)
Oversight of Socio-Environmental Impacts in Transport Infrastructure ROA Applications	ROA in transport infrastructure ignore uncertainties and flexibility options that relate to the positive or negative socio-environmental effects of projects, presenting an incomplete picture of the complexity of megaprojects.	Machiels et al. (2020)
Isolation from environmental dynamics	Many real option valuation models lack explicit instructions for identifying primary change drivers and examining their potential development.	Di Maddaloni et al. (2024); K. D. Miller and Waller (2003)
Prone to Heuristics and Decision Biases	There's a risk that the application of ROA might fall prey to various decision-making biases, affecting the accuracy and reliability of its outcomes, and leading to suboptimal choices.	Lyons and Davidson (2016); Boyadzhiev (2023); Rhee et al. (2008)
ROA Requires Higher Initial Costs and Efforts (More Costly To Apply)	Incorporating flexibility into design typically involves higher initial costs. ROA demands extra efforts due to its reliance on complex modelling for evaluating future scenarios and strategic decisions under uncertainty, requiring comprehensive data collection, advanced statistical analysis, and diverse expertise. Additionally, the iterative process of ROA, along with the necessity for thorough scenario and sensitivity analyses, further increases the time and resources needed to accurately identify, assess, and communicate a project's strategic options.	Lyons and Davidson (2016); Herder et al. (2011); Rhee et al. (2008)

2.3.2 ROA Barriers to Implementation

For the last two decades, real options thinking has been heralded as a new approach to handling uncertainty in investment decisions. However, the application of the approach in infrastructure investment decision-making is negligible thus far, particularly in public sectors compared to private sectors (Herder et al., 2011). According to the new Dutch guidelines for societal cost-benefit analysis (MKBA), the real-option approach is promising in theory, but its practical applicability is still a problem (Bos & Zwaneveld, 2014). Recently, special attention was paid to the reasons behind this limited application. Table 9 illustrates ROA barriers to Implementation in the context of infrastructure projects:

Table 9: ROA Barriers to Implementation In Infrastructure Projects

ROA Barriers to Implementation	Explanation	Guide to literature
Challenges in Valuing Real Asset Options	Due to the necessity of calculating the volatility of the underlying asset price, a crucial determinant of real option value, and other market variables. The volatility of real assets often remains ambiguous or unobservable, making it impossible to ascertain option value.	Di Maddaloni et al. (2024); Trigeorgis and Reuer (2016); Van Den Boomen et al. (2018)
Unrealistic Assumptions on Decision-makers' Quantitative Skills	The presupposition that decision-makers possess the quantitative financial skills needed for real option valuation is often unrealistic. Senior management frequently lacks the mathematical proficiency necessary for the application, comprehension, and communication of real options valuation. Furthermore, given the diverse range of stakeholders in the decision-making process, ROA expertise present within one department may not be readily available to others.	Di Maddaloni et al. (2024); Lander and Pinches (1998); Herder et al. (2011)
Applicability Challenges	ROA's applicability becomes challenging when dealing with unique products or projects that have no market alternatives, making it hard to use original ROA valuation techniques. This necessitates time to tailor the method to specific projects.	Herder et al. (2011)
Monopolistic Infrastructure Settings	Many infrastructure environments are non-competitive, reducing the urgency for project initiators to adopt best practices like ROA compared to a competitive market.	Herder et al. (2011)
Multi-agent Complexity	The involvement of various public actors and stakeholders complicates the implementation of flexibility, with decision-making extending beyond simple board meetings to potentially include political and stakeholder negotiations.	Herder et al. (2011)

ROA Barriers to Implementation	Explanation	Guide to literature
Principal-Agent Problem in Public Settings	Optimal decisions are ideally made by those who pay and benefit from them being combined, which is challenging in public settings, compared to private companies, where these roles are often separated.	Herder et al. (2011)
The Problem of Lock-in (organisational, institutional and political lock-in)	Projects are often constrained by political, institutional, and organizational settings that limit the flexibility to adopt ROA tools and methods. This includes the political sensitivity of projects, the need for transparency and predictability in public sectors, and the organizational rigidity in adopting new methods. The Problem of lock-in seems to be the most prominent barrier to ROA implementation in infrastructure projects according to Herder et al. (2011).	Herder et al. (2011); Van Den Boomen et al. (2018)
Mathematical Complexity	ROA models can be a significant barrier, limiting their accessibility and usability for average decision-makers who may not have the required mathematical skills	Machiels et al. (2020); Garvin and Ford (2012); Grimes (2011); Boyadzhiev (2023); Lyons and Davidson (2016); Van Den Boomen et al. (2018); Van der Pol et al. (2016); Block, (2007)
Lack of Empirical Evidence	There is a notable gap in empirical evidence supporting the practical application of ROA in real-world projects. Most studies are theoretical case studies or ex-post evaluations rather than direct applications, making it difficult to assess the real-world impact and effectiveness of ROA.	Machiels et al. (2020); Van der Pol et al. (2016)

2.4 Conclusion

This chapter concludes the exploration of the first research question:

What is currently known about the Real Options Approach (ROA) and its applicability & application in infrastructure projects?

ROA represents a paradigm shift in project evaluation and decision-making. The comprehensive literature review undertaken elucidates the theoretical underpinnings of ROA, tracing its evolution from financial markets to its pivotal role in tangible asset management. ROA emerges as a strategic framework that evaluates investment opportunities under uncertainty, leveraging financial theory to enhance decision-making. This approach emphasizes the value of flexibility, enabling project managers to adapt strategies in response to evolving market conditions, thereby mitigating risks and exploiting emerging opportunities.

The exploration of ROA's applicability, specifically in infrastructure projects, has revealed its global and local (Dutch context) implications, showcasing its strategic relevance and utility in decision-making under uncertainty. Despite the acknowledged potential of ROA, its practical application, particularly in the Dutch infrastructure sector, remains limited, underscoring a gap between theoretical promise and real-world implementation. This discrepancy highlights the need for further empirical research to validate ROA's theoretical benefits, address its drawbacks, and overcome barriers to its wider adoption.

The review not only outlines ROA's benefits, such as enhancing system design, promoting strategic insight, and providing a concrete value proposition but also addresses its disadvantages and the barriers to its implementation. These include challenges in valuing real asset options, unrealistic assumptions about decision-makers' quantitative skills, and the complexity of the mathematical models involved. Furthermore, the review suggests that while ROA offers a robust framework for managing investment uncertainties, it necessitates a balanced consideration of its practical challenges and the development of strategies to mitigate these hurdles.

The insights gleaned from this literature review provide a robust foundation for the subsequent phases of this research. The detailed exploration of ROA's application in infrastructure projects sets the groundwork for the planned interviews, which aim to delve deeper into the types of uncertainties faced, the methods employed to navigate these uncertainties, and the familiarity and application of ROA in real-world scenarios. Furthermore, the review investigates the practical benefits of ROA, its disadvantages, and the reasons behind its limited use despite its proven advantages. The analysis of ROA's real-world applications within the Dutch infrastructure sector, informed by the literature, will offer empirical evidence to either support or challenge the theoretical advantages and challenges associated with ROA implementation. The planned interviews will not only validate the theoretical insights from the literature but also identify practical barriers, opportunities, and strategies for integrating ROA into infrastructure project management. This will contribute to the broader discourse on enhancing infrastructure investment decision-making under uncertainty.

In sum, this chapter bridges the theoretical exploration of ROA with the forthcoming empirical investigations, offering a comprehensive overview of the current knowledge on ROA's applicability and application in infrastructure projects. It sets the stage for an in-depth examination of its practical implementation, ensuring that the research is well-positioned to contribute meaningful insights to the field of infrastructure planning and management.

3. Methodology

The methodology of this thesis revolves around empirical data gathered from two primary sources: interviews with professionals actively engaged in the Dutch infrastructure sector and validation through focus group discussions. The focus is on decision-making processes under uncertainty and the application of the Real Options Approach (ROA). These interviews are crucial for understanding the practical challenges and opportunities associated with implementing ROA in Dutch infrastructure projects. Data collection is executed through semi-structured interviews, with questions derived from a thorough review of related literature on ROA application in practice under uncertainty. The findings from these interviews are subsequently validated through focus group discussions to ensure reliability and accuracy, enhancing the robustness of the research.

The following sections detail the methodology employed in this research. Section 3.1 outlines the structure and characteristics of the interviews. Section 3.2 introduces the interview participants, emphasizing their unique backgrounds and the similarities and differences in their experiences. Section 3.3 describes the interview protocol and the steps involved. Section 3.4 explains the methodology used to analyze the gathered data, detailing the processes for processing and utilizing the interview results. Section 3.5 covers the validation of the findings using focus group discussions.

3.1 Semi-structured Interviews

Interviews stand out as one of the most commonly utilized methods for gathering qualitative data. Semi-structured interviews, whether conducted individually or in groups, often serve as the primary source of data for qualitative research projects, representing the most widely employed format for qualitative research interviews (DiCicco-Bloom & Crabtree, 2006). The interviews will be semi-structured, allowing for both flexibility and in-depth exploration of participants' perspectives, experiences, and perceptions, while ensuring sufficient structure to comprehensively address the research questions (Mathers et al., 1998). This format combines pre-determined questions with opportunities for open-ended discussions, ensuring thorough coverage of key topics while allowing for the emergence of new insights, and capturing rich qualitative data (Saunders et al., 2016). The primary goal of the semi-structured interviews is to gain in-depth insights into the practical aspects of ROA application and decision-making processes from professionals involved in infrastructure projects. These interviews aim to uncover current practices, identify challenges, and gather best practices that can enhance decision-making processes under uncertainty.

Approximately 25 introductory messages were sent via networking media platforms to initiate contact. Following these initial messages, detailed interview invitations were sent via email. These invitations included a brief description of the research topic and objectives. Interviews were then scheduled based on the availability and preferences of the participants to ensure maximum engagement and participation. To ensure a structured approach, an interview guide (Appendix A) was carefully prepared after reviewing relevant books and research papers on semi-structured interviews. Informed consent forms were provided to each potential participant along with the interview request. These forms outlined the data management procedures to be followed during the interview process. Key aspects covered in the consent forms included obtaining agreement from interviewees to allow audio recording and transcription of the interviews. This step is crucial to maintaining ethical standards and assuring participants of their privacy and the confidential handling of the information they provide. During the interviews, questions were adapted based on participants' responses, and additional spontaneous inquiries were introduced to enrich the data collection process.

After obtaining informed consent, the interviews were recorded and transcribed anonymously verbatim, ensuring participants' confidentiality. These transcriptions were prepared and made available to the interviewees upon request for any comments or corrections. This process allowed the interviewees to review and refine their reflections and insights, ensuring accuracy and thoroughness in the documentation. Following that, thematic analysis was used to analyze the qualitative data gathered. Thematic Analysis was deemed an appropriate method for this study as it facilitates the identification and analysis of themes within data, offering a nuanced understanding of individuals' experiences, opinions, and challenges relevant to ROA. Moreover, thematic analysis aligns with a constructivist approach and the study's exploratory nature, providing a systematic framework for analyzing qualitative data (Clarke & Braun, 2017).

3.2 Interview Participants

The interviews involved discussions with experts in the field of decision-making and project evaluation, scheduled for one-hour sessions with a designated break in the middle. These interviews took place in a virtual setting via the Microsoft Teams platform. A positive rapport with the participants was actively established, aiming to foster a relaxed and productive atmosphere that facilitated open dialogue. The selection of interview participants was based on their expertise, experience, and direct involvement in the decision-making processes related to infrastructure projects. This group included professionals with roles in project management, finance, economics, and strategic planning, ensuring a diverse perspective on the challenges and benefits of using ROA. Each participant has been engaged in the sector for at least two years, providing them with substantial experience and insights into the complexities of infrastructure projects.

To enrich the research, a total of 16 interviews were conducted with expert from both public and private entities, including engineering and consultancy firms involved in infrastructure projects, representing diverse sectors within the Netherlands. This approach aimed to gather perspectives from a wide range of stakeholders. Different public entities were specifically targeted to gather comprehensive insights into the application and perception of ROA. Additionally, a mix of participants familiar and unfamiliar with ROA was sought to provide a balanced understanding of the current knowledge, acceptance, and potential barriers to the implementation of ROA. Fifteen interviews were conducted via online meetings, while one interview was conducted in person. The table below provides an overview of the participant profiles:

Table 10: List of Interviewees

Participant Number	Sector	Role	Experience (Years)	Data of the Interview
1	Public	Asset Management Advisor	22	02/05/2024
2	Public	Senior Program Manager	20	06/05/2024
3	Public	Project Manager	25	15/05/2024
4	Public	Economist & Asset Management Specialist	15	27/05/2024
5	Public	Coordinator	+30	05/06/2024
6	Public	Program Manager	20	10/05/2024
7	Public	Deputy Director of the Department of Roads and Canals	14	15/05/2024
8	Public	Asset Manager	11	31/05/2024
9	Private	Director	30	31/05/2024
10	Private	Advisor	7	22/05/2024
11	Private	Advisor	+5	29/05/2024
12	Private	Opportunities & Risk Advisor	6	21/05/2024
13	Private	Flood Risk & Climate Adaptation Consultant	3	03/06/2024
14	Public	Maintenance Expert	+17	11/06/2024
15	Private	Consultant	16	17/06/2024
16	Public	Coordinator of Value Management	20	26/06/2024

3.3 Interview Protocol

The interview protocol comprised two parts: a pre-interview questionnaire and the main semi-structured interview. The pre-interview questionnaire gathered basic information about the participants' roles and experience, which helped tailor the questions to their specific expertise. The main interview started with broad questions about their role in infrastructure projects and progressed to more detailed inquiries about their use and perception of ROA.

➢ **Interview Format and Setting:**

The interviews were conducted online unless otherwise requested by the participants. Each interview was planned for 60 minutes, with an additional 10 minutes allocated for introductions and closing remarks.

➢ **Interview contents:**

The interview process commenced with introductions between the researcher and the interviewee, during which the purpose of the research and the interview was clearly articulated. Before starting the recording, the interviewer reiterated the confidentiality assurances provided in the informed consent form. The main content of the interview included the following:

- Uncertainty in Infrastructure Investment.
- Current Evaluation Methods in the Dutch Infrastructure.
- Familiarity with the Real Options Approach (ROA).
- Application and Benefits of ROA.

- Forms and Use of Flexibility in ROA.
- Barriers and Strategies for ROA Adoption.

In each part, follow-up questions were tailored following the background and ongoing discussion findings.

3.4 Thematic Analysis: Methodology of Data Analysis

Braun and Clarke (2006) outline a six-step process for conducting thematic analysis depicted in the figure below:

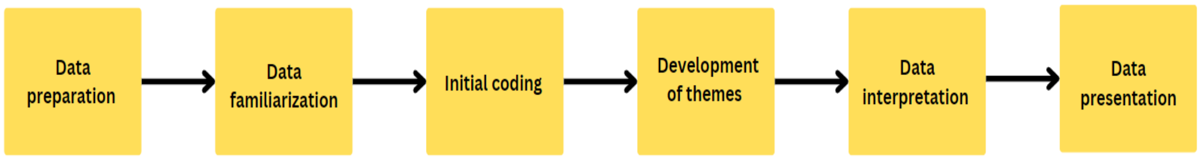

***Figure 7**: Workflow of Data Analysis*

1- Data Preparation: As detailed in Section 3.2, the semi-structured interviews were conducted virtually using Microsoft Teams. These interviews were recorded and transcribed verbatim, utilizing Microsoft Teams. Following transcription, a comprehensive grammar check and editing process were conducted to ensure accuracy. Within the transcripts, there exists a substantial amount of interview data, some of which may be extraneous to the research objectives. Thematic analysis allows us to efficiently filter through and exclude this unwanted information while preserving the integrity of the interviewer's perspective, enabling a focused concentration on the data that is relevant to the research goals (Flick, 2014).

To enhance the reliability of the data collected, participants were given the opportunity to review summaries of their interviews. These summaries were sent as PDF files to the corresponding participants for confirmation. This step verified the accuracy of the recorded information and allowed participants to clarify or expand on certain points, thereby minimizing researcher bias and enhancing the study's validity. This detailed approach was crucial for preserving the richness of the qualitative data and facilitating a thorough analysis.

2- Data Familiarization: After transcribing and reviewing the interviews, the next critical step is to become fully acquainted with the data. This involves reading the transcribed interviews multiple times in order to become fully immersed in the topic and gain a comprehensive understanding of the participants' perspectives. By repeatedly engaging with the transcripts, emerging insights, patterns, and themes become more apparent. It is important to document initial ideas and observations during this process, as these notes can highlight significant points and guide subsequent analysis. This careful and focused reading ensures that the researcher is fully acquainted with the nuances of the data, setting a solid foundation for accurate coding and meaningful interpretation in the later stages of the research.

3- Initial Coding: Begin the coding process by categorizing the data using ATLAS.ti software, which facilitates the organization and analysis of qualitative data. This involves identifying segments of text and assigning labels (codes) to each segment. ATLAS.ti enables efficient coding, retrieval of quotes, and exploration of correlations between codes, aiding in the generation of themes and narrative insights through qualitative data analysis (Smit, 2002). Multiple rounds of coding may be necessary to ensure comprehensive coverage and depth in the analysis and ensure a thorough interpretation aligned with the research objectives. Both predefined codes, derived from the literature review and research questions, and emergent codes, identified during the analysis, were utilized.

In Atlas. Ti, the interview transcripts are thoroughly reviewed. Relevant and important data related to the research is identified, highlighted, and quoted within the software. Simultaneously, these quotations are associated with specific codes based on the concepts and areas they address. Creating the codes is a systematic, data-driven process guided by a subsumption strategy as outlined by Mayring and Fenzl (2014). This approach involves a detailed examination of each quotation, following a series of defined steps. To begin, there is a careful reading of the quotations, during which they are summarized into core concepts or ideas. Subsequently, for each quotation, there is a check to determine if an existing code already encompasses its corresponding concept or idea. If such a code exists, the concept or idea is subsumed under that pre-existing code. However, if no suitable code is found, a new one is generated to encompass the concept or idea in question. This method continues iteratively until all the related concepts and ideas within the data have been accounted for. It is a methodical process aimed at effectively categorizing and organizing the textual data for subsequent analysis and interpretation.

4- Development of Themes: Following the final round of coding, group related codes into potential themes that represent consistent patterns within the data. This involves organizing codes that reflect similar ideas or concepts into broader categories. Review and refine these themes to ensure they align closely with the research topic. It is important to establish clear definitions and names for each theme to accurately convey their essence. Refinement may be necessary to clarify themes and ensure they accurately represent the underlying data.

5- Data Interpretation: In this step, the identified themes will be analyzed in depth to explore their nuances and complexities, ensuring a clear connection to the research questions and sub-questions. This involves synthesizing the themes to extract meaningful insights, allowing you to draw conclusions that directly address the research objectives and capture the essence of the findings.

6- Data Presentation: Present the findings coherently and logically, addressing the research questions.

3.5 Validation of the Findings

Given the inherent limitations of semi-structured interviews, such as potential biases from individual perspectives and limited depth of data gathered, it is essential to validate the findings to ensure their reliability and accuracy (Alshenqeeti, 2014). An effective method for this validation is the use of focus group discussions, which provide a platform for participants to interact, offer different viewpoints, clarify ambiguities, and achieve a more comprehensive understanding of the research topic (Smithson, 2000). By incorporating diverse perspectives, focus groups help identify inconsistencies or gaps in the interview data, thereby enhancing the robustness of the research findings. This approach facilitates deeper exploration of the themes identified during the interviews and ensures that the conclusions drawn are well-grounded and reflective of a broader consensus (Morgan, 1997). The focus group discussions will be conducted after the initial analysis allows for cross-checking and refining the results, thereby maintaining high research quality and credibility.

Two experts with extensive experience in decision-making under uncertainty and evaluation methods in infrastructure projects, including ROA, have been selected for this validation process. Their profound knowledge, distinct backgrounds and practical experience will provide diverse perspectives, enriching the research.

- **Expert 1**: A senior consultant with over 20 years of experience in infrastructure planning and project management.
- **Expert 2**: A university professor and researcher specializing in infrastructure investment and uncertainty management.

❖ **Purpose and Anticipated Outcomes:** By engaging experts who are deeply experienced in decision-making under uncertainty and evaluation methods, the study aims to:

  - **Enhance Validity**: The experts' feedback will help verify the accuracy and applicability of the findings to real-world infrastructure projects, ensuring they are grounded in practical reality.
  - **Identify Oversights**: Any gaps, overlooked aspects, or biases in the initial analysis can be identified and addressed.
  - **Improve Practical Relevance**: Insights from experts will ensure that the findings are not only theoretically sound but also practically valuable to the industry.
  - **Providing Additional Insights**: Offering further perspectives or examples that support or challenge the findings.
  - **Strengthen Conclusions**: Incorporating expert perspectives will lead to more robust, credible, and actionable conclusions.

❖ **Validation Procedure**: The steps involved are:

  1. **Preparation of Validation Materials**: A concise summary of the main findings and themes identified from the interview data will be prepared. This summary will include key insights, conclusions, and any models or frameworks developed during the research.
  2. **Presentation to Experts**: The summary will be shared with the experts prior to the meetings to allow them enough time to review and reflect on the findings. Furthermore, a concise and professional presentation will be provided during the meeting to streamline the process.
  3. **Discussion Sessions Format**: A group meeting will be held with the two experts lasting approximately 60 minutes.
  4. **Recording and Documentation**: With the experts' consent, the discussions will be recorded to ensure accurate capture of their feedback. Detailed notes will also be taken during the sessions. Additionally, a transcript will be prepared with the help of Microsoft Teams.
  5. **Analysis of Expert Feedback**: The transcript will be systematically analysed to identify common themes, confirmations, or discrepancies with the original findings.
  6. **Refinement of Findings**: Based on the experts' input, the findings will be refined and adjusted to address any identified issues, thereby enhancing their robustness and validity.

❖ **Ethical Considerations**

- **Confidentiality**: The identities of the experts and the specifics of their feedback will be kept confidential unless explicit permission is granted for disclosure.
- **Informed Consent**: Consent forms outlining the purpose of the validation, the use of the information provided, and data handling procedures will be provided and signed before the interview.

4. Findings

This chapter presents the findings from the empirical research conducted through interviews with industry professionals, offering a comprehensive overview of the key themes and patterns that emerged. To illustrate important points, quotations from the interviews are included. These quotations were selected for their clarity in addressing the issues, relevance to the topics discussed, and to ensure inclusivity by drawing from different interviews to represent diverse perspectives.

4.1 Uncertainty in Decision-Making for Dutch Infrastructure Projects

This section delves into the various uncertainties encountered in decision-making processes for Dutch infrastructure projects. To partially address sub-research question two, participants were asked to identify the key uncertainties they face in practice while making decisions for infrastructure projects. The insights highlight the prevalent types of uncertainties and their implications on project planning and execution. Twelve types of uncertainties were identified and grouped into four main categories. The figure below depicts these types and their corresponding groups, with each category representing a source of uncertainty:

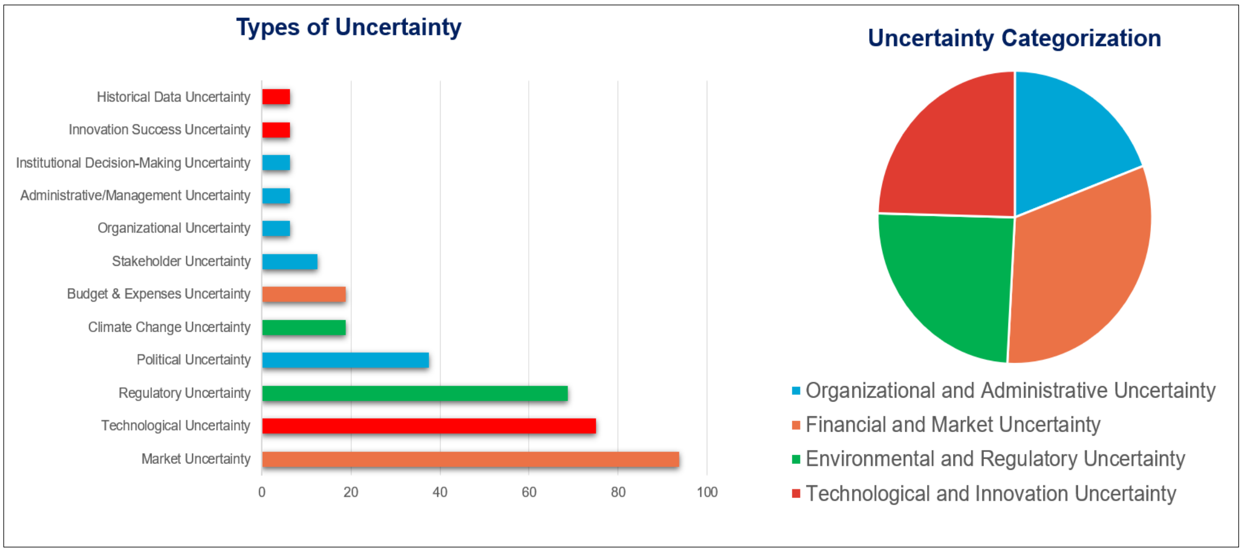

Figure 8: *Uncertainty Types In the Dutch Infrastructure Decision-Making Process*

What stands out from the figure is that Market Uncertainty is the dominant one which impacts material costs, labour availability, and market demand. Regulatory Uncertainty follows, reflecting the challenges posed by changing regulations and compliance requirements. Technological Uncertainty is also prominent, indicating the difficulties in integrating new technologies and ensuring compatibility. Other notable uncertainties include Climate Change, Budget & Expenses, and Political factors, each presenting unique risks to project planning and execution. Lesser but still relevant uncertainties involve Organizational, Stakeholder, and Administrative aspects, along with Historical Data and Innovation Success uncertainties, all contributing to the complex landscape of decision-making in infrastructure projects.

Categorizing uncertainty is important for several reasons. It helps stakeholders identify and understand the various sources and nature of uncertainties in infrastructure projects. Additionally, this categorization allows project managers to develop targeted strategies to mitigate specific uncertainties effectively.

4.1.1 Organizational & Administrative Uncertainty

This category encompasses uncertainties related to institutional processes, management practices, and stakeholder interactions.

1- Political Uncertainty

Interviewees emphasized that the political landscape, including regular elections and shifting policies and ideologies, introduces substantial uncertainty and impacts the feasibility and long-term strategy of infrastructure projects. Political shifts can alter project scope, policy direction, and regulatory requirements, often leading to increased costs and extended timelines. While advisory bodies like the Delta Commission provide guidance, political will ultimately determine the strategic course. Although tools like Environmental Impact Assessments (EIA) and lifecycle analysis are valuable for quantifying uncertainties, their effectiveness ultimately hinges on political priorities. Detailed analyses may provide crucial information, but action is only taken when it aligns with the current political agenda. Additionally, compliance with evolving European Union regulations adds further complexity, requiring continuous adaptation in project planning and execution.

"And then we also have the European Union, which can make their own legislation which we should adhere to. So these are, I think, two different uncertainties at the same time. It's like a political uncertainty but also a driver in the form of climate change but maybe also the economic state of the country."

One participant highlighted the implementation of road toll systems in the Randstad as an example of political uncertainty, where decisions were heavily influenced by the political landscape, with different approaches depending on whether a left-wing or right-wing government was in power. Interviewees noted that political considerations often override technically optimal solutions, with stakeholder satisfaction, especially among political actors, taking precedence over technical or economic efficiency, resulting in decisions that prioritize political gains over optimal project outcomes. Another interviewee referenced a 200-million-euro road project decision made five years ago, where political pressure led to enlarging existing roads rather than constructing a new, more cost-effective, and safer route through agricultural lands. Political parties with strong ties to the agricultural sector opposed the new road, illustrating how political interests can shape project outcomes. Despite these challenges, interviewees acknowledged that managing political uncertainty is inherent to their roles, emphasizing the need for flexibility and adaptability in navigating political influences.

"*The only thing in politics, that's maybe the strange thing about business, which in the business, it's the best option we will choose. In politics, it's not the best option, but the option will get the most votes"*

2- Stakeholder Uncertainty

Stakeholder uncertainty is an issue identified by interviewees, impacting project timelines and outcomes. This uncertainty stems from varying expectations and demands, particularly from stakeholders in the surrounding areas, often requiring additional communication and adjustments to project plans. Requests for extra work beyond initial agreements can further extend timelines.

Interviewees emphasized the need for continuous and effective stakeholder engagement, highlighting the dynamic nature of these interactions and the importance of adaptive communication strategies to manage their influence on infrastructure projects.

3- Administrative and Management Uncertainty

Administrative and management uncertainty is a concern highlighted by interviewees, resulting from bureaucratic and procedural inefficiencies that cause delays and complications in project execution.

"Yeah, and administrative too. That's not political. It's just management in practice. And then it's already a problem with all kinds of procedures".

4- Institutional Decision-Making Uncertainty

Interviewees identified institutional decision-making uncertainty as a prominent issue, driven by the complexities and inconsistencies within institutional processes. This uncertainty often leads to unpredictable and inconsistent outcomes in project planning and execution. Navigating diverse institutional frameworks and protocols adds additional layers of uncertainty to the decision-making process.

5- Organizational Uncertainty

Organizational uncertainty, as highlighted by interviewees, arises from the need to adapt an organization to manage multiple large-scale projects simultaneously. This uncertainty involves challenges related to altering the organizational structure and processes to handle such projects effectively. The adaptation process can create uncertainty as the organization strives to maintain performance and project timelines during these changes. Managing large-scale projects within a shifting organizational framework emphasizes the importance of robust change management strategies to mitigate uncertainties and ensure successful outcomes.

4.1.2 Financial & Market Uncertainty

This category includes uncertainties related to market conditions, budgeting, and economic factors.

6- Market Uncertainty

Market uncertainty was repeatedly identified by participants as a key challenge impacting project planning and execution. Major issues include fluctuations in material and labour costs and their availability, which complicate budgeting and financial planning for infrastructure projects. Volatile market conditions and labour shortages, especially of skilled workers and engineers, can lead to delays, increased expenses, and difficulties in maintaining work quality. The data also highlighted the difficulty in anticipating future market demands and technological advancements, which can result in mismatches between project capabilities and market requirements. External factors such as geopolitical events like the war in Ukraine further influence material costs and availability, necessitating flexible and adaptive planning strategies. Additionally, the competitive and dynamic market environment requires project managers to continuously adjust their strategies to remain responsive and competitive.

Interviewees identified several instances of market uncertainty affecting infrastructure projects. Long-term initiatives such as dike reinforcement and land upliftment face potential sand scarcity despite the current abundance, with international claims and rising demand likely to cause shortages and price increases. The Brienenaar Bridge project in Rotterdam experienced tender phase failures due to a lack of suitable contractors, driven by the project's high-risk profile and technical complexity. Additionally, the COVID-19 pandemic reduced ridership for Dutch Railways (NS), resulting in financial strain and resource shortages. Market uncertainty in the rail sector is further intensified by competition from other transport modes and an unpredictable regulatory environment, which could either support or hinder its growth.

"It already starts with the uncertainty of what the market will do. We have to plan like in some cases 10 years before but in some cases, like on innovations we have to anticipate the capacity growth already for 10 or 20 years ahead."

7- Budget and Expenses Uncertainty

This uncertainty originates from funding fluctuations and the unpredictability of future financial resources, often forcing project managers to make tough decisions regarding project prioritization and resource allocation. One interviewee noted that recent budget cuts have left funding barely sufficient to maintain existing infrastructure and ensure safety, further limiting the focus on long-term planning and sustainability initiatives. Budget uncertainty also affects the innovation and implementation phases, stressing the need for long-term financial stability and adaptability in infrastructure planning. Additionally, inconsistent budget allocations complicate project management, requiring frequent adjustments and contingency planning to maintain efficiency.

"I think it's most uncertainty we have now is about the money we need and the money we get."

4.1.3 Environmental & Regulatory Uncertainty

This category addresses uncertainties related to environmental factors and regulatory frameworks.

8- Regulatory Uncertainty

This uncertainty stems from evolving legislation, particularly stringent environmental regulations and frequent policy changes that impact project planning and execution. Interviewees specifically highlighted the influence of nitrogen deposit regulations, which can restrict activities, especially in Natura 2000 regions protected under EU environmental law. This creates challenges in ensuring compliance with both existing and new environmental standards while advancing projects. However, some interviewees believe that the regulatory framework remains relatively stable, providing a predictable foundation for planning and execution despite potential changes.

9- Climate Change Uncertainty

Unpredictable effects such as sea-level rise and increased frequency of extreme weather events complicate long-term investments and challenge the ability to plan without accurate projections of future climate conditions. Interviewees recommended phased decision-making to adapt to the evolving nature of climate change, rather than committing to single, potentially over-engineered solutions. This approach entails continuous monitoring and adjustments to ensure infrastructure resilience against shifting climate threats. These insights highlight the complexity of addressing climate change uncertainty and emphasize the need for adaptive, flexible strategies to ensure the long-term viability and safety of infrastructure investments amid unpredictable climate impacts.

"Rijkswaterstaat developed real options analysis because, in view of climate change, sea level rise, and heavier rain showers, it is more difficult by constructing now to take care of everything in the future. It is often too expensive and it interferes too much with the public space"

4.1.4 Technological & Innovation Uncertainty

This category focuses on uncertainties associated with technological advancements, historical data reliability, and innovation success.

10- Technological Uncertainty

Technological uncertainty derives from the difficulties of adopting new technologies, staying updated with advancements, and guaranteeing compatibility with existing systems. The sector's conservative nature, particularly in railways, hampers the adoption of innovative technologies, delaying potential benefits from solutions already proven in other industries. Additionally, integrating new technologies while complying with existing regulations and standards adds further complexity and uncertainty. The need to balance innovation with practical and regulatory constraints is especially evident in large-scale projects that require advanced technological solutions. An example provided by interviewees is the upcoming replacement of GSM with the Future Railway Mobile Communication System (FRMCS) by 2030, which underlines the uncertainty surrounding the rollout of new technologies in the railway network. The transition to digital technologies will require major resource allocation and strategic planning to ensure successful implementation.

11- Innovation Success Uncertainty

This uncertainty concerns the effectiveness and viability of new technologies and methods. It results from the risks of implementing innovations that may not achieve their intended outcomes, complicating decision-making as project managers must balance potential benefits against the possibility of failure. To mitigate these risks, interviewees emphasized the importance of thorough evaluation and pilot testing.

12- Historical Data Uncertainty

Historical data uncertainty originates from the lack of comprehensive, accurate, and reliable information about the past actions, conditions, and treatments of infrastructure assets, which is essential for making informed maintenance decisions. Incomplete or inaccessible historical records pose considerable challenges in this process. Participants stressed the urgent need for maintaining accurate and detailed records throughout the lifespan of infrastructure assets to mitigate historical data uncertainty and ensure reliable future maintenance decisions.

4.1.5 Uncertainty Management Challenges

Participants highlighted several factors that complicate and intensify the difficulty of addressing uncertainty in Dutch infrastructure projects, including:

- ❖ Handling Multiple Sources of Uncertainty
- ❖ Lengthy Development Periods
- ❖ Project Balance and the Quality-Time-Money Triangle
- ❖ Impact on Project Stages
- ❖ Balancing Information Overload and Uncertainty

Combining multiple uncertainties, such as sea level rise, saltwater intrusion, and intense rainfall, within a single plan is challenging. These overlapping uncertainties complicate project planning and require sophisticated modelling for effective management. Furthermore, long development periods for infrastructure projects intensify uncertainties. Projects spanning decades face evolving policies, changing market conditions, and shifting environmental factors, restricting long-term planning. Additionally, uncertainties impact the balance between quality, time, and money in project management. Changes in one factor due to uncertainty can cascade, affecting the other two and disrupting project balance.

"There is a difficulty when various uncertainties from climate change come together in one plan. It's very difficult to combine them effectively."

Uncertainty affects projects and programs differently at various stages. Early stages are primarily influenced by technical uncertainties, while market and regulatory uncertainties become critical as projects progress. Ministries often face decision-making challenges due to new regulations and cost fluctuations. Despite having abundant information, essential data for informed decisions is frequently lost, leading to prolonged studies. Effective decision-making requires politicians to make decisive choices despite these uncertainties. The allocation of uncertainty varies based on contract types and responsibilities. Successful project management requires a clear division of responsibilities for different uncertainties. Regulatory changes and cost increases are common, making uncertainty a routine aspect of decision-making. However, the relative comparison between project alternatives remains consistent despite these challenges. Moreover, uncertainty is subjective and varies across projects, sectors, and individuals. For instance, technological changes are less important in stable sectors like railways, whereas environmental factors such as regulations, municipal issues, and political shifts pose greater challenges.

4.2 Evaluation Methods Used

This section examines the evaluation methods used by practitioners in Dutch infrastructure projects to address sub-research question two. Interviewees identified common decision-making methods, assessed their effectiveness in managing various uncertainties, and discussed their limitations. They emphasized the importance of flexibility and transparent decision-making processes, providing practical examples from their experiences. Figure 9 illustrates the predominant evaluation methods employed in the Dutch context.

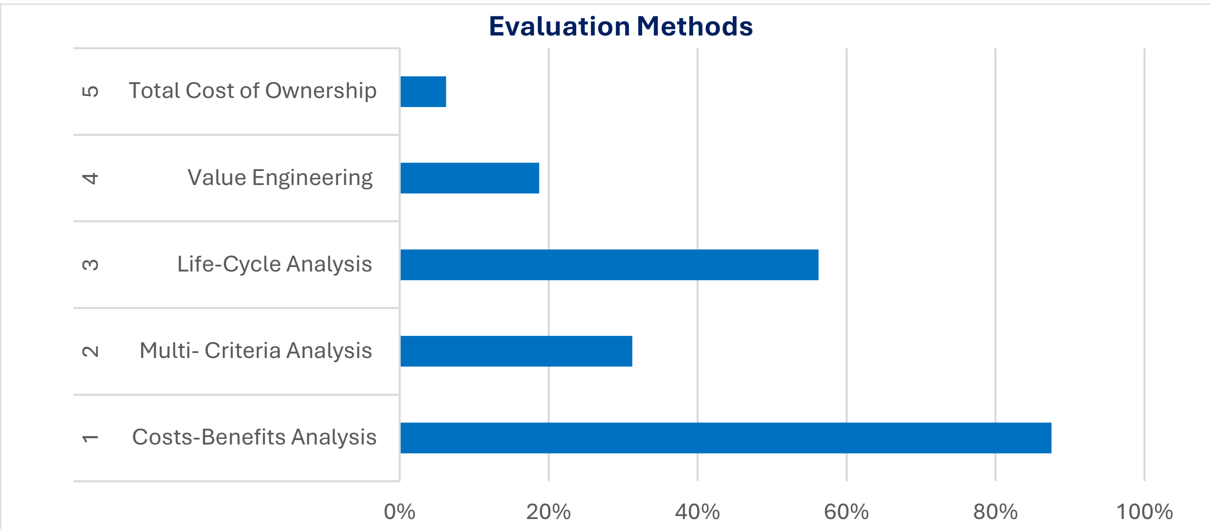

***Figure 9**: Evaluation Methods Used In The Dutch Sector*

The figure above presents the frequency of evaluation methods used, including:

- Costs-Benefits Analysis (CBA)
- Life-Cycle Analysis (LCA)
- Multi-Criteria Analysis (MCA)
- Value Engineering (VE)
- Total Cost of Ownership (TCO)

1. Cost-Benefit Analysis (CBA)

Widely used by government entities such as Rijkswaterstaat and ProRail for large infrastructure projects. CBA standardizes decision-making and considers return on investment, thereby justifying public expenditure. Primarily applied during the planning phases, CBA is essential for assessing project feasibility and comparing alternatives, making it a critical tool for pre-implementation decision-making.

2. Life-Cycle Analysis (LCA)

LCA provides a comprehensive overview of the total costs associated with a project from initial construction through maintenance to eventual decommissioning. This method integrates financial costs with environmental and social impact assessments, offering a more holistic evaluation than purely financial approaches. LCA is extensively used in maintenance and asset management to assess the long-term viability and sustainability of infrastructure investments and it is adaptable to various asset management questions.

3. Multi-Criteria Analysis (MCA)

MCA assesses projects using a diverse set of criteria, including financial, environmental, social, and technical aspects. This approach incorporates various stakeholder perspectives, which is essential for projects with significant social and environmental impacts. MCA is adaptable to different decision-making contexts and is typically employed in the initial planning stages to narrow down alternatives before conducting a detailed CBA.

4. Value Engineering (VE)

VE aims to optimize project functionality and enhance value by systematically analyzing project functions to achieve necessary performance at the lowest cost. VE is applied iteratively throughout all project stages, from initial concepts to final execution, continuously refining and improving value delivery. VE is utilized both proactively during planning and reactively during execution to optimize outcomes and address unforeseen challenges.

5. Total Cost of Ownership (TCO)

TCO offers a comprehensive cost assessment by accounting for all expenses associated with a project, including initial construction, maintenance, operation, and disposal costs. It promotes a long-term perspective on infrastructure investments, emphasizing sustainability and lifecycle efficiency. TCO is particularly relevant for projects with extended operational lifespans, such as transportation infrastructure, where ongoing maintenance and operational costs are significant. However, TCO is rarely utilized and seldom applied in practice.

Additionally, In project planning, interviewees reported using various evaluation methods to assess how projects and assets fit within the broader landscape beyond economic factors. Methods such as Global Research and Regional Analysis are employed. Global Research involves preliminary, broad analyses to explore options and assess feasibility based on general criteria, setting the stage for more detailed studies. Regional Analysis places the project within a wider context, considering factors like traffic, land use, and water corridors, serving as a foundational evaluation before conducting a CBA. Furthermore, the Netherlands' Ministry of Infrastructure and Water Management utilizes the MIRT framework, which specifies tools for major decision-making processes, ensuring alignment with national and regional planning objectives.

4.2.1 Methods Limitations

Each evaluation method offers unique features and is often combined to address various aspects of project evaluation. However, interviewees reported that different methods are frequently used within the same organization without adequate communication between departments. Advocates for each method strongly promote their preferred approach, seeking company-wide adoption. This lack of coordination leads to fragmented decision-making and missed opportunities for comprehensive project assessments. While effective, these methods have limitations in addressing uncertainties, requiring continual refinement.

For instance, CBA often relies on discounting cash flows, which can produce unrealistic outcomes for long-term projects like nuclear plants by heavily minimizing future costs. This may lead to decisions that do not accurately reflect true economic impacts. Additionally, CBA tends to prioritize immediate financial returns over future flexibility and adaptability, limiting its ability to account for long-term uncertainties and impacts. Although CBA sometimes incorporates scenario analyses and sensitivity tests to explore different future scenarios, these often use broad, hypothetical uncertainty ranges (e.g., ±30%) that lack a solid foundation and do not link changes to actionable outcomes. Moreover, three interviewees highlighted that traditional CBA struggles to effectively address long-term uncertainty without integrating ROA into the calculations. Another concern is the static nature of these evaluations, which fails to account for the dynamic and evolving real-world conditions. The implementation of new technologies can also pose challenges, as initial evaluations may indicate benefits that do not materialize, as seen in the case of track improvement tools that ultimately proved ineffective. VE is limited when not applied across multiple project stages with appropriate tools to address specific uncertainties at each phase. Similarly, MCA generally does not effectively manage uncertainty.

" There's no problem to have a discount rate, including some uncertainty, but having two scenarios, which are a bit balanced, high and low, something like that is in practice already perhaps the biggest hurdle. "

4.2.2 The Importance of Transparency in Decision-Making

In project evaluation and planning, the debate over whether the outcome of decisions or the process used to make these decisions is more critical is significant. Figure 10 illustrates the perspectives of the interviewees on this topic:

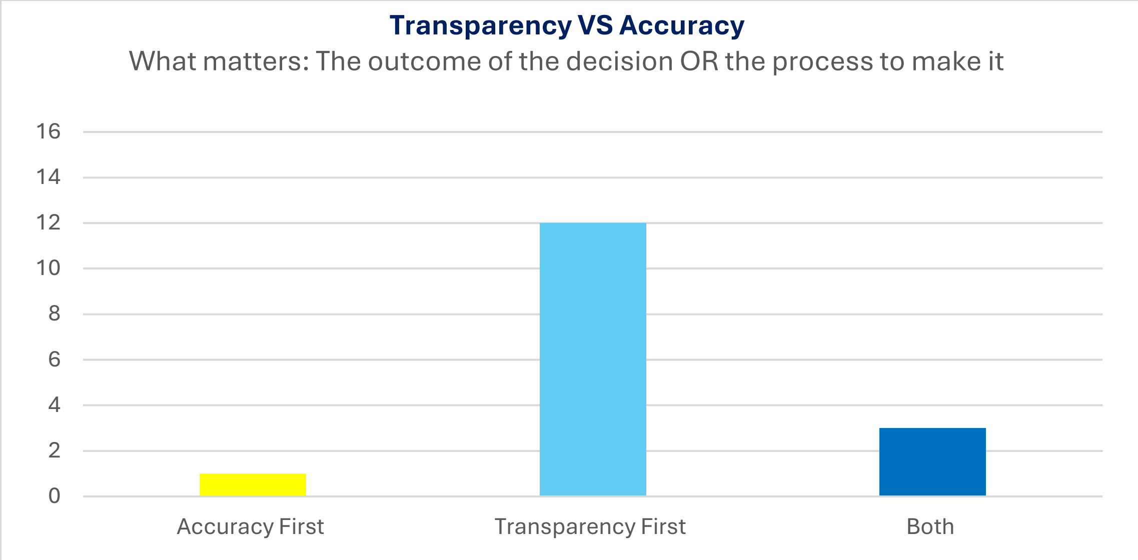

***Figure 10**: Prioritization of Transparency vs. Accuracy in Decision-Makings*

As shown in Figure 11, the majority of interviewees prioritize transparency over accuracy, with 12 respondents favouring transparency first, 1 prioritizing accuracy, and 3 considering both equally important. While accuracy is essential, interviewees emphasized that transparency in the decision-making process is paramount. They highlighted the need for decisions to be clear and understandable to stakeholders, especially in complex projects involving public resources and diverse interest groups. Decision-making is viewed as an ongoing process that requires collaboration and transparency to keep all stakeholders engaged and aligned. One consultant noted that governmental clients must fully understand the advice provided to ensure decisions are accepted and implemented. Without transparency, stakeholders may reject decisions regardless of the data's accuracy.

Interviewees noted that traditional evaluation methods like CBA often fail to address the dynamic and evolving nature of real-world scenarios, highlighting the need for transparency in the information and assumptions used in decision-making. They advocated for a phased approach, where each project stage incorporates increasingly detailed and transparent data, ensuring stakeholders understand the rationale behind decisions at every step. Moreover, proponents of transparency emphasized that many decision-makers, such as politicians, lack technical training in these processes. Therefore, presenting information clearly and understandably is essential, ensuring that decisions are not only based on precise computations but are also accessible and comprehensible to all involved parties.

4.2.3 The Role of Flexibility

Interviewees stressed the crucial role of flexibility in project planning and decision-making, particularly in managing uncertainty in infrastructure projects. Flexibility is essential due to the inherent unpredictability of future conditions and information availability. They advocated for a balanced approach: sufficient flexibility to adapt to changing circumstances and the inevitable changes while avoiding excessive flexibility that can obscure decision clarity and complicate implementation. Clear and actionable decisions, combined with adaptability, maintain the integrity of the decision-making process. For example, overly broad Environmental Impact Assessments (EIA) can lead to unnecessary research and resident concerns about long-term developments. A more focused scope is more manageable and less disruptive, while still allowing necessary flexibility within the project.

Interviewees highlighted that implementing flexible and adaptable infrastructure solutions in challenging environments like Dordrecht involves high costs and complexity. Significant initial investments and intricate constructions, driven by geographical and urban characteristics, are necessary, but the long-term benefits justify these expenses. Furthermore, participants stressed the importance of having mechanisms or methods to facilitate flexibility, and advocated for smaller, incremental steps rather than large-scale changes, allowing for greater control and certainty while managing opportunities and threats without disrupting planned actions. Maintaining flexibility requires keeping options open and avoiding premature commitment to a single solution. Versioning in VE was identified as an effective method to preserve options, prevent early agreement on one solution, and continuously evaluate alternatives based on their relative value. This ongoing assessment ensures that decisions remain adaptable and responsive to new information and changing conditions.

Finally, Interviewees highlighted the growing adoption of scenario thinking as a flexible, modern approach. This method involves developing and comparing various alternatives with different scopes, enabling dynamic responses to uncertainties. By continuously assessing risks and opportunities, it provides a framework for adapting to changing conditions. Respondents noted that this approach marks a substantial transition from traditional single, static analyses to ongoing evaluations, better aligning with the evolving nature of projects.

4.3 Real Options Approach (ROA) in Practice

This section of the Findings Chapter delves into the insights, thoughts, and opinions of the interviewees regarding ROA in the context of Dutch infrastructure projects. To answer sub-research questions three and four, the interviewees were mainly asked about their familiarity and understanding of ROA, the barriers to its application in practice, and any recommendations they could offer to facilitate its incorporation in practice.

4.3.1 ROA Familiarity, Practical Perspectives & Perceived Benefits

This section explores the level of awareness and knowledge that interviewees have regarding ROA, as well as the implications of this familiarity on its practical application. Figure 11 demonstrates the interviewees' familiarity with ROA.

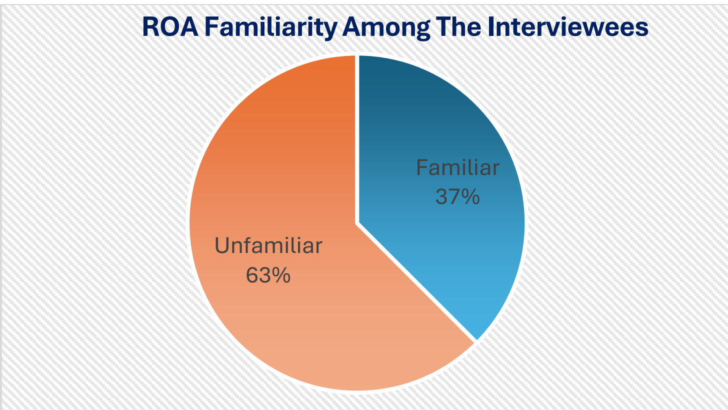

***Figure 11**: ROA Familiarity Among Participants*

As depicted, 63% of participants are unfamiliar with ROA, while 37% have some level of familiarity. Despite the low overall awareness, a few interviewees demonstrated a nuanced understanding and have applied ROA or its principles in practice, recognizing its value in managing uncertainty in decision-making. Additionally, some participants unknowingly utilized ROA concepts, such as flexibility and adaptability, without formally identifying their methods as part of ROA This indicates that ROA's core concepts are inherently valuable and can be integrated into practice even without formal recognition. One interviewee highlighted the knowledge gap, leading to continued reliance on traditional evaluation techniques like CBA. This reflects a broader trend where limited ROA awareness sustains the use of conventional methods.

Most interviewees view ROA as more beneficial for public entities and policymakers, finding it less valuable for private entities. They argue that ROA is well-suited to the dynamic political environment of governmental bodies. Conversely, consultancy firms expressed reluctance to adopt ROA not due to disinterest but because of limited influence over their clients. Public entities' preference for traditional methods and established tools drives this reliance, making it challenging to introduce ROA to clients who may not understand its abstract and long-term approach. Without client comprehension, gaining support for ROA implementation is difficult. ROA's success also depends on a long-term perspective, which some organizations currently lack. However, interviewees noted that ROA is particularly appealing to policymakers, as Dutch policies often span 5, 10, or even 20 years. Over such extended periods, numerous changes may occur, as demonstrated by the Noord-Zuidlijn project, which failed to account for major changes over a decade. This underlines the importance of a flexible, long-term approach. Additionally, governmental authorities tend to be more rigid compared to market parties, further hindering ROA adoption.

"Well, as a consultancy firm, we are strongly dependent on the tools our clients use, that's one part. Also, we don't make policy, we're not policymakers, so we cannot influence policy in that way "

Some participants noted that companies may prefer the phased approach as it leads to a more evenly distributed workflow across multiple projects, increasing collaboration and potentially more frequent hiring. However, public perception may differ, with users and residents seeing the phased approach as unnecessarily slow, and wondering why the project is not completed all at once. For example, in dike upgrades typically done every 50 years, the phased approach might be seen as too slow, too frequent, or appropriate, depending on the community's understanding of the risks involved. Furthermore, interviewees emphasized that consultants need to evolve from merely designing according to client specifications to exploring broader options and providing comprehensive advice. For this shift to occur, infrastructure managers should pose less specific questions and allow consultants the freedom to investigate more thoroughly. This change requires adjustments from both parties: infrastructure managers must foster a culture that supports broader, more investigative approaches, while consultants should focus on enhancing their work and adding value beyond simply adhering to instructions.

Moreover, many interviewees emphasized the growing need for ROA in future infrastructure planning, highlighting the importance of adaptability and flexibility in response to uncertainties like sea-level rise. They referenced the historical example of the Closure Dike in the Netherlands, constructed after major floods in 1916 and 1953, which turned the Ijsselmeer into a lake. While this project enhanced safety and prevented further disasters, it negatively impacted biodiversity, an issue not considered at the time. This underlines the necessity of balancing immediate safety needs with long-term environmental impacts, aligning with ROA's principles of adaptive and flexible decision-making.

Additionally, interviewees noted that current economic constraints and rising market prices are leading to more frequent considerations of project postponement, phasing, or downsizing. They believe that as these constraints intensify, there will be a shift toward adopting ROA or stepwise approaches more broadly. With tightening budgets and limited space, the need for flexible and phased investment strategies like ROA is expected to grow out of necessity. Looking ahead, they anticipate that increasing uncertainties will drive a greater need for ROA and methods that value flexibility and advanced uncertainty management. However, they also acknowledged that while not every policy officer needs to use ROA, there is a clear platform for its application in scenarios requiring long-term, flexible planning.

"Then budgetary restrictions stimulate innovative thinking and real options analysis"

Participants agreed that although their organizations are not yet experts in ROA, they possess the foundational knowledge and technical expertise to implement it effectively. With a solid understanding of ROA principles, they are well-positioned to adopt it as a standard method, provided there is organizational commitment and a willingness to move away from traditional practices perceived as simpler and more controllable. Interviewees expressed confidence in their teams' ability to learn and manage ROA, indicating optimism for its integration into decision-making processes.

According to interviewees, ROA enhances infrastructure project decision-making through a structured and flexible approach that effectively manages uncertainty and encourages incremental investments. By dividing large projects into manageable stages, ROA enables phased investments, allowing efficient resource allocation, adaptability to changing conditions, and steady progress within budget constraints. ROA also facilitates detailed evaluation of alternatives by linking key variables to specific outcomes, promoting proactive and adaptive project management. This approach clearly outlines the implications of different actions, aiding in strategic decision-making. Financial feasibility is improved as ROA enables smaller, phased projects that minimize upfront investments and distribute costs over time, making initial expenses more manageable within current financial constraints. Although total costs may increase due to multiple phases, ROA is particularly beneficial during transitions, such as shifts in power systems and energy use, where adaptability is essential.

Furthermore, ROA aligns diverse stakeholder interests and ensures regulatory compliance. In complex collaborations like dike fortification projects involving multiple governmental and private entities, ROA streamlines decision-making by allowing adjustments as new information emerges. This flexibility accommodates evolving stakeholder priorities and helps parties with varying risk tolerances and objectives find common ground at each project stage. By evaluating different scenarios and outcomes, ROA improves communication and transparency, ensuring all interests are considered. This approach supports long-term strategic goals while mitigating short-term uncertainties and stakeholder disagreements.

"The extra quality of ROA, or a stepwise approach, is that you have defined your alternatives better and add a consequence to a certain step. And you say the consequence will be, I don't go left, I go right. So that is extra of it"

4.3.2 ROA Practical Applications

Interviewees' application of ROA in infrastructure projects varies markedly, reflecting different levels of familiarity and experience. This section summarizes examples from those who have explicitly used ROA, those who have applied its principles implicitly, and situations where ROA could have improved project outcomes.

Examples from Interviewees Familiar with ROA: Interviewees experienced with ROA have applied it in various infrastructure projects to manage uncertainties and enhance decision-making. Table 11 summarizes these applications.

Table 11: Applications of ROA in Infrastructure Projects

Project Type	Explanation
Road Projects	One interviewee cited the A27, A7, and A44 road projects. For the A44, ROA was used to determine the optimal timing and extent of road widening, aligning investments with projected traffic growth while considering uncertainties about the need for full expansion.
Canal Projects	During a politically turbulent period with restricted government spending, the municipality of Zevenbergen aimed to revitalize its city centre. They considered two options: transforming the area into a green boulevard or restoring the historical Rodevaart Canal, which had been filled in for parking. While both options would enhance liveability, restoring the canal offered strategic benefits by facilitating water transfer from the Haringvliet to western Brabant, addressing agricultural freshwater needs exacerbated by climate change. Facing uncertainty about the future need for additional water supply routes, the municipality realized that choosing the green boulevard could lead to higher costs and logistical challenges if a waterway became necessary later. Constructing a new canal around the city would be more expensive and disruptive, especially due to existing greenhouses. By applying ROA through decision tree analysis, it was determined that even with a slim chance of needing the extra waterway in the future, restoring the canal immediately was economically prudent. This approach minimized potential future costs and logistical complications. Recognizing the urgency, the local government arranged special financial agreements with the province of Brabant to secure funding, allowing the project to proceed despite spending limitations. This example illustrates how ROA can effectively navigate uncertainties and inform strategic infrastructure decisions, ensuring long-term benefits and cost efficiency.
Railway Projects	One interviewee mentioned the application of ROA in 2019 in a project for the Metropole Region of The Hague, Rotterdam. It was specifically used for the train route from Leiden to Dordrecht to determine whether and when the track should be doubled, and to establish the optimal timing for these upgrades.
Delta Program	In 2010, the Dutch Delta Program sought assistance with adaptive delta management, where the interviewee applied ROA to address various problems. However, this initiative evolved into a broader, more process-oriented approach rather than just focusing on real options calculations.

Additionally, an interviewee noted that Rijkswaterstaat has adopted a stepwise method for regional projects, particularly for water structures like locks and dams, to streamline traditionally lengthy processes. Instead of conducting a full-scale ROA, they perform a quick preliminary analysis, taking about half a day, to identify key cost and benefit drivers. This initial focus allows the team to determine where detailed efforts are needed. The process resembles the Scrum method, using iterative, incremental steps to progressively add detail. This approach quickly identifies non-feasible projects and enables more targeted feasibility analyses. While not a true ROA, this stepwise methodology embodies similar flexibility and adaptability, ultimately accelerating project timelines and improving resource allocation.

ROA Implicit Use: Examples from Interviewees Unfamiliar with ROA but Applying Its Principles: Some interviewees, although unfamiliar with ROA by name, have implemented its underlying principles in their projects.

An interviewee described a notable example involving the Afsluitdijk (Enclosure Dam) in the Netherlands, which, although not explicitly labelled as ROA, embodied its principles through scenario comparison and adaptive decision-making. During a CBA of this infrastructure, a critical issue was identified: rising sea levels and the increasing difficulty of managing excess river water during western storms. The initial solution proposed was to raise the dikes around the Ijsselmeer, a large lake in central Netherlands, which was deemed very expensive. A commission concluded that raising the dikes was unavoidable due to the high costs associated with climate change and sea-level rise. However, the Netherlands Bureau for Economic Policy Analysis (CPB) suggested an alternative: installing large pumps on the Afsluitdijk, similar to those used elsewhere, to manage the excess water. Rijkswaterstaat was initially sceptical, citing high energy costs. Nevertheless, a CPB economist with expertise in energy cost calculations argued that these costs might not be as prohibitive as assumed.

A comprehensive CBA comparing the costs of installing pumps versus raising the dikes revealed that installing pumps was far more cost-effective, saving billions of euros. This approach avoided the extensive costs associated with raising dikes, adjusting harbours, and modifying other structures around the IJsselmeer. Consequently, the decision was made to install pumps, a solution currently being implemented, demonstrating how thorough analysis and innovative thinking led to an optimal and economical outcome. This example highlights the practical benefits of applying ROA principles, even when not formally recognized as such, in making cost-effective and adaptive infrastructure decisions.

An interviewee highlighted the Delta Program as an example where ROA principles are applied, though not explicitly labelled as such. Operating on a six-year cycle focused on water safety, the Delta Program addresses issues related to precipitation, surface water, groundwater, and their use in sectors like agriculture, drinking water, and industrial cooling. The program employs a decision tree approach, projecting up to 2080 and revisiting issues every six years based on updated data and climate change progress. This iterative, stepwise process aligns with ROA principles, enabling adaptive management and continuous reassessment of water-related challenges. Despite initial concerns among civil servants and administrators about losing control, this method provides a structured and flexible approach to long-term water safety planning.

"The Delta program Fresh Water, where I said we use cycles where we update the program, it's not ROA as defined in the textbooks, but it is, it more or less looks like it. So, there we sort of used it"

Situations Where ROA Could Have Enhanced Decision-Making: Interviewees identified scenarios where applying ROA could have improved decision-making by enabling more adaptive and informed choices.

One participant highlighted the challenges in choosing between battery trains and electrification for railway tracks. Initially, battery trains were preferred due to lower upfront costs. However, as the project progressed, the costs associated with battery trains increased, narrowing the cost difference between the two options. Ultimately, electrification was selected as the safer option because of the reduced cost gap and perceived lower risk. This situation demonstrates how ROA could have enhanced the decision-making process by allowing flexibility to delay or adjust choices based on new information, potentially revealing the long-term benefits of battery trains. Additionally, the option of maintaining existing trains while awaiting new technologies was not considered. Applying ROA could have incorporated future scenarios and market changes, leading to more resilient and cost-effective outcomes.

An interviewee discussed a major infrastructure project near Amsterdam and Almere involving a €4 billion highway expansion. Initially, a CBA conducted over a decade ago focused solely on a high-growth scenario without exploring alternative scenarios or flexible options. This narrow approach missed opportunities to consider broader solutions such as expensive tunnels, local road pricing, or other infrastructure alternatives that could have provided a more comprehensive analysis. The interviewee emphasized that evaluating long-term strategies would have been beneficial, particularly in densely populated regions like the Netherlands where infrastructural demands are increasing. He cited an example from Paris, where limitations on building wider tunnels led to innovative solutions like narrower lanes, road pricing on specific lanes, and speed restrictions, a combination that proved optimal under the circumstances. Highlighting the growing necessity for flexible options in infrastructure planning, the interviewee stressed the importance of considering both infrastructure and non-infrastructure solutions. Non-infrastructure measures include road pricing and agreements with employers or universities for staggered work or class times. While this broader perspective is gaining attention, its practical implementation is still evolving. The Amsterdam project exemplifies the importance of incorporating flexible planning approaches to achieve cost savings and better long-term outcomes. The interviewee advocated for the application of ROA in future infrastructure projects to consider various scenarios and flexible options, illustrating how such an approach could lead to improved decision-making and more effective resource utilization.

"the big infrastructure project of four billion near Amsterdam is an example that they didn't do any serious analysis on the options for flexibility. So, I think that is a missed opportunity. And it would have been very interesting, especially for such a case, to look at what would have made sense"

Another interviewee described a study on upgrading the traction power supply system for Dutch railways to a higher voltage, which required modifications to both power substations and train systems. The project faced major obstacles due to the involvement of multiple parties and strict government guidelines. Traditional methods did not adequately address the uncertainty and flexibility needed for such a complex initiative. The interviewee suggested that applying ROA could have provided a more adaptable and flexible strategy, better managing market-related uncertainties and technological advancements. By pre-investing in certain options, the project might have been better prepared for future changes, potentially saving substantial costs associated with retrofitting infrastructure later.

One participant discussed a long-term dike fortification project in the Netherlands aimed at ensuring dike safety until 2050, involving multiple stakeholders such as a water agency, the province, Rijkswaterstaat, and several municipalities. It was highlighted that decision-making often suffered from short-term perspectives and reactive choices rather than a cohesive long-term strategy. The interviewee suggested that applying ROA could have provided a structured framework for adaptive, long-term decision-making, mitigating inconsistency and reactive decision-making experience, ensuring a more logical and coherent progression of the project. Another interviewee pointed to the Noord-Zuidlijn urban rail project as an example where the lack of ROA led to misaligned decisions due to changing conditions over the project's duration. Additionally, an interviewee noted that incorporating ROA into water safety projects addressing climate change and sea-level rise would have been beneficial, allowing for incremental adaptations over time.

"There will be examples, especially in water safety, of how climate change and sea level rise will develop, and how fast. So, there, in that sense, it would always be good to have a ROA analysis added"

<u>To sum up</u>, the participants highlighted a range of practical applications of ROA, including ex-post evaluations and case studies, as well as occasions where ROA principles were applied implicitly. Additionally, they pointed out several missed opportunities where ROA could have provided great benefits. These varied examples demonstrate the versatility and promise of ROA in infrastructure projects. These insights emphasize the critical importance of integrating ROA to enhance decision-

making processes, effectively manage uncertainties, and optimize resource allocation within the dynamic environment of infrastructure development. By leveraging the flexibility and structured approach of ROA, organizations can improve the resilience and efficiency of their infrastructure investments.

4.3.3 ROA Barriers to Implementation in Practice

The section will give a detailed analysis of the key barriers to implementing ROA in infrastructure projects as indicated by the respondents, providing answers for research sub-question 3. While several other barriers were highlighted by the participants (Appendix D), to address sub-research question three, only the main barriers, as depicted in Figure 12, will be considered. This focused approach ensures that the study targets the most pressing issues, offering a clear and practical roadmap for overcoming obstacles to ROA adoption. Understanding these barriers is essential for developing strategies to enhance the adoption and effective use of ROA in practice.

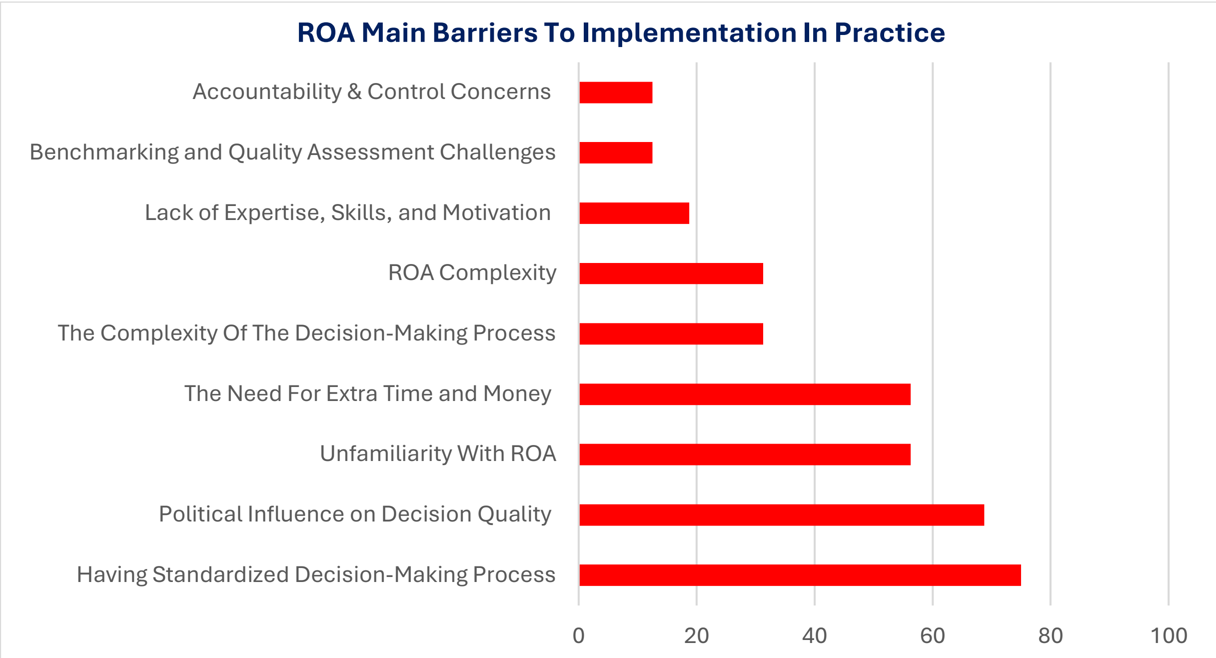

***Figure 12**: ROA Main Barriers To Implementation*

4.3.3.1 Having Standardized Decision-Making Process

One of the most frequently mentioned barriers is the existence of standardized decision-making processes within organizations. Interviewees pointed out that these established frameworks appear simpler, faster, and offer more control, making it challenging to integrate new approaches. The rigidity of these standardized processes fosters resistance to change, hindering the adoption of innovative approaches like ROA. This resistance stems from several factors. Traditional decision-making methods are deeply embedded, providing familiarity and reliability, which makes stakeholders hesitant to adopt new, potentially complex and time-consuming methodologies.

Additionally, existing frameworks are often tailored to meet specific regulatory and procedural requirements, discouraging the introduction of alternatives. Standardized processes are viewed as less risky because they align with known regulations and expectations. Deviating from these processes requires considerable time, resources, and a shift in organizational culture, including retraining staff and adjusting procedures, which often meets resistance.

Furthermore, the bureaucratic structure of many organizations exacerbates this resistance. Decision-making responsibilities are typically segmented, with departments operating in silos and focusing on their specific tasks. This fragmented approach leads to inefficiencies and a reluctance to adopt holistic methodologies like ROA, which require cross-departmental collaboration and a unified strategy. In the Dutch context, the involvement of multiple stakeholders, including ministries, infrastructure managers, and public and private organizations, amplifies complexity. Each stakeholder has distinct interests and expertise, making coordinated decision-making difficult. The adherence to standardized processes is therefore not just a matter of preference but also a practical necessity to ensure coherence and manageability in such a multifaceted environment.

4.3.3.2 Political Influence on Decision Quality

A major barrier to implementing ROA is the influence of political considerations, which often override technical and economic factors, resulting in suboptimal outcomes. Eleven of sixteen interviewees identified political interference as a critical obstacle to ROA adoption. Politicians tend to prioritize short-term gains that appeal to voters' base over long-term benefits, favouring decisions that secure immediate public approval or align with their political agenda rather than those based on comprehensive analyses of project benefits and risks. For example, a decision five years ago regarding a €200 million road project illustrated this issue. Although constructing a new road through agricultural lands was more cost-effective, easier, and safer, political opposition from parties supported by the agricultural community led to the decision to enlarge existing roads instead. This case highlights how political factors can significantly impact infrastructure project decisions.

Additionally, the short-term focus of political cycles conflicts with the long-term horizons required for infrastructure projects. Politicians aim to deliver visible results within their terms, often compromising project sustainability and resilience. This misalignment hinders the integration of ROA, which relies on evaluating future uncertainties and strategic flexibility. Frequent changes in political leadership and shifting priorities further complicate long-term project planning, leading to inconsistent policies and a lack of continuity. The involvement of multiple stakeholders, including ministries, infrastructure managers, and public and private organizations, each with their priorities and political pressures, exacerbates this complexity. Consequently, technical and economic considerations often take a backseat to political expediency. Furthermore, politicians prefer single, decisive actions within their terms to achieve notable accomplishments, which conflicts with the ROA's incremental and long-term approach. Large projects like the Maaslandkering, spanning 15 to 20 years, make it unlikely for any single minister to oversee the entire process, discouraging the adoption of ROA's phased decision-making framework. Overcoming these barriers requires depoliticizing infrastructure decision-making, allowing for more objective, technically driven evaluations that align with ROA principles.

" Well, we're always interested in new methods. The only thing in politics, that's maybe the strange thing about business, which in the business, it's the best option we will choose. In politics, it's not the best option, but the option will get the most votes."

4.3.3.3 Unfamiliarity with ROA

A primary barrier to implementing ROA is the lack of familiarity among stakeholders. Many interviewees reported that both clients and internal teams are not well-versed in ROA, resulting in a reluctance to adopt the methodology. This unfamiliarity is driven by the entrenched use of traditional methods like CBA, which organizations consider sufficient for decision-making. The preference for established practices, perceived as less risky and more predictable, makes organizations hesitant to explore new approaches. Additionally, organizational cultures often resist adopting unfamiliar methodologies, and the absence of policy mandates for ROA further reduces its attractiveness.

4.3.3.4 The Need for Extra Time & Money

Implementing ROA is often hindered by the requirement for extra time and financial resources. Many interviewees identified the substantial initial investment as a significant barrier, noting that necessary funds are frequently unavailable. This financial constraint is compounded by the additional time required, which is challenging in fast-paced project environments. In the Dutch context, the involvement of multiple stakeholders, including ministries and public and private organizations, intensifies these constraints due to tight budgets and strict timelines. One interviewee highlighted that budget limitations prevent the allocation of resources for ROA, leading to decisions against adopting new methodologies. This financial shortfall is a common concern among practitioners, making ROA adoption unlikely without adequate budgetary support.

" But at the moment in Holland, the problem really is how do you get the money for initially building bigger than you need. Because every time we have to convince the government that for instance, we are going to build this object"

Additionally, infrastructure managers have experienced reduced budgets in recent years, prioritizing the maintenance and safety of existing assets over exploring new methods like ROA. This focus on operational efficiency restricts their ability to implement adaptive planning or sustainability initiatives. However, one interviewee pointed out that the additional time and effort required for ROA constitutes only 5-6% of a typical project timeline of 15-20 years. In the context of long-term projects, this investment is minimal and should not be viewed as a major barrier, contrasting with the general perception of extra time and resources as obstacles to ROA adoption.

4.3.3.5 The Complexity of the Decision-Making Process

The intricate decision-making processes within Dutch institutions impede the implementation of ROA. Each decision step requires initiating new administrative and procedural tasks, making the process cumbersome and time-consuming. This segmentation leads decision-makers to manage fragmented aspects of projects without a comprehensive understanding of the overall picture, complicating the holistic approach that ROA requires.

Coordinating multiple stakeholders and aligning diverse interests further adds to the complexity. Dutch decision-making is highly segmented, involving ministries, infrastructure managers, and various public and private organizations, each with distinct priorities and expertise. This multifaceted involvement often results in a lack of coherence and continuity, creating roadblocks for adopting comprehensive methodologies like ROA. Additionally, the procedural nature of large institutions causes delays and inefficiencies. Each decision point may trigger multiple administrative reviews and approvals, slowing down the process and making it difficult to implement new methods that demand timely and integrated decision-making. This bureaucratic inertia poses a challenge to the effective adoption of ROA.

" And it's very segmented. So you get small portions of projects, which are maybe part of the puzzle, but which puzzle we don't know. And whether they fit for the bigger picture, we don't know. We don't know if there is a bigger picture. And it's maybe a little exaggerating. But it is true somehow that we were lacking the bigger picture to really apply the real option thing"

4.3.3.6 Complexity of ROA Methodology

The complexity of the ROA methodology is a major barrier to its implementation, as identified by five of sixteen interviewees. ROA is often perceived as a highly statistical and mathematical approach, which can intimidate practitioners and discourage its practical application. Its intricacies require a deep understanding of financial modelling and statistical analysis, making integration into decision-making processes challenging for many organizations. Additionally, the need for extensive and precise data further heightens this perception. Furthermore, the absence of clear, simplified implementation guidelines exacerbates the complexity, with even experts sometimes finding the process unnecessarily complicated. ROA's detailed and nuanced nature demands specialized expertise and skills that are not always available within organizations. Moreover, applying ROA involves managing complex scenarios with multiple variables, which can overwhelm practitioners. This inherent complexity creates a psychological barrier, deterring practitioners from adopting ROA and hindering its broader use.

To overcome this barrier, it is essential to simplify the ROA methodology and provide comprehensive training and support to build the necessary skills and confidence among practitioners. Additionally, ROA often requires expert involvement to interpret and apply the methodology correctly. Without such experts, there is a higher risk of misapplication, potentially leading to inaccurate or misleading results.

"A good model to model the problem is very difficult. Only simple problems with a limited number of alternatives and one main variable can be effectively modelled. When there are too many variables, the complexity overwhelms the programmer."

4.3.3.7 Lack of Expertise, Skills, & Motivation

Effective implementation of ROA requires specific expertise, skills, and motivation, which are often lacking among practitioners. Several interviewees identified this deficiency as a key barrier, limiting ROA's potential benefits in strategic decision-making and project management. The complexity of ROA demands a strong understanding of financial modelling and statistical analysis, areas in which many practitioners are not proficient. Additionally, there is often little motivation to adopt new methodologies. Established practices like CBA are familiar and comfortable, making practitioners hesitant to invest the time and effort needed to learn and apply ROA. This reluctance is compounded by the lack of clear incentives or mandates to encourage the adoption of new methods.

Furthermore, organizational cultures may not support continuous learning and development, hindering the acquisition of necessary skills. Without concerted efforts to build expertise and motivate practitioners, ROA remains underutilized. Interviewees emphasized that skilled personnel are essential for effectively navigating ROA's complexities and that the absence of such expertise can lead to suboptimal decision-making. Additionally, the benefits of ROA are not immediately apparent, and the required training and infrastructure investments discourage its adoption. Without clear incentives or a compelling case for ROA's value, organizations are unlikely to develop the necessary capabilities.

4.3.3.8 Challenges in Benchmarking & Quality Assessment

Interviewees identified benchmarking and quality assessment as important barriers to adopting ROA. The lack of comparative studies and clear metrics demonstrating ROA's advantages over traditional methods like CBA makes it difficult for organizations to justify the transition. Without robust benchmarks, evaluating ROA's effectiveness is challenging. The absence of standard benchmarks creates uncertainty about ROA's reliability and benefits, leading to stakeholder hesitation. Traditional methods such as CBA are well-supported by extensive case studies and performance metrics, providing credibility and reassurance. In contrast, ROA lacks a substantial evidence base, causing apprehension among practitioners. Furthermore, establishing a standardized benchmarking system across various government entities is difficult, complicating the assessment of ROA quality across multiple agencies. This inconsistency adds another layer of complexity to promoting ROA.

4.3.3.9 Accountability & Control Concerns

Concerns over accountability and the perceived loss of control by practitioners have emerged as important barriers to ROA implementation in large infrastructure projects. Project managers and decision-makers often prefer traditional methods due to the fear of being held responsible for uncertain outcomes associated with ROA. This concern is rooted in the familiarity and perceived safety of established methods such as CBA, which, despite being opaque, offers a well-understood framework for decision-making, a sense of managerial control, ensures decisions are defensible and transparent to stakeholders, and minimizes personal and professional risks. The transparency and explicit nature of ROA, which requires breaking down decisions into more detailed steps, can create discomfort, as it invites broader scrutiny and complicates the decision-making process. This increased complexity and openness can lead to a sense of reduced control, making managers hesitant to adopt ROA. This conservative stance stifles innovation and impedes the practical application of ROA, which requires a deeper understanding of uncertainty and flexibility.

"As a promoter of a certain project, you want more or less to have a grip on the process. I guess using ROA may give these district managers the feeling that they have less grip,"

4.3.3.10 ROA Common Misconceptions

In addition to the nine barriers to ROA implementation already discussed, the research uncovered several common misconceptions among participants that further hinder its adoption. This section seeks to demystify and clarify these misunderstandings about ROA in practice. Participants identified a few misconceptions about ROA that need to be addressed, including:

1. Universal Applicability

2. Cost Implications

3. Perceived Complexity

A common misconception about ROA is that it is a fit-for-all solution. However, ROA is best suited for long-term mega infrastructure projects where the effort can be justified by the added value. For a deeper understanding of the conditions under which ROA is most beneficial, please refer to (section 4.3.5.1). Another common misconception is that ROA always incurs additional expenses. While ROA may initially require more time and resources, it can be effectively implemented within limited budgets through phased approaches. Under budgetary constraints, ROA fosters innovative thinking by exploring flexible options instead of costly, fixed solutions. This ensures efficient use of resources and allows for future adjustments, demonstrating that ROA is not inherently expensive. One interviewee highlighted that in low-budget scenarios, ROA can identify flexible alternatives, promoting practical decision-making and optimal resource allocation.

The third common misconception is that ROA is complex and difficult to simplify. In reality, ROA can be streamlined by adopting a strategic mindset or using simplified decision trees for additional insights. This allows practitioners to break down complex decisions into manageable components, enhancing understanding and application. Simplifying ROA makes it accessible for a broader range of projects, enabling organizations to leverage its strategic benefits without being overwhelmed by complexity. Interviewees emphasized that when used as a strategic way of thinking, ROA is particularly valuable for top management involved in long-term decisions. It facilitates high-level planning aligned with long-term goals without getting bogged down in details. Additionally, ROA supports adaptive planning by determining when detailed calculations are necessary or when simpler decision-making processes are sufficient, thereby enhancing its practicality and effectiveness.

"Many will have wrong ideas about it. Many will think it is very complex and cannot be simple. So, there is, I think, a lot of confusion about what it is, how it can be applied, how it can be used and such"

Option-Specific Barriers: Option-specific barriers to ROA applications include managing projects through multiple decision-making steps, which increases complexity and administrative burdens. Each phase requires initiating new processes, potentially extending project timelines to 2050 while earlier stages remain in design or analysis. Prolonged study periods of six to seven years before the design phase further exacerbate these issues. Interviewees highlighted difficulties in maintaining interest and focus in multi-phase projects, with uncertainties about duration and direction hindering ROA adoption. Additionally, political and societal changes can create funding and support obstacles for subsequent phases, complicating project control.

Participants also highlighted the problem of indecision in phased approaches, where projects are delayed in hopes of future reassessment, leading to inaction. They advocate for making clear decisions to initiate small project segments immediately and expand as more information becomes available, rather than postponing due to potential future reassessment. Furthermore, phased approaches encounter legal and ethical challenges, such as the requirement to evaluate the entire project from the outset to prevent the "salami tactic", dividing projects into smaller parts to avoid thorough scrutiny or regulations. This can result in legal and ethical issues, as the project's full scope and impact are not transparently considered initially. Similarly, the defer options in infrastructure projects are constrained by several factors. For instance, deferring projects in road and rail sectors is often impractical due to political and logistical pressures. Environmental permits and regulations are typically valid for a limited time, necessitating immediate action. If deferred, restarting the project could become overly complex due to expiring permits and changing conditions.

"When you cut up one big decision in two or three, then you have to go through the uncertainty of permits, regulations that may change over time again. This is quite an uncertainty to reckon with. I think it may even be a bigger uncertainty than, for instance, climate change"

4.3.4 ROA Practical Recommendations

4.3.4.1 ROA Enablers

This section presents steps and strategies proposed by the interviewees to facilitate the incorporation of ROA in practice, partially addressing sub-research question four. Whether explicitly stated or interpreted from the interviews, these enablers are intended to address the barriers discussed in the preceding section to effectively incorporating ROA into infrastructure project decision-making. Initially, 16 enablers were identified and classified into six major groups, as seen in Figure 13.

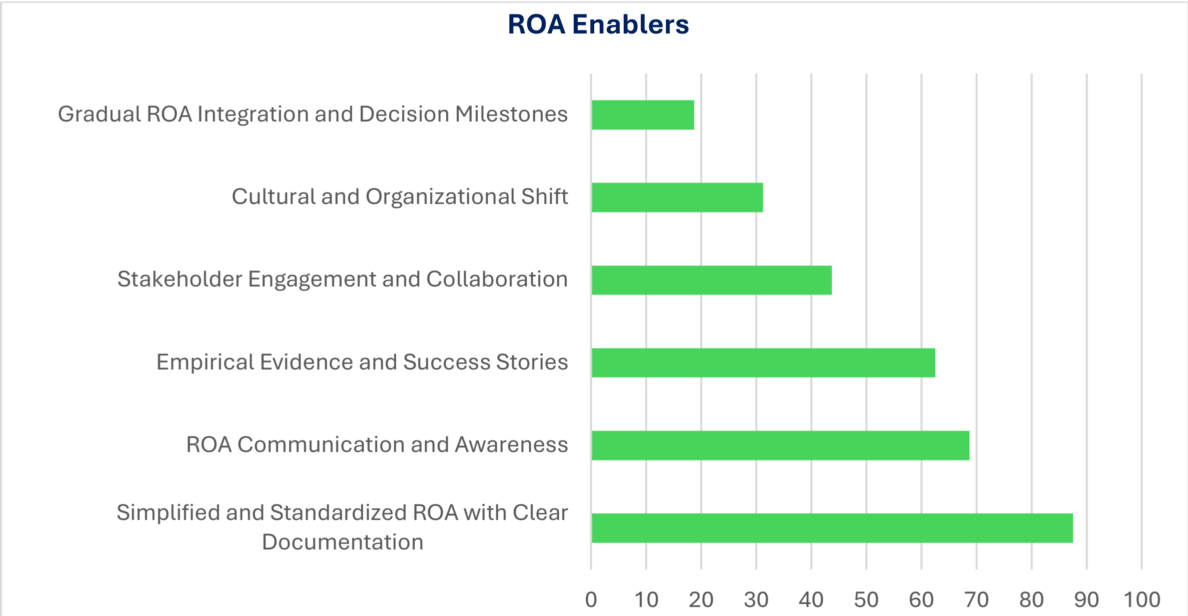

***Figure 13**: ROA Enablers*

4.3.4.1.1 ROA Communication & Awareness

This category contains the following enablers:

- Effective Presentation and Communication
- Building Urgency and Understanding
- Explain the Added Value

Communicating ROA's processes and benefits effectively is crucial to gaining support. Visual tools such as charts and diagrams, as well as engaging presentations, may assist ROA's promoters in illustrating complex ROA concepts clearly, making them more accessible and understandable to stakeholders. Furthermore, creating a sense of urgency and fostering a deep understanding of ROA's benefits among stakeholders is vital. This can be accomplished through targeted communication campaigns and educational initiatives that highlight the importance and advantages of adopting ROA. Additionally, properly describing the additional value ROA brings to projects is vital. Promoters should demonstrate the economic benefits, improved decision-making capabilities, and other advantages simply and understandably to attract stakeholder interest.

4.3.4.1.2 Stakeholder Engagement & Collaboration

This category contains the following enablers:

- Approach The Right People
- Collaborative Approach
- Having Ambassadors or Frontrunners

Engaging influential stakeholders who can promote ROA throughout the organization is critical. Identifying and involving decision-makers and key influencers who support ROA can drive its adoption and integration by advocating for the method's benefits and ensuring it receives the necessary support. Moreover, to enhance the overall effectiveness of ROA implementation, cross-departmental collaboration should be promoted, ensuring that different perspectives are considered. Regular re-evaluation and input from various departments can help adapt the approach to changing conditions, keeping ROA relevant and effective. Appointing champions or frontrunners who are enthusiastic about ROA can help accelerate its adoption. These ambassadors can lead by example, showcasing successful applications and encouraging others to follow suit.

4.3.4.1.3 Simplified and Standardized ROA with Clear Documentation

This category contains the following enablers:

- The Importance of Documentation
- Make it Simple & Transparent
- Make ROA a Standard

Keeping detailed records to support the ROA application is essential. Thorough documentation aids in maintaining continuity and stability, particularly during changes in leadership or decision-makers. This guarantees that ROA-based decisions are well-supported and can be referenced in the future. Simplifying ROA procedures and ensuring transparency can facilitate broader acceptance. Breaking down complex methods into understandable parts and clearly communicating each step helps in gaining stakeholder buy-in and trust. Standardizing ROA practices across organizations ensures consistent and effective application. Developing a structured and standardized model for ROA helps in benchmarking against other projects and problems, providing a clear framework for its use. Additionally, policymakers need to integrate ROA into infrastructure policy thinking to maximize its utility.

4.3.4.1.4 Gradual ROA Integration & Decision Milestones

This category features the following enablers:

- Incremental Implementation
- Practical Decision Points for the Phasing Approach

Gradually applying ROA allows organizations to adapt to the new method over time. Starting with small, manageable projects and scaling up as stakeholders become more comfortable can reduce resistance to change and ensure a smoother transition. Furthermore, applying ROA in phases with practical decision points assures that the approach remains feasible and realistic. Long-term decision points, such as every 10-20 years, can provide stability and allow for informed adjustments based on new data.

4.3.4.1.5 Cultural & Organizational Shift

This category contains the following enablers:

- Ownership and Cultural Shift for ROA Application
- Implement Effective Change Management Strategies
- Addressing Human Factors
- Training

Fostering a culture that values ROA and encourages stakeholders' ownership is crucial. Cultivating a sense of responsibility and enthusiasm for ROA helps in embedding the practice within the organizational culture, ensuring its long-term success. This entails instilling a mindset that values flexibility and adaptability in decision-making. Additionally, organizations need structured strategies to manage the transition to ROA. This involves developing a comprehensive plan to handle human factors, provide necessary training, and support the cultural shift required for ROA adoption. Effective change management ensures that the new methods are integrated easily and efficiently. Furthermore, recognizing and addressing human behaviours that impact ROA adoption is crucial. Understanding colleagues' concerns and providing the necessary support can facilitate a smoother transition to new methods. Moreover, providing comprehensive training programs to stakeholders is necessary to equip them with the knowledge and skills to understand and apply ROA principles effectively. Continuous education ensures that stakeholders remain updated on best practices and new developments. This includes workshops, seminars, and hands-on training sessions.

4.3.4.1.6 Empirical Evidence & Success Stories

Enablers for the category are as follows:

- Case Studies and Success Stories
- Explain the Added Value

Utilizing successful examples to build confidence and demonstrate the value of ROA is essential. Well-documented case studies and real-world success stories can show ROA's practical benefits and efficacy, presenting convincing arguments for its use. Clearly articulating the additional value ROA brings to projects is vital. Promoters should illustrate the economic benefits, improved decision-making capabilities, and other advantages in a simple and understandable way to attract stakeholder interest.

Finally, differentiating between enablers for organizations and those for ROA promoters is important for effectively integrating ROA into practice. In other words, it is essential to identify who holds the responsibility for addressing specific challenges, referred to as the problem owner. Organizational enablers concentrate on internal strategies, fostering a supportive culture, and establishing practical frameworks for implementation. These steps ensure that the organization is structurally and culturally prepared to adopt ROA. On the other hand, enablers for ROA promoters emphasize external advocacy, effective communication, and stakeholder engagement. By clearly delineating these responsibilities, both organizations and promoters can work in tandem, addressing specific needs and overcoming barriers to facilitate the successful adoption of ROA. The table below outlines the enablers' responsibilities:

Table 12: Enablers Responsibility

NO	Problem Owner	
-	**Enablers for Organizations**	**Enablers for ROA Promoters**
1	Implement Effective Change Management Strategies	Effective Presentation and Communication
2	Make ROA a Standard	Approach the Right People
3	Ownership and Cultural Shift for ROA Application	Case Studies and Success Stories
4	The Importance of Documentation	Having Ambassadors or Frontrunners
5	Addressing Human Factors	Training
6	Collaborative Approach	Building Urgency and Understanding
7	Incremental Implementation of ROA	Make ROA Simple & Transparent
8	Practical Decision Points For The Phasing Approach	Explain the added value

4.3.4.2 ROA Application Conditions

It is important to understand that ROA is not a one-size-fits-all solution. Interviewees emphasized that its application must be carefully tailored to specific project needs and contexts, highlighting several optimal scenarios for its use. They noted that ROA is particularly beneficial in the pre-implementation phase of projects, where market development and other uncertainties are still being evaluated. Once an infrastructure project starts and final commitments are made, there is often no turning back, making it crucial to have a clear and adaptable plan in place from the beginning. Several conditions for ROA application were identified, including:

1 -High Uncertainty and Diverse Uncertainty Types: ROA is particularly valuable in scenarios with high uncertainty where decision outcomes vary greatly under different conditions. Its effectiveness spans various types of uncertainties, including market conditions, technological advancements, regulatory changes, and environmental factors. One interviewee emphasized that ROA applies to all forms of uncertainty, making it an essential tool for managing diverse risks in infrastructure projects. This adaptability allows for informed decision-making regardless of the nature of the uncertainty

"So that was a general story about all kinds of uncertainties. And for all kinds of uncertainties, the case uses real options analysis. So it doesn't matter what type of uncertainty "

2 -Significant Investments: ROA is essential when large investments are involved, as it allows for adaptive decision-making, which can save costs and optimize outcomes in the long run. It is particularly valuable in high-stakes scenarios where large financial commitments are at risk, ensuring that investments are made wisely and efficiently.

3 - Asymmetric payoffs: The method is most beneficial when there are divergent outcomes based on varying levels of uncertainty. ROA proves its worth and may help in making the most advantageous choice when different scenarios suggest different courses of action, especially when the stakes are high. Conversely, if all scenarios point in the same direction, its value diminishes (less value). One interviewee illustrated the concept with a hypothetical scenario where the weather forecast is highly variable, predicting temperatures anywhere between 10 to 30 degrees. In such volatile contexts, ROA can help make more informed decisions.

"So there are some criteria of the question that are needed to make it valuable. For instance, if all scenarios point in the same direction, then there's less value. If one scenario says that right and the other way, then more value, in particular, when the stakes are high"

4 -Applicability to Larger Projects (when benefits justify the effort): ROA is generally more suited to larger projects where the benefits of detailed analysis outweigh the costs. In contrast, for medium to smaller projects, the need for such detailed calculations often does not justify the effort and resources required or there is no need to be that accurate. In these cases, simpler decision-making processes might be sufficient.

5 -Project Segmentation: Projects that can be divided into discrete or additive elements are more suitable for ROA. This segmentation allows for manageable decision-making processes and the ability to adapt as new information becomes available. For instance, in infrastructure projects like the Maaslandkering, ROA's utility lies in breaking down the project into separate, manageable elements, making it easier to adapt and optimize as the project progresses.

4.3.4.3 Utilization & Application Areas: Practical Insights

Before delving into the application areas, it is important to mention that participants noted two distinct ways in which ROA can be utilized. The first is as a way of strategic thinking, ROA as a mindset, and the second is as a quantification tool to calculate the value of flexibility. While the latter could be beneficial, most participants advocated for using ROA primarily as a mindset. And only if additional insights are needed, the simplified decision tree analysis can be used.

Some interviewees highlighted that for clients to truly understand and appreciate ROA, it must be simplified. Complex calculations often do not resonate with clients and can lead to outcomes that do not resemble reality, thereby diminishing their value. They emphasized the importance of thinking in terms of opportunities, whether to abandon, extend, or switch and considering the costs of pre-investments to enable future extensions. Other interviewees reinforced this view, stating that the mindset is the most crucial element, arguing that none of the tools should be mandated in studies due to the inherent complexity of the projects. Instead, adopting a mindset that seriously considers alternatives and other options provides great benefits. They further noted that initial strategic thinking is essential, with calculations later confirming these insights. Without this first step, the process would not be effective.

"The first, as a way of thinking. Because the client has to understand it. And that means a lot of calculations which are simply too complicated. And sometimes you have to simplify the problem to be able to calculate. And in the simplifications, there are also reasons or negative stuff that say, well, this is not resembling reality. So the outcome is also not valuable. So I think the thinking and thinking on, are there opportunities to face? Are there opportunities to abandon, to extend, to switch, et cetera? That's very valuable. And think about what can we do. And how much does it cost to do a pre-investment, for instance, to be able to extend later on"

Additionally, it was stated that beginning with the mindset approach is easier and more practical, whereas the quantification method might be too far from everyday practice. This strategic approach fosters a cultural shift that enhances decision-making processes and aligns projects more closely with long-term goals and objectives. Thus, while quantifying flexibility through detailed analysis can provide valuable insights, the foundation lies in adopting a strategic mindset that embraces the principles of ROA.

"Well, I think as a way of thinking, because it's all about taking serious alternatives and other things. So, if you don't do that, well, there it starts and there are big benefits. And later on, of course, some

calculations can confirm this. But without the first step, without thinking like a real options analysis, it will not work "

Moving to ROA application areas, ROA is recognized for its ability to manage uncertainty and provide flexibility in infrastructure projects. Interviewees, both those familiar with ROA and those who have applied its principles unknowingly, identified several application areas where ROA can be particularly beneficial:

1. **Climate Adaptation**

One of the prominent areas for ROA application is climate adaptation and flood risk management. ROA provides a framework for making incremental and adaptive decisions, which is crucial for addressing long-term environmental uncertainties such as sea-level rise and climate change. This phased approach allows organizations to make decisions that can be adjusted over time as new information becomes available, ensuring that infrastructure remains resilient and effective under changing conditions. The Delta Program, which operates on a six-year cycle addressing water safety, incorporates a stepwise approach akin to ROA. This method revises issues in water management sectors in light of climate change projections, enabling adaptive decision-making over extended periods.

"The thing is, Rijkswaterstaat developed real options analysis, because in view of climate change, sea level rise, heavier rain showers, it is more difficult to, by constructing now, take care of everything in the future"

2. **Long-Term Planning**

ROA is also valuable for long-term planning, particularly for infrastructure projects that involve high levels of uncertainty. One interviewee highlighted the importance of ROA in evaluating different scenarios and making informed decisions over time. He mentioned that this approach enhances the resilience of infrastructure investments by allowing for adjustments based on evolving circumstances. This strategic application ensures that projects remain viable and effective throughout their lifecycle.

3. **Adaptive Management**

In addition to strategic planning, ROA supports adaptive management practices. Adaptive management involves continuously monitoring and adjusting strategies based on the outcomes and new data. Interviewees pointed out that ROA's flexibility makes it suitable for adaptive management, as it allows for modifications to be made as projects progress. This approach is particularly beneficial in managing complex infrastructure projects where conditions and requirements can change rapidly. The phased decision-making enabled by ROA ensures that adjustments can be made without compromising the overall project goals, thereby maintaining project efficiency and effectiveness.

4. **Strategic Planning**

Lastly, ROA is advantageous for strategic planning, where it aids in aligning the interests of various stakeholders, including government agencies, private companies, and the public. This alignment is crucial in the Dutch context, where multiple entities are involved in infrastructure projects, each with its own interests and regulatory requirements. By providing a structured framework for decision-making, ROA helps ensure that all stakeholders are on the same page, thereby facilitating smoother project execution and better resource allocation.

4.3.4.4 Future Infrastructure Projects Options

In the context of Dutch infrastructure projects, interviewees identified several specific types of options that could be particularly beneficial when applying ROA. These options, Each with distinct advantages and can be applied to address specific challenges, enhance flexibility, adaptability, and resilience in planning and executing large-scale infrastructure projects. Figure 14 depicts the frequency of various option types indicated by the participants, highlighting that phase and expand options were the most commonly noted, each mentioned by four interviewees, demonstrating their importance in infrastructure planning. Other options, such as defer and pre-invest, were noted by two interviewees each. Additionally, options like contract, abandon, switch, and accelerate were each mentioned by one interviewee, reflecting their more specialized but still important roles in project management.

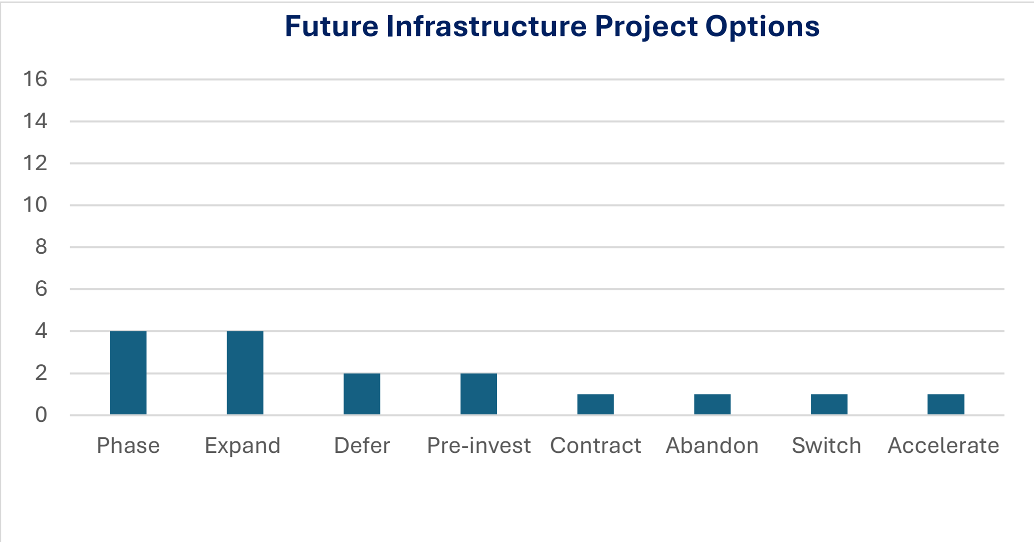

***Figure 14**: Future Infrastructure Project Options*

Table 13 summarizes the common options identified by the interviewees:

Table 13: Option Types Summary; Practical Insights

-	Option Types	Explanation	Relevant Quotations
1	**Phase**	Options that involve breaking down large projects into smaller, manageable phases. This approach allows for incremental investment and assessment at each stage, which mitigates risk and ensures that each phase of the project is feasible before proceeding to the next.	*"I think to make wise decisions in the light of climate change, in the light of effects on nature, on shipping, it is wise to cut up one big decision in two or three"*

-	Option Types	Explanation	Relevant Quotations
2	**Expansion**	Options that are valuable for projects that might need to scale up in response to increasing demand or other emerging needs. By planning for potential expansions, infrastructure projects can accommodate future growth without costly redesigns or disruptions. The phase and expand options are particularly notable for their frequent mention, indicating their perceived value in enhancing project flexibility and scalability.	*" Well, I like myself, of course, step by step and expanding when necessary. That's first always for me a natural one if there's a need"*
3	**Defer**	Options that involve delaying investments until more information becomes available, allowing for more informed decisions and avoiding premature commitments.	*"Delay is also an option that's often used or more or less determine the best time"*
4	**Pre-Invest**	Options that entail making initial investments to preserve future opportunities. This strategy helps in securing the necessary resources and capabilities to expand or modify projects as needed.	-
5	**Contract**	Options that provide the flexibility to reduce project scale or scope in response to changing conditions. This approach helps in minimizing costs and reallocating resources more efficiently.	-
5	**Abandon**	Options that allow project managers to discontinue projects or parts of projects that are no longer viable or necessary. This flexibility is crucial for minimizing losses and reallocating resources to more promising initiatives.	*"I don't see it yet. Yeah. But I'm expecting it within 20 years that we will sometimes make that decision"*
7	**Switch**	Options that provide flexibility to switch between different operational modes or technologies in response to changing conditions or new information. This is important for projects in dynamic environments where conditions can change rapidly.	*"Sometimes multi-use. For instance, building a tram that can also be a high-speed metro track. You can name that phasing, but it's more likely to be switched"*
8	**Accelerate**	Options that involve speeding up project timelines to capitalize on emerging opportunities or respond to urgent needs. This approach allows for rapid adaptation and maximization of potential benefits.	-

4.3.5 Research Main Themes

To summarize the findings of ROA in practice, the thematic analysis of interview documents revealed several key themes, with seven main themes and their relevant codes identified, as depicted in table 14. The most prominent theme, "Barriers to ROA Implementation," highlights challenges such as the complexity of the ROA methodology, political influence, and the need for additional resources. The second major theme, "Enablers for ROA Adoption," outlines strategies to facilitate adoption, highlighting the importance of stakeholder engagement, effective communication, and simplifying the ROA process. Other themes, such as "Growing Need for ROA," "ROA Utilization and Application Areas," and "Perceived Benefits of ROA," offer insights into the increasing demand for adaptable strategies, the various contexts in which ROA can be applied, and the potential advantages it offers. Meanwhile, themes like "Practical Examples of ROA Application" and "ROA Familiarity and Practical Perspectives" received comparatively less emphasis but provided valuable examples and perspectives on the practical application of ROA.

Table 14: Main Themes & Associated Codes

NO	Themes	Relevant Codes
1	**ROA Familiarity and Practical Perspectives**	Awareness of ROA
		ROA Different Perspectives
		Capacity to Apply ROA
2	**Barriers to ROA Implementation**	Standardized Decision-Making Processes
		Political Influence
		Complexity of ROA Methodology
		Unfamiliarity with ROA
		Need for Extra Time and Money
		Complexity of Decision-Making Processes
		Lack of Expertise and Skills
		Challenges in Benchmarking and Quality Assessment
		Process Pitfalls and Control Issues
3	**Enablers for ROA Adoption**	ROA Communication and Awareness
		Stakeholder Engagement and Collaboration
		Simplified and Standardized ROA with Clear Documentation
		Gradual ROA Integration and Decision Milestones
		Cultural and Organizational Shift
		Empirical Evidence and Success Stories
4	**Growing Need for ROA**	The Need For Adaptability and Flexibility
		Historical Context
		Economic Constraints
5	**Practical Examples of ROA Application**	Case Studies and Examples
		Implicit Use
		Missed Opportunities
6	**Perceived Benefits of ROA**	Phased Investments
		Enhanced Alternative Definitions
		Financial Feasibility
		Stakeholder Alignment
7	**ROA Utilization and Application Areas**	Strategic Thinking and Mindset
		Quantification Tools
		Climate Adaptation
		Long-Term and Strategic Planning
		Adaptive Management

4.3.6 Summary of the Findings

This section aims to synthesize the key findings from the research and address the sub-research questions that guide the study. Through the analysis of uncertainties in decision-making for Dutch infrastructure projects, the evaluation methods currently employed, the barriers to the adoption of the Real Options Approach (ROA), the enablers that can facilitate its implementation, and the practical recommendations for ROA effective application, this summary will provide a comprehensive understanding of the challenges and opportunities within the sector.

SQ2: What types of uncertainties are prevalent in Dutch infrastructure decision-making, and how do existing evaluation methods address these uncertainties?

The research identified twelve key types of uncertainties prevalent In Dutch infrastructure decision-making, categorized into four main groups: Organizational and Administrative, Financial and Market, Environmental and Regulatory, and Technological and Innovation. These uncertainties critically influence decision-making processes at various levels, requiring stakeholders to navigate complex and dynamic conditions. The subsequent sections provide an in-depth analysis of each uncertainty category, highlighting their distinct effects on decision-making.

Organizational and Administrative Uncertainty encompasses issues such as political shifts, stakeholder expectations, and inefficiencies within institutional processes, all of which can lead to fragmented decision-making and delays in project execution. Political uncertainty, driven by changes in government policies and elections, can alter project scopes and timelines, while stakeholder uncertainty arises from varying demands and expectations, often leading to extended project timelines due to the need for continuous communication and adjustments. Additionally, administrative inefficiencies and complexities within institutional frameworks further exacerbate these uncertainties, making project management more challenging. **Financial and Market Uncertainty** encompasses the unpredictability of budgeting, market conditions, and economic factors, which are critical in infrastructure projects. Market uncertainty, particularly fluctuations in material costs and labour availability, was frequently mentioned by interviewees as a significant concern. The dynamic nature of market conditions and the impact of external factors such as geopolitical events further complicate financial planning and long-term project stability and force project managers to continuously adapt their strategies.

Environmental and Regulatory Uncertainty primarily stems from rigorous and evolving environmental regulations, particularly those related to emissions and protected areas, which can delay or alter project plans. Additionally, the unpredictability of climate change impacts, such as sea-level rise and extreme weather events, complicates long-term infrastructure planning, necessitating adaptive and flexible strategies. **Technological and Innovation Uncertainty** reflects the challenges associated with adopting new technologies and innovations in infrastructure projects, ensuring compatibility with existing systems, and predicting long-term viability. The conservative nature of the infrastructure sector, particularly in areas like railways, often delays the adoption of proven innovations from other industries. The regulatory requirements for new technologies can further complicate their implementation, leading to increased uncertainty. The success of innovations is also unpredictable, which can impact decision-making processes and necessitates thorough evaluation and pilot testing to mitigate risks. Finally, the lack of reliable historical data on infrastructure assets intensifies uncertainty and complicates maintenance-related decisions.

Effective management of uncertainties is critical for successful decision-making in Dutch infrastructure projects, as it influences every stage of the project lifecycle and necessitates tailored strategies to address diverse challenges. The findings reveal that decision-makers often struggle to navigate the overwhelming amount of information available, leading to critical data being overlooked and causing project delays. In such environments, effective decision-making requires politicians to make clear and decisive choices despite these challenges. Managing overlapping uncertainties, such as those related to sea level rise and intense rainfall, further complicates planning and necessitates the use of advanced modelling techniques. Uncertainty impacts projects differently at various stages, with technical uncertainties being most prominent in the early phases, while market and regulatory uncertainties become more critical as the project progresses. Long development periods exacerbate these issues, as evolving policies and market conditions introduce additional complexities. Effective project management, therefore, requires a clear allocation of uncertainties based on contract types and a careful balance between quality, time, and budget, a balance often disrupted by these uncertainties. Despite these challenges, managing uncertainty has become routine in certain sectors, like railways, where environmental and political factors are more concerning than technological changes. Given that uncertainty is inherently subjective and varies across projects, it is essential to tailor management strategies to the specific context and challenges of each project.

To effectively manage these multifaceted uncertainties and navigate their associated challenges, Dutch infrastructure projects rely on a range of established evaluation methods. Key among these are Cost-Benefit Analysis (CBA), Life-Cycle Analysis (LCA), Multi-Criteria Analysis (MCA), Value Engineering (VE), and Total Cost of Ownership (TCO). Each method offers unique strengths, including comprehensive assessments of costs, benefits, and impacts, yet they also present limitations. The interviewees highlighted various challenges in the use of these evaluation methods within organizations, noting that a lack of communication between departments often leads to fragmented decision-making processes, which can undermine the overall effectiveness of project evaluations. Advocates for different methods, such as CBA, LCA, and MCA, tend to push for their preferred approach, causing inconsistency and missed opportunities for comprehensive assessments. Despite their effectiveness, these methods struggle with addressing uncertainties, particularly in long-term projects and areas requiring integration and coordination across different departments. Traditional CBA, for example, relies on discounting cash flows, which can lead to unrealistic outcomes, especially for long-term projects where future costs are heavily minimized. Additionally, these methods often apply broad, hypothetical uncertainty ranges without a solid foundation, resulting in decisions that do not connect to actionable outcomes. The static nature of these evaluations, coupled with the challenges in applying new technologies, further limits their ability to adapt to dynamic real-world conditions.

Overall, the findings emphasize the urgent need to continuously refine and adapt evaluation methods to effectively address the evolving challenges and uncertainties inherent in Dutch infrastructure projects. A more holistic approach that balances flexibility with clarity is crucial, ensuring these methods not only tackle immediate project concerns but also anticipate and mitigate long-term risks. Enhancing transparency in decision-making is also critical for improving stakeholder understanding and acceptance, which is key to achieving more resilient and sustainable infrastructure development. Improved communication strategies, better departmental coordination, and a focus on adaptability are essential steps toward strengthening the effectiveness and resilience of infrastructure projects in the Netherlands.

SQ3: What are the key reasons and barriers that have prevented the widespread adoption of ROA in the Dutch infrastructure sector?

The findings revealed that the widespread adoption of the Real Options Approach (ROA) in the Dutch infrastructure sector has been hindered by several key barriers, each rooted in the sector's existing organizational, political, and procedural frameworks. **Standardized decision-making processes** within organizations tend to resist the adoption of new methodologies like ROA because they are valued for their perceived simplicity, speed, and control. This preference for familiar methods creates an environment resistant to change, making it difficult for innovative approaches like ROA to gain attention. This resistance is further exacerbated by **political influence on decision-making** which limits ROA adoption. Decision-making in Dutch infrastructure projects is often swayed by political considerations, where short-term gains and politically advantageous outcomes take precedence over long-term benefits and technical merits. Politicians often make decisions based on immediate public approval rather than thorough technical analysis. This misalignment between political agendas, with its short political cycle, and the long-term strategic focus of ROA creates a challenging environment for its implementation, leading to suboptimal outcomes. Additionally, a general **unfamiliarity with ROA** among stakeholders with a preference for traditional methods like cost-benefit analysis (CBA), coupled with the lack of clear policy prescriptions for ROA, reduces its appeal and limits its adoption and exploration despite its potential advantages. Moreover, the implementation of ROA is often perceived as **requiring substantial time and financial resources**, as the initial investment required for ROA is often seen as prohibitive in an environment constrained by tight budgets and timelines. This financial constraint is further compounded by the broader focus on maintaining existing infrastructure within limited budgets.

The inherent **complexity of the decision-making processes** in Dutch institutions, characterized by segmented responsibilities and bureaucratic inertia, further complicates the application of ROA. This segmentation impedes the holistic perspective necessary for ROA's successful implementation. Furthermore, the **methodology itself is viewed as complex** and challenging, requiring specialized knowledge and skills that are not always readily available within organizations. This complexity, combined with the **lack of expertise, skills and motivation** among practitioners further prevents the effective use of ROA, as there is often a skills gap and insufficient motivation to adopt and apply the methodology. The statistical and mathematical demands of ROA further contribute to a psychological barrier for practitioners who may feel ill-equipped to apply the approach. Additionally, **challenges in benchmarking and quality assessment**, due to the absence of comparative studies and clear metrics, add to the uncertainty about ROA's reliability and benefits, making stakeholders hesitant to adopt it. Moreover, **concerns over accountability and control** further contribute to the reluctance to adopt ROA. Project managers often feel that the increased transparency and explicitness required by ROA can diminish their sense of control. This, combined with the fear of being held accountable for uncertain outcomes, leads many to prefer traditional methods, which are perceived as offering more stability and less personal risk.

Lastly, **common misconceptions about ROA**, including its perceived universal applicability, cost implications, and complexity, further hinder its adoption. ROA is not a one-size-fits-all solution and is best suited for large-scale, long-term projects. Although it may initially require more resources, ROA can be adapted to limited budgets through flexible options and simplified for practical use, making it accessible for strategic planning without complex calculations. Moreover, its adoption is often hindered by a **lack of long-term perspective** in some organizations, impacting practical implementation. Interviewees also noted **options-specific barriers**, such as the added complexity and extended timelines of phased approaches, which require new decisions at each stage and can increase bureaucratic burdens. Additionally, maintaining political and financial support across multiple phases poses challenges, as do legal concerns around transparency and regulatory compliance. Defer options face practical issues, including political pressures and risks from expiring permits and changing conditions. These barriers reflect the broader challenges of integrating innovative methodologies within established and complex institutional frameworks, emphasizing the need to overcome them for effective ROA adoption. This leads us to the answer to the fourth research sub-question.

SQ4: What recommendations can be provided to facilitate the adoption and implementation of ROA in the Dutch Infrastructure Sector?

The following response reflects only the empirical research findings and provides <u>a partial answer.</u> It highlights the empirical data's contribution to the overall research aims and objectives. A comprehensive answer, integrating these insights with the literature review results, will be fully addressed in the conclusion and recommendations chapter, as outlined in the research design.

To facilitate the adoption and implementation of ROA within the Dutch infrastructure sector, several critical recommendations have emerged from the research, centred around six main enablers. These include a strategic blend of effective communication, active stakeholder engagement, simplification of processes, and gradual integration of ROA into existing frameworks. First and foremost, **effective communication and awareness-building** are paramount. Clear presentation of ROA's benefits, through visual tools, engaging communication strategies, and straightforward language to demystify the approach, can enhance stakeholder understanding and support. This can help in overcoming resistance stemming from unfamiliarity and complexity. Additionally, building a sense of urgency, particularly in enhancing decision-making under uncertainty, and clearly articulating the added value of ROA is essential to secure stakeholder commitment and interest. This can be achieved by demonstrating ROA's economic benefits and its potential to improve long-term project outcomes through targeted communication campaigns and educational initiatives. Second, **Stakeholder engagement and collaboration** are also vital components in promoting ROA adoption. The research highlights the importance of involving key and influential stakeholders who can advocate for ROA within their organization. Fostering cross-departmental collaboration will ensure that diverse perspectives are considered, making the implementation process more robust and inclusive. Moreover, appointing ambassadors or frontrunners within the organization who are enthusiastic about ROA can drive its adoption. These champions can showcase successful applications of ROA, thereby encouraging broader acceptance and integration.

Third, **simplification and standardization** of ROA processes, supported by clear documentation, are necessary to make the methodology more accessible and widely accepted within organizations. Detailed documentation and transparency in each step of ROA's application are vital for maintaining trust, ensuring continuity and providing a reference for future decision-makers. Additionally, standardizing ROA within organizational frameworks helps align it with existing policies, ensuring consistency in its application across projects. Fourth, a **gradual integration with practical decision milestones** should be implemented, allowing organizations to adopt ROA incrementally, reducing resistance to change and ensuring a smoother transition with practical decision points based on emerging data. Fifth, fostering a **cultural and organizational shift** is necessary, requiring structured and adaptive change management strategies, training programs to equip employees with the skills and knowledge needed to apply ROA effectively, and a commitment to embedding ROA into the organizational culture. Sixth, leveraging **empirical evidence and success stories** can build confidence in ROA's value, with well-documented case studies demonstrating its practical benefits and showcasing successful applications.

Finally, differentiating between enablers for organizations and those for ROA promoters is important for effectively integrating ROA into practice. As outlined in Table 10, section 4.3.4, organizational enablers concentrate on internal strategies, fostering a supportive culture, and establishing practical frameworks for implementation. These steps ensure that the organization is structurally and culturally prepared to adopt ROA. On the other hand, enablers for ROA promoters emphasize external advocacy, effective communication, and stakeholder engagement. By clearly delineating these responsibilities, both organizations and promoters can work effectively, addressing specific needs and overcoming barriers to facilitate the successful adoption of ROA, ultimately enhancing investment decision-making under uncertainty. Additionally, the findings revealed that ROA's successful adoption will demand a strong organizational commitment and a cultural shift away from traditional practices, supported by both infrastructure managers and consultants.

To effectively implement ROA and fully leverage its unique approach, most interviewees emphasized its optimal use during the pre-implementation phase of projects characterized by high uncertainty, significant investments, asymmetric payoffs, and large-scale scopes. ROA is particularly valuable for managing diverse uncertainties and substantial financial commitments, making it ideal for projects that can be segmented into manageable components, allowing for adaptability and optimization as conditions evolve. In contrast, simpler and traditional decision-making processes may suffice for smaller or less complex projects. The dynamic political environment and the need for long-term planning make ROA particularly well-suited for public entities.

Furthermore, interviewees emphasized the importance of adopting ROA as a strategic mindset rather than relying solely on complex quantifications. ROA can be applied in two main ways: as a strategic mindset or as a tool for quantifying flexibility. They highlighted that focusing on strategic options, such as abandoning, extending, or switching, yields greater benefits than complex calculations, which often confuse clients and reduce ROA's practical value. A strategic approach fosters cultural change, improves decision-making, and aligns projects with long-term goals. While quantification provides valuable insights, it should complement, not replace, the strategic mindset. Simplified decision tree analysis can offer additional insights if needed, but the core benefit of ROA lies in its strategic application. Key areas for ROA identified in the research include climate adaptation, long-term planning, adaptive management, and strategic planning. ROA effectively addresses climate-related uncertainties, such as sea-level rise and extreme weather, by enabling incremental and adaptive decision-making. It supports long-term planning by offering a framework to evaluate scenarios and adjust investments over time. Additionally, adaptive management benefits from ROA's capacity to monitor and adjust strategies based on new data, while strategic planning leverages ROA to align stakeholder interests and ensure regulatory compliance. Moreover, interviewees emphasized that phase and expansion options offer the greatest potential for enhancing decision-making in Dutch infrastructure projects by enabling staged investments and future scalability, while defer and pre-invest options are considered less impactful.

5. Validation

5.1 Introduction

This section validates the research findings through a focus group discussion with two experts, each with over 20 years of experience in decision-making under uncertainty and evaluation methods, including ROA. Their distinct backgrounds provide diverse perspectives, enriching the research. The goal is to assess the applicability, relevance, and comprehensiveness of the findings. The validation, conducted using a semi-structured interview approach (outlined in the methodology chapter), facilitated targeted questions and open dialogue. Discussions focused on key findings, with each aspect explored in detail. The interview guide can be found in Appendix B.

5.2 Findings

Uncertainty In Infrastructure Decision-Making: Both interviewees agreed that the list of uncertainties in infrastructure projects is comprehensive, reflecting the reality and complexity of decision-making. From a ROA perspective, addressing all the uncertainties would create an overly complex and difficult-to-understand model. Combining them into one uncertainty could turn the model into a "black box," complicating its use. The experts noted that while ROA is a useful tool, it struggles with excessive uncertainty. They stressed the importance of researchers presenting uncertainties clearly to help decision-makers, suggesting they be explained separately in reports, allowing decision-makers to make informed judgments.

Evaluation Methods in Practice: The participants confirmed that CBA, MCA, and LCA accurately reflect current practices, validating the research findings. One expert was surprised that CBA, mandatory for most projects, was not mentioned by all practitioners, while the other noted the limited use of MCA, which she frequently works with and values for handling uncertainties qualitatively. Both experts agreed that each method has its purpose, with its strengths and weaknesses, comparing them to tools in a toolbox to be used depending on project needs.

The experts noted that method choice often depends on individual experiences and preferences, with economic departments favouring CBA and non-economic departments leaning toward methods like MCA. Both participants were unfamiliar with value engineering and questioned whether it is an evaluation tool or simply for cost reduction. They observed that methods like CBA, LCA, and TCO are closely related, with LCA focusing more on the asset itself and TCO being more concerned with the period during which an asset is owned, or the different phases of ownership.

The first expert expressed surprise that TCO was not mentioned more often, considering its importance in industry standards. She highlighted that MCA and LCA are common in asset management, while CBA operates on a higher level and is used for broader decisions, such as rearranging entire areas. The second expert pointed out that TCO only covers project costs, not benefits, limiting its scope. He explained that he hears a lot about CBA and very little about MCA in transport, while the other expert has the opposite experience, attributing this to their respective fields of expertise.

Limitations of Current Evaluation Methods: The experts argued that the challenges of discounting cash flows were overstated, noting that while discounting can complicate capturing long-term effects, it is essential for accurate evaluations. They emphasized that discounting is common across most methods, including ROA and MCA, and is not unique to any one approach. The real issue is in how the methods are applied, particularly when only one scenario is used. The experts stressed that using multiple scenarios would make analyses more dynamic and reflective of real-world complexities, pointing out that the problem lies in the evaluators' mindset, not the methods themselves. For example, traditional methods can be adapted by planning to reconsider decisions in ten years if new information emerges.

ROA stands out by integrating all possible scenarios within a single decision tree, allowing updates as new information evolves, making it more adaptive and comprehensive than traditional methods. It simplifies decision-making by enabling incremental evaluations and handling uncertainty across multiple paths, unlike CBA or LCA, which typically consider fewer scenarios. Experts highlighted that ROA's value also lies in accounting for scenarios that might otherwise be dismissed as unlikely, revealing overlooked factors and offering huge benefits, stating that ROA is a more dimensional type of dealing with uncertainty in adaptive paths.

Barriers to ROA Implementation: Both experts agreed that the identified barriers to ROA implementation are generally accurate but noted a missing issue: people's dislike of uncertainty, often causing them to ignore it. For instance, decision-makers tend to choose a single scenario in CBA for traffic growth, avoiding the complexity of managing multiple uncertain scenarios, as if they could predict how the world will evolve over the next 30 years. This reluctance is not unique to ROA but applies broadly to other methods, ROA complicates this by incorporating multiple uncertainties into decision trees. Interviewees suggested that this dislike of uncertainty, viewed also as a psychological barrier, should be fully recognized as a major barrier, beyond just accountability and control concerns which is one component of it. ROA's different way of handling uncertainties may drive people away from it because ROA is a more dimensional type of dealing with uncertainty in adaptive paths. Even if people overcome the reluctance to deal with uncertainties, they often resort to simpler methods like Monte Carlo simulations or sensitivity analysis, which take a linear, non-adaptive approach. The main issue is that many do not fully understand how to apply ROA, and its complexity makes it difficult to develop effective models. This creates a paradox: ROA is essential for complex projects but is challenging to implement because of its complexity.

Additionally, experts also noted that the complexity of ROA, combined with this resistance, further discourages its adoption. The additional time and cost involved in ROA were also highlighted, with one expert stating that while research is costly, making wrong decisions due to inadequate research is even more expensive, suggesting a rule of thumb to allocate 1% of the project budget to research to prevent poor decisions. The second expert pointed out that ROA is not widely taught in schools or universities, contributing to a lack of familiarity and comfort with the method among practitioners. Furthermore, the Ministry of Transport and Rijkswaterstaat have a strong preference for large, impressive infrastructure projects like bridges and surge barriers. This focus on big projects, according to the experts, makes smaller or phased approaches less appealing, limiting more strategic or incremental solutions and often leaving uncertainties only partially addressed.

Strategies For Facilitating ROA Adoption: The participants agreed on the relevance of the ROA enablers but emphasized the need to demonstrate its benefits through case studies and practical examples. Without clear advantages over current practices, people will not adopt ROA. Both experts stressed the importance of training practitioners and starting with the ROA mindset approach, which is already a big step, before progressing to more complex quantitative methods. They explained that having the right mindset and understanding uncertainties and choices is more important than the full ROA method.

They also stressed the need to simplify ROA's complex decision trees and models to make them understandable and useful. Without simplification, ROA risks being seen as a "black box," leading to resistance and reduced utility. While traditional approaches are not adaptive and straightforward, changing them is difficult due to standardized decision-making processes. A key facilitator suggested by the experts for ROA adoption is the development of user-friendly software and models that are easily understood and applied by practitioners, addressing the practical challenges in implementing adaptive planning and ROA. One expert cited Rijkswaterstaat's use of complex fault trees, including extensive calculations, for reliable storm surge barriers, supported by software and training, noting that similar tools for ROA are lacking. Without appropriate software and a user-friendly interface, ROA remains less accessible to people and organizations.

Additionally, Experts emphasized the importance of joint learning, collaboration, and risk dialogue in project planning. Engaging all stakeholders in discussions about potential risks helps inform ROA models by identifying key uncertainties. Revisiting these risks in follow-up discussions further strengthens the process. Integrating ROA into this collaborative approach increases stakeholder acceptance and enhances model effectiveness.

Conditions for ROA Application: the interviewees agreed with the conditions under which ROA is most applicable, highlighting that these conditions are very often met in practice, especially in infrastructure investments and water management projects. Because there are often large and complex investments with high uncertainty and can be often split up into phases. However, they noted that in most real-world projects, these conditions are present, suggesting ROA should be more widely applied, yet it remains underutilized. Additionally, for smaller projects, the effort required for ROA may not justify its benefits, despite the fact that most infrastructure projects nowadays are large enough to benefit from it.

ROA Application Areas: The validation confirmed a consensus that ROA could play a crucial role in the areas identified in the empirical research, including adaptive management, climate adaptation, long-term planning, and strategic planning, particularly for large infrastructure projects like dikes and storm surge barriers, given the challenges of accounting for future conditions such as sea-level rise. The experts fully agreed on the benefits of ROA in these contexts. Despite past challenges with ROA integration, Rijkswaterstaat now faces a new opportunity through an upcoming call, driven by the growing necessity for adaptive asset management. This window of opportunity highlights the increasing importance of adopting more flexible and resilient approaches to infrastructure planning. Awareness of ROA, especially in adaptive climate planning, is growing, with more investment needed to develop this mindset, one expert stated.

Moreover, one expert emphasized the relevance of Marjolein Haasnoot's adaptive pathways work in water planning, particularly for addressing challenges like rising sea levels and strengthening dikes and storm surge barriers. While currently qualitative, efforts are underway to make this approach more quantitative, aligning with ROA principles. The expert stressed the importance of adaptive pathways in future spatial planning and water management.

ROA Utilization Approaches: Both participants confirmed the empirical research and recognized ROA's value as a mindset. They recommended creating an appealing example to demonstrate the practical benefits of applying the ROA mindset to a project.

Future Infrastructure Options: Both participants agreed on the value of phased and expansion options for future infrastructure projects, stating that each of the listed options serves a specific purpose and that the need for these options will grow. They emphasized the growing need for phased approaches due to the uncertainty of the future and the necessity to take the first step, while also determining the best steps to take up to a certain point and when future decisions should be made. Although expansion is relevant, there should be a stronger focus on innovation and renewal, especially with the energy transition and climate adaptation and expansion may not be the way forward. Instead, experts noted that accelerated options could be valuable in this context. Projects like heightening dikes will still involve some expansion.

While it is technically possible to defer infrastructure projects, this option is rarely used in practice due to the significant financial investment required, making it difficult to justify postponement once resources have been committed. The high costs involved create pressure to proceed rather than delay.

However, experts see deferral as important for transportation projects, which may not be needed now but could gain value over time, given the growing demand and need for such infrastructure. Finally, experts indicated that some options are more industry-related and are less used in infrastructure projects.

Finally, in discussing whether the process of making decisions or decision outcomes is more important, both experts stressed the role of transparency and process quality. One expert highlighted that delays in dike strengthening often result from the complexity of involving all stakeholders while adhering to legal procedures, highlighting the dilemma between ensuring safety and achieving stakeholder support. The second expert while acknowledging the importance of the process, stressed that the outcome, particularly in terms of safety, is far more critical. He argued that while hundreds may be involved in the process, the result, such as a dike, protects millions of people for many years, making safety the top priority.

" But indeed, the process and how people deal with each other and how people feel that the process has been going. Whether they were involved or not, and whether they understood, is often perceived as more important than the outcome or the accuracy of the outcome. But that's psychological "

5.3 Interpretation

The validation process confirmed the overall findings of the empirical research, offering valuable insights into their relevance, strengths, and applicability while revealing key insights and observations that further enrich the research conclusion. A notable point of emphasis is the complexity ROA introduces when addressing uncertainty. While both experts agreed on the comprehensiveness of the uncertainties listed in infrastructure projects, they highlighted that ROA struggles with excessive uncertainty, which can turn ROA models into "black boxes." To address this issue, the experts suggested simplifying the process by focusing on key uncertainties identified through stakeholder consultations. These uncertainties can then be integrated into ROA models, facilitating clearer and more informed decision-making. While this perspective underscores the utility of ROA, it also highlights that its complexity can limit effectiveness, especially when managing multiple uncertainties.

In terms of evaluation methods, the experts offered new insights into the variation in method usage across departments, with economic departments favouring CBA and non-economic ones leaning toward MCA. This reflects a departmental divide that was not fully addressed in the empirical research, suggesting that method selection depends heavily on the user’s background and expertise. The surprise expressed by one expert regarding the underuse of mandatory CBA in some projects adds an interesting dimension to the research, highlighting the possibility of inconsistent application of methods.

The experts critiqued the perceived limitations of current evaluation methods, particularly around the overstated issue of discounting cash flows. They emphasized that the problem is less about the methods themselves and more about how they are applied, especially when only one scenario is considered. This suggests that the challenge is more related to the mindset of decision-makers, a finding that nuances the empirical research by shifting the focus from technical limitations to human factors in method application.

Regarding ROA’s implementation barriers, both experts stressed an overlooked psychological resistance to uncertainty, or as they described, a general dislike to uncertainty. This adds a new layer to the empirical findings, indicating that the reluctance to engage with multiple uncertainties is a major obstacle to ROA adoption. The complexity of ROA, combined with this resistance, further complicates its use, confirming that while ROA is a powerful tool, its application remains limited due to both technical and psychological barriers. This insight deepens the understanding of the empirical research’s conclusions while emphasizing the psychological side of ROA application, beyond just a perceived loss of control.

Additionally, the absence of user-friendly software to support ROA implementation, which hinders its practical use, and the preference at the Ministry of Transport and Rijkswaterstaat for large projects over phased approaches, a cultural preference that limits the adoption of more flexible, strategic methods like ROA, were also identified as new barriers to ROA adoption. Moreover, the experts noted that while methods like CBA are straightforward, they lack adaptability, making it difficult to change rooted practices despite growing awareness of ROA’s importance. These insights further deepen the understanding of the research findings, emphasizing both the psychological and practical barriers to ROA adoption. Furthermore, although ROA research can be costly, the expense of wrong decisions due to insufficient research is far greater, downplaying cost as a barrier.

In terms of facilitating ROA adoption, the experts placed a strong emphasis on the need for training, ROA methods simplification, and demonstrating ROA’s benefits through case studies. They agreed that starting with a mindset shift, rather than immediately focusing on quantitative methods, is crucial for ROA's success. This recommendation enhances the empirical research by highlighting the need for a gradual approach to ROA adoption, starting with awareness and mindset, before tackling the complexity of the full method. In addition, developing user-friendly software and models that are easily understood and applied by practitioners was suggested as a crucial step to facilitate ROA adoption.

Experts highlighted that, in the context of energy transition and climate adaptation, expansion may not be the optimal path forward. Instead, there is a growing emphasis on accelerated options, reflecting an increasing recognition of the need for adaptive, forward-thinking strategies. This shift in focus toward acceleration over expansion suggests a rethinking of traditional approaches in light of current environmental and strategic pressures. Although defer options are difficult to apply in practice, it is seen as critical for transportation projects that may not be immediately necessary but could gain importance over time, uncovering more specific areas of application for this type of option.

Despite ROA's applicability conditions being met in practice, it remains underutilized, a contradiction also noted in the empirical research. This disconnect highlights the need for a clearer demonstration of ROA's value, particularly for large-scale projects with high uncertainty. Finally, the experts confirmed that ROA has strong potential in areas like adaptive management and climate adaptation, as highlighted in the empirical research. However, they also pointed out that efforts to integrate ROA need to be supported by practical tools, such as user-friendly software and models. This finding stresses that ROA’s technical limitations, combined with psychological barriers, need to be addressed for wider adoption, aligning with the research’s conclusion that ROA is an essential but underutilized tool.

A key revelation from the validation is that ROA’s true power lies in its multidimensional approach to uncertainty. By integrating all possible scenarios within a single decision tree, ROA simplifies the decision-making process, making it more manageable for decision-makers to navigate complex uncertainties. Additionally, ROA shines by accounting for scenarios that might otherwise be dismissed, revealing overlooked opportunities and offering substantial benefits These new insights provide a deeper understanding of ROA’s potential, further enhancing the practical and theoretical contributions of this research.

To sum up, the validation provided critical insights, particularly on the psychological barriers to ROA adoption and its practical complexity. These findings refine the empirical research by emphasizing the need for mindset shifts, training, and practical tools to overcome ROA's challenges. While ROA's relevance was confirmed, key barriers must be addressed to fully realize its potential in infrastructure decision-making. ROA's importance in complex projects like dikes and surge barriers was stressed, noting that while awareness is growing, further investment in developing the right mindset is essential. Despite ROA’s necessity for complex projects, its very complexity hinders its implementation, creating a paradox.

6. Discussion

This chapter integrates the findings from the empirical research with the theoretical insights gained from the literature review, offering a comprehensive analysis of the Real Options Approach (ROA) within the Dutch infrastructure sector. The discussion addresses the core research questions and sub-questions, providing recommendations for enhancing decision-making processes under uncertainty and highlighting the implications of the findings.

6.1 Discussion of the Research Results

The section will emphasize the alignment and divergence between theoretical perspectives and practical insights, as well as uncover new dimensions that have emerged from the empirical research or the subsequent validation.

Uncertainty In Decision-Making: Both the literature and empirical findings affirm that infrastructure projects are plagued with uncertainties, which have a considerable influence on decision-making. Globally, uncertainties are classified as market, technology, and policy-related, with market uncertainty, particularly regarding transport demand, being the most prevalent (Machiels et al., 2020). The literature identified these uncertainties as critical factors that influence project outcomes, with interviewees confirmed by citing specific instances where these uncertainties shaped project execution and decision-making frameworks. In the Dutch context, the empirical data highlights similar challenges but adds a notable emphasis on organizational and administrative uncertainties, such as political decision-making and stakeholder expectations. This additional layer of complexity emphasizes the distinctive administrative environment within Dutch infrastructure projects, aligning with global findings while providing a more nuanced understanding specific to the Netherlands. From a ROA perspective, addressing all these uncertainties would result in an overly complex, difficult-to-interpret model, as highlighted by expert validation. This insight deepens the understanding of ROA's practical challenges in managing multiple uncertainties, a point that received less emphasis in both the literature and the empirical research.

Evaluation Methods & Their Limitations: The limitations of traditional evaluation methods, such as CBA, are well-documented in the literature, particularly their inability to account for flexibility in dynamic project environments (Dixit & Pindyck, 1994). The empirical research supports these concerns, with interviewees frequently noting that these methods fail to fully capture uncertainties in infrastructure projects, leading to suboptimal decisions and reinforcing the call for adaptive frameworks like ROA. However, experts critiqued the emphasis on discounting as a major limitation, arguing that while it complicates long-term evaluations, it is essential for accuracy and is widely used across methods, including ROA and MCA. They concluded that the issue is rooted in the evaluators' mindset, how the methods are applied, not the methods themselves, suggesting that traditional methods can be improved by revisiting decisions when new information arises.

Both the literature and empirical findings agree on ROA's benefits in enhancing decision-making through flexibility, uncertainty management, and strategic planning. Key advantages include the ability to adapt projects to changing conditions and provide a concrete valuation of flexibility for better risk assessment. While the literature emphasizes strategic reconfiguration, the empirical findings highlight ROA's practical role in phased investments, improving resource allocation and adaptability. Additionally, ROA helps align stakeholder interests, ensures regulatory compliance, and supports proactive decision-making, particularly in managing financial constraints. A key insight from the validation is ROA's strength in managing uncertainty through its multidimensional approach, integrating all scenarios into a single decision tree. This simplifies decision-making, highlights overlooked opportunities, and offers substantial benefits. These insights deepen the understanding of ROA's potential, enhancing both the practical and theoretical contributions of this research.

Additionally, The literature highlights the importance of flexibility in managing uncertainties in infrastructure projects, enhancing both project value and adaptability (Bos & Romijn, 2017; De Neufville & Scholtes, 2011). This aligns with empirical findings, where interviewees stressed the need for flexibility to effectively respond to unforeseen circumstances. However, the empirical evidence adds depth by cautioning against excessive flexibility, which can lead to confusion and undermine decision clarity, advocating for a balanced approach.

ROA State of The Art In The Dutch Context: Both literature and empirical findings reveal that ROA's practical application is limited but gradually increasing. The literature predominantly discusses ROA through exploratory case studies where ROA was used to explore strategic options and manage uncertainties. However, these studies are mostly theoretical or retrospective, focusing on hypothetical rather than real-world applications. Empirical findings provide more concrete examples of ROA in practice, though still limited. Projects like the A44 road widening and the Rodevaart Canal explicitly apply ROA principles for phased investments and strategic decisions under uncertainty. Additionally, the research reveals implicit ROA use, where decision-makers apply its concepts to navigate complex project environments without formally recognizing them as ROA, as seen in projects like the Noord-Zuidlijn and Amsterdam-Almere highway. Furthermore, the research highlights instances where the absence of formal ROA application resulted in missed opportunities for better outcomes, emphasizing the need for more ROA real applications to navigate project complexities.

ROA Barriers To Implementation: The discussion on ROA implementation barriers highlights both corroborated findings and new insights. While the literature acknowledges ROA as a valuable yet underutilized tool due to its complexity, lack of empirical evidence, institutional resistance, and stakeholder unfamiliarity, the empirical findings deepen this understanding. These findings indicate that implementing ROA is not only technically challenging but also requires a cultural shift within organizations, suggesting that adoption is more difficult than previously perceived. Additionally, the influence of political considerations, which often prioritize short-term, voter-driven outcomes over long-term benefits, is highlighted as a substantial impediment, making it difficult to align with ROA's long-term strategic focus. This political dimension, although mentioned in the literature, was given much more weight in the empirical findings, indicating that it is a more significant obstacle than previously thought.

Furthermore, the research uncovers new insights, such as the fear of losing control over project outcomes due to the transparency and detailed nature of ROA, emphasizing the psychological side of ROA application that might not be as apparent in theoretical discussions. Expert validation reinforces the empirical findings, suggesting the barrier is better described as a general dislike of uncertainty, rather than merely a perceived loss of control. This confirms that, while ROA is a powerful tool, its adoption remains limited by both technical and psychological obstacles. In addition, while both the empirical research and literature identified the cost and time required for ROA as a key barrier, expert validation downplayed this concern, stating that although ROA research can be expensive, the cost of wrong decisions due to insufficient research is far greater.

Moreover, the deeply ingrained nature of standardized decision-making processes presents a significant barrier. Even when individuals overcome their general dislike of uncertainty, they often default to linear, non-adaptive approaches. This resistance, noted in the literature, empirical research, and expert validation, reflects a strong preference for traditional methods, which are seen as simpler and more reliable, further hindering the adoption of innovative methodologies like ROA. Additionally, the absence of user-friendly software to support ROA implementation, which hinders its practical use, and the preference at the Ministry of Transport and Rijkswaterstaat for large projects over phased approaches, a cultural preference that limits the adoption of more flexible, strategic methods like

ROA, were also identified as new barriers to ROA adoption, paying more attention to importance to tackling both the psychological and technical challenges to facilitate more effective ROA adoption.

Lastly, the empirical research provides valuable new insights into ROA's common misconceptions that also act as barriers to its implementation. One misconception is that ROA is a universally applicable tool, while the findings suggest it is best suited for large-scale, long-term infrastructure projects where its benefits can outweigh the costs. Another misconception is that ROA is inherently expensive, but the research shows that it can be applied cost-effectively by promoting flexible solutions over costly, fixed alternatives. Additionally, the perceived complexity of ROA is overstated, as the research demonstrates how it can be simplified and used as a strategic tool, making it more accessible.

ROA Practical Recommendations:

1- **ROA Application Conditions:** The conditions for applying ROA identified in both the literature and empirical research align, highlighting its suitability in high uncertainty, irreversibility, managerial flexibility, and asymmetric payoffs, making it ideal for large-scale, long-term projects. Both sources agree that ROA may be less useful for smaller projects due to the costs of detailed analysis. However, the empirical research adds that ROA is particularly valuable in the pre-implementation phase and for projects with segmented decision points, emphasizing the need to tailor ROA application to specific project characteristics. Expert validation further confirms that while ROA's applicability conditions are frequently met, especially in infrastructure and water management projects, it remains underutilized, a contradiction also noted in the empirical research. Additionally, the empirical findings highlight ROA’s applicability to a broader range of uncertainties regardless of their sources, disproving literature that limits its use primarily to market price uncertainty (van Den Boomen et al., 2018).

2- **Future Infrastructure Options:** The literature on ROA highlights defer, expand, and abandon options as most beneficial for large-scale infrastructure projects (Machiels et al., 2020; Marques et al., 2023). However, the empirical research narrows this focus, with interviewees identifying phase and expansion options as the most practical, particularly emphasizing the value of expansion in projects like heightening dikes. These options are seen as crucial for enhancing project flexibility and scalability, aligning with the sector's practical needs.

   Although the literature emphasizes the strategic value of defer and abandon options, the empirical findings suggest these are less practical due to political, logistical, and regulatory pressures that require timely decision-making and the difficulties of resuming deferred projects in changing conditions. Expert validation supports this, highlighting that deferral is critical for transportation projects that may gain importance over time. Additionally, the empirical study introduces pre-invest, contract, and accelerate options, less emphasized in the literature but seen as valuable in specific contexts. Experts noted that in energy transition and climate adaptation, there is a shift from expansion to accelerated options, reflecting the need for adaptive, forward-thinking strategies. This divergence underlines a gap between theoretical discussions and the practical application of options in real-world projects.

3- **ROA Utilization Approaches:** The literature and empirical findings both recognize ROA as both a strategic mindset and an analytical tool, yet they reveal distinct preferences in practice. While the literature highlights ROA’s versatility in structuring and quantifying flexibility, the empirical research highlights a stronger preference among practitioners for using ROA primarily as a strategic mindset rather than a complex analytical tool. Interviewees noted that simplifying ROA and focusing on its conceptual benefits, such as exploring alternatives and pre-investment opportunities, provides more practical value, especially in client interactions. Expert validation supports this view, emphasizing a gradual approach to ROA adoption, starting with awareness and mindset before addressing its full complexity. This reflects a shift toward using ROA to enhance strategic thinking, reserving detailed analysis for when additional insights are needed, a perspective less explored in the literature. This finding suggests a practical refinement of ROA's application, emphasizing the importance of adaptability and strategic alignment over rigid analytical methods.

4- **ROA Potential Application Areas:** The research highlights key contexts where ROA is particularly valuable, as shown in Figure 15, which outlines the main application areas and utilization strategies identified by interviewees.

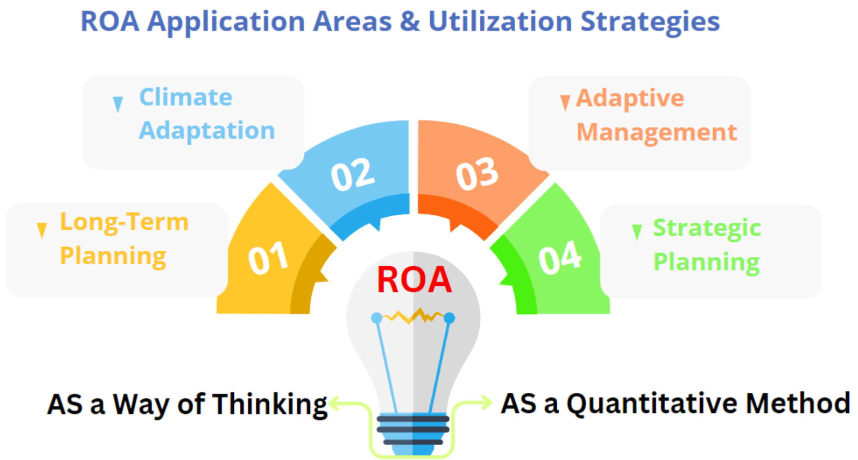

Figure 15: ROA potential Application Areas: Practical Insights

First, ROA is highly beneficial in climate adaptation and flood risk management, where it supports incremental decision-making in response to long-term environmental uncertainties such as sea-level rise and climate change. Second, ROA proves valuable in long-term planning, especially for infrastructure projects facing high levels of uncertainty, as it enables continuous adjustments over time, ensuring project resilience. Third, ROA supports adaptive management by allowing for ongoing modifications based on new data and outcomes, making it particularly effective for managing complex infrastructure projects. Lastly, ROA is advantageous in strategic planning, where it helps align the interests of multiple stakeholders, ensuring that all parties are coordinated and that project execution is smooth and efficient.

Experts confirmed ROA's crucial role in these areas, particularly for large infrastructure projects like dikes and storm surge barriers, given the challenges of accounting for future conditions such as sea-level rise. Despite past challenges with ROA integration, Rijkswaterstaat has a new opportunity through an upcoming call, driven by the growing necessity for adaptive asset management. This highlights the increasing importance of adopting more flexible and resilient approaches to infrastructure planning. Awareness of ROA, especially in adaptive climate planning, is growing, with more investment needed to develop this mindset, one expert stated. These new, valuable insights demonstrate the diverse applications of ROA, emphasizing its practical utility in a variety of project contexts.

5- **ROA Enablers:** The empirical research makes a critical contribution by offering practical strategies to support ROA adoption, a gap previously overlooked in the literature. While the theoretical advantages of ROA have been extensively discussed, this research highlights the importance of simplifying and standardizing processes to ensure broader acceptance and usability. These findings are important because they move beyond theory and provide actionable steps, such as fostering stakeholder engagement and introducing cultural shifts towards flexibility and adaptability, which are crucial for real-world application. The emphasis on change management, training, and gradual integration of ROA into organizational practices addresses the common resistance to change in infrastructure projects. By providing decision milestones and using success stories to build confidence, the research aligns ROA implementation with practical realities, making it easier for organizations to transition from traditional methods.

   Expert validation reinforces the importance of these enablers by emphasising the need to start with a mindset shift, rather than immediately diving into complex quantitative methods, which enhances the research's practical relevance. Moreover, the suggestion to develop user-friendly software is pivotal, as it directly addresses one of the key barriers to ROA adoption identified by practitioners. These insights collectively provide a clear, actionable roadmap for ROA implementation, ensuring the research offers not just theoretical but also practical contributions.

6- **Evaluation Technique Selection** (The debate over whether the decision-making process or the outcome is more important; Transparency VS Accuracy): A key insight from the research is the emphasis on transparency over accuracy in decision-making for complex infrastructure projects. Interviewees consistently noted that the process of making decisions, with clear communication and stakeholder engagement, is often more important than the decisions themselves. This prioritization of transparency ensures that stakeholders, including non-technical ones like politicians, can understand and accept the rationale behind decisions, facilitating smoother implementation and buy-in. This finding is particularly relevant in scenarios where traditional methods, like CBA, fail to capture the dynamic nature of real-world conditions. Experts supported this, stressing the role of transparency and process quality, with one expert highlighting that delays in dike strengthening often result from the complexity of involving all stakeholders while adhering to legal procedures, highlighting the dilemma between ensuring safety and achieving stakeholder support. While another emphasized that although transparency is crucial, the ultimate priority must be the safety and effectiveness of the outcome, as it impacts millions over the long term.

   These findings have a direct impact on the application of ROA in my research. Given the emphasis on transparency in decision-making, the selection of evaluation methods becomes crucial, particularly for applying ROA where there are several techniques available. The research suggests that opting for Simplified Decision Tree Analysis, as endorsed by the CPB, is a suitable method, despite some debate regarding its accuracy. This aligns with the literature, which highlights its transparency, applicability, and ease of integration with CBA (van der Pol et al., 2016), making it an ideal tool for ROA. Additionally, Brandão et al. (2005) assert that decision analysis, when applied to real-option valuation, is suitable since Decision Trees effectively model project flexibility and produce results comparable to option pricing theory when applied correctly. While Decision Tree analysis is straightforward and may be seen as overly simplistic, its ease of application is essential for encouraging decision-makers to engage with and understand the benefits of ROA.

   The figure below illustrates a Decision Framework for Applying ROA in large-scale, long-term projects. The framework is the result and culmination of synthesizing both the literature and empirical research findings. ROA is recommended when projects involve high uncertainty, significant investment, asymmetric payoffs, and managerial flexibility. It is applied in areas like Strategic Planning, Long-Term Planning, Adaptive Management, and Climate Adaptation, where flexibility and options such as expanding, phasing, and deferring are valuable. If these conditions are absent, traditional methods like CBA or NPV suffice. The decision on whether to apply ROA as a mindset or as a quantitative method is largely determined by the availability of data, the nature of uncertainties involved, and the project stage. For more detailed information on when to apply the ROA mindset versus the ROA quantitative method, please refer to Appendix E.

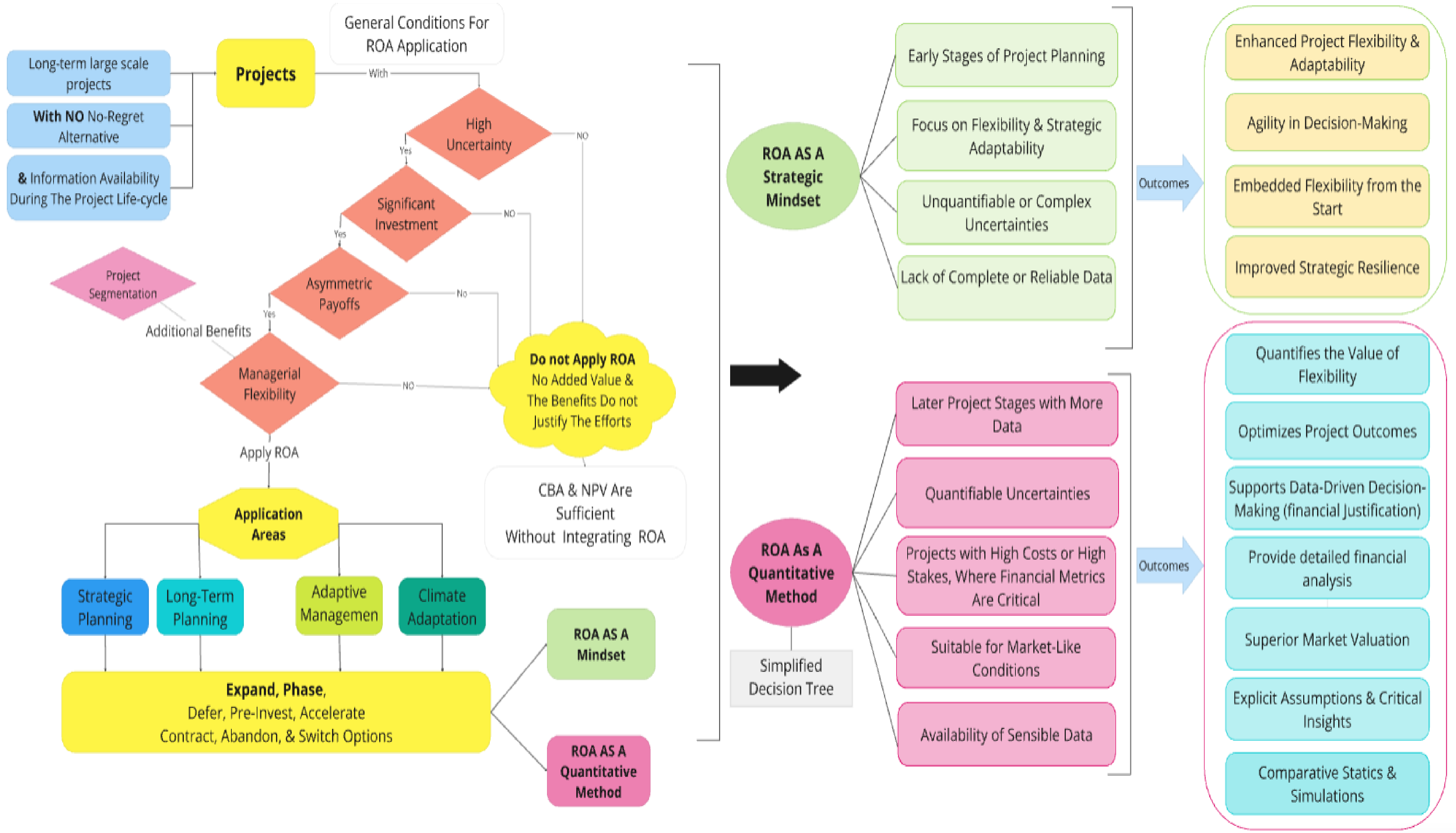

Figure 16: *ROA Framework*

ROA "in" & "on" Projects: Despite the extensive distinction between ROA "in" and "on" projects in the literature, the empirical findings reveal that this differentiation is not commonly recognized by practitioners. In theory, ROA "on" projects involves applying financial options at a macro level, focusing on investment decisions and portfolio management, and often treating the project as a complete system in response to market uncertainties. On the other hand, ROA "in" projects embeds flexibility within the design and operational strategies of the project, allowing managers to directly adapt to uncertainties within the project's technical and architectural frameworks. However, the empirical data shows that interviewees, even those familiar with ROA, did not explicitly distinguish between these two approaches. This oversight might be due to the practical focus of the interviewees, who are more concerned with the immediate challenges of implementation rather than the theoretical nuances. Additionally, this gap suggests that the theoretical frameworks discussed in academia are not fully translated into practical applications, possibly due to the complexity and abstract nature of the distinction, which may not resonate with practitioners focused on tangible outcomes.

One possible explanation for this lack of distinction is the preference of the interviewees to use ROA primarily as a strategic mindset rather than a technical tool. This aligns more closely with the function of ROA "on" projects, which emphasizes high-level decision-making and flexibility in response to market conditions, rather than the more detailed and technically demanding application of ROA "in" projects. The strategic focus allows practitioners to think about ROA in terms of broad investment strategies without delving into the complex design and operational details that ROA "in" projects would require. This approach might be more appealing to practitioners who are tasked with making decisions under uncertainty but do not have the technical background or resources to apply ROA at the micro-level within project designs. This observation highlights a critical area for further research and professional development. There is a need to bridge the gap between theory and practice by making these distinctions more accessible and relevant to practitioners. This could involve developing practical guidelines that demonstrate how ROA "on" and "in" projects can be effectively applied in real-world scenarios, thereby enhancing the practical utility of ROA in managing infrastructure projects. Additionally, future studies should explore how this theoretical distinction could be better communicated and integrated into the decision-making processes of infrastructure projects, potentially leading to more informed and strategic use of ROA.

Reflecting on the research findings, it is important to consider the influence of the research design and the potential alternative interpretations that might affect the robustness of the conclusions. This study, which relied on semi-structured interviews with 16 industry practitioners and a subsequent validation step with two experts, introduces a degree of subjectivity that could influence the outcomes. The qualitative nature of the interviews allowed for deep exploration of practitioners' perspectives on ROA in Dutch infrastructure projects, but this approach has limitations, particularly regarding generalizability due to the small and specific sample size. While the insights provided a comprehensive view of the barriers and enablers for adopting ROA, different results might have emerged with a more quantitatively driven methodology or a larger, more diverse sample. The validation process, though valuable, was also constrained by the limited number of experts, potentially affecting the generalizability of the findings. Future research could enhance the robustness of these findings by incorporating a mixed-methods approach, combining qualitative insights with quantitative data, to achieve a more balanced and generalizable understanding of ROA's applicability in infrastructure decision-making across various contexts.

Figure 17 presents a concise overview of the research's key findings. At the heart of the figure are the four main application areas of ROA: Strategic Planning, Climate Adaptation, Adaptive Management, and Long-term Planning. Surrounding these core areas are the two primary approaches to applying ROA: as a strategic mindset and as a quantitative method. The different sizes of the options types (e.g., Expand, Phase, Defer) reflect their relative importance and potential benefits in infrastructure projects, with larger options indicating those expected to be more frequently utilized and valuable. On either side of this central focus are the key barriers and enablers to ROA adoption, all within the context of various uncertainties, Technological, Environmental, Organizational, and Financial, that ROA is designed to address. This integrated layout effectively visualizes the interconnected factors that influence the implementation of ROA in infrastructure projects.

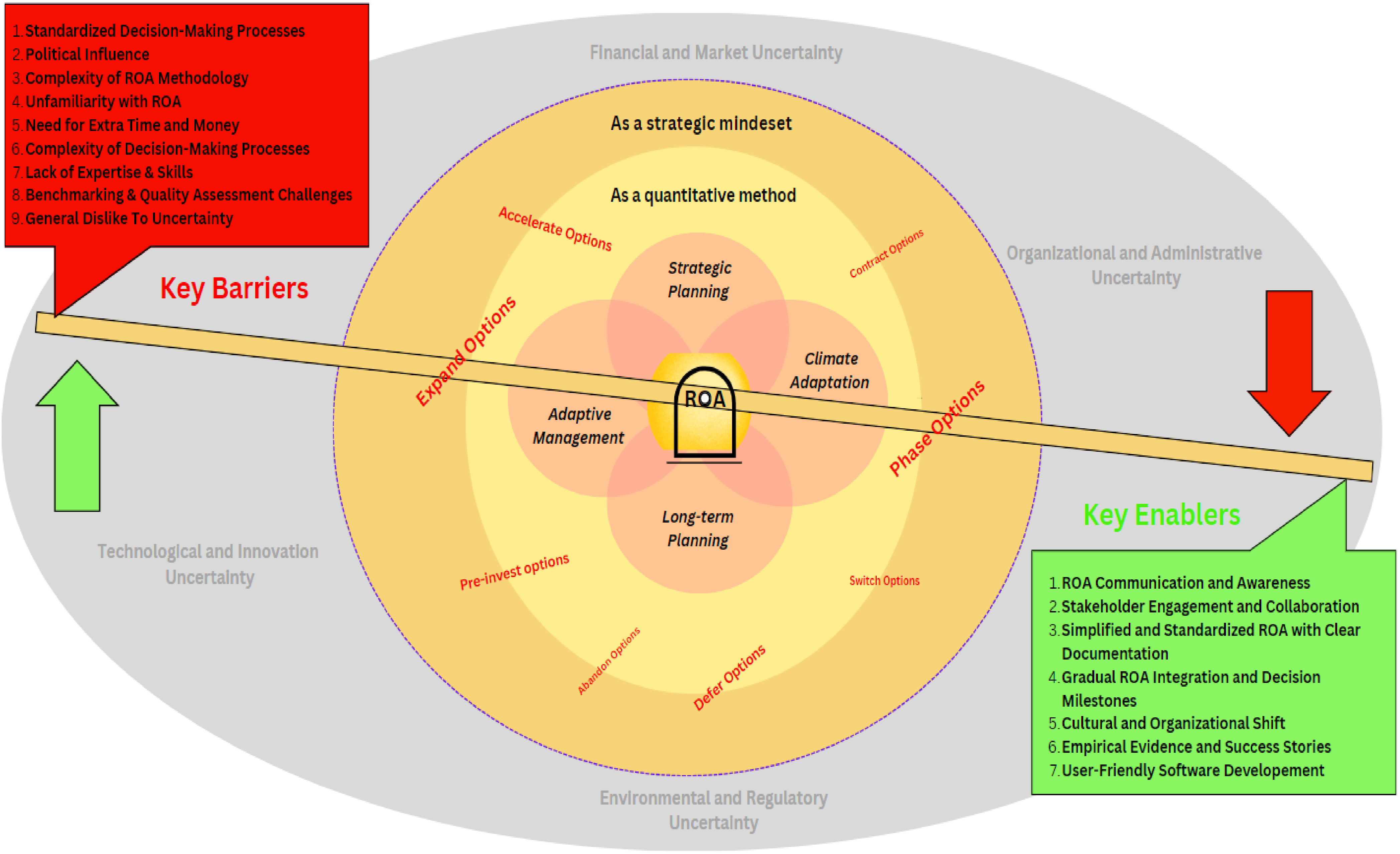

Figure 17: *Research Findings Overview*

6.2 Interpretations & Implications

The results of this study provide several important interpretations and implications for the use of ROA in the Dutch infrastructure sector. These insights not only bridge the gap between theory and practice but also offer practical guidelines for organizations aiming to enhance their decision-making processes under uncertainty.

The empirical findings align with the literature in highlighting the critical role of uncertainty in infrastructure projects. However, they go further by demonstrating that the successful application of ROA is contingent not just on the recognition of uncertainties, but also on an organization's ability to adapt its decision-making culture and processes. The widespread perception that ROA is overly complex and difficult to implement underlines a key barrier that the literature had identified but perhaps underestimated in its impact. This indicates that while the theoretical benefits of ROA are well-recognized, their realization in practice is often hindered by institutional inertia and the prevailing decision-making culture. Moreover, the empirical data reveal that the barriers to ROA implementation are not merely technical but also deeply rooted in organizational and political structures. This finding suggests that the introduction of ROA requires more than just technical adjustments, it necessitates a broader cultural shift towards long-term strategic thinking. The empirical research has shown that political influence and short-term project focus are significant obstacles, emphasizing the need for strategic alignment between political objectives and project evaluation frameworks.

The practical implications of these findings are significant. For organizations in the Dutch infrastructure sector, the adoption of ROA should be approached as a comprehensive change management initiative rather than a simple methodological shift. This involves not only training and capacity-building to enhance technical understanding of ROA but also fostering a culture that values long-term strategic planning over short-term gains. One practical step organizations can take is to integrate ROA with existing evaluation methods rather than attempting to replace them. This complementary approach allows organizations to leverage the strengths of traditional methods while also incorporating the flexibility and adaptability that ROA offers. By doing so, organizations can develop a more robust decision-making framework that is better equipped to handle the uncertainties inherent in infrastructure projects.

Furthermore, the empirical findings suggest that successful ROA implementation will require active stakeholder engagement, particularly with political actors who often have a significant influence on project outcomes. Organizations should consider involving these stakeholders early in the decision-making process to ensure that their interests are aligned with the long-term strategic goals of the project. This could involve developing communication strategies that clearly articulate the benefits of ROA in managing uncertainties and achieving sustainable project outcomes. Lastly, the study highlights the importance of empirical validation and the need for future research to focus on practical applications of ROA in real-world settings. The discrepancies between the theoretical benefits of ROA and its practical challenges highlight the need for more case studies and empirical data that can provide organizations with actionable insights into how to effectively implement ROA.

On a broader scale, the findings of this study have implications for the entire infrastructure sector, particularly in the context of increasing uncertainty due to factors such as climate change, technological advancements, and shifting regulatory landscapes. The adoption of ROA could play a critical role in enhancing the resilience and adaptability of infrastructure projects, ensuring that they are better equipped to handle these uncertainties. For policymakers and industry leaders, the study suggests that there is a need to create an enabling environment for the adoption of innovative evaluation methods like ROA. This could involve revising regulatory frameworks to encourage long-term planning and providing incentives for organizations that adopt flexible and adaptive decision-making approaches.

6.3 Research Limitations

This study provides valuable insights into the Real Options Approach (ROA) within the Dutch infrastructure sector, yet several limitations must be acknowledged, which may have influenced the scope and outcomes of the research. These limitations also suggest avenues for future exploration.

1. **Sample Size and Diversity**: The study's empirical research was primarily based on interviews with a limited number of participants. While efforts were made to include a diverse group of stakeholders, the relatively small sample size may not fully represent the broader spectrum of perspectives within the Dutch infrastructure sector. Additionally, the participants were predominantly from certain sectors, which might have introduced bias and limited the generalizability of the findings across different types of infrastructure projects.

2. **Geographical Focus**: The study's focus on the Dutch infrastructure sector may limit the generalizability of the findings to other contexts. The research was concentrated on the Dutch infrastructure sector, which may limit the applicability of the findings to other regions or countries. While the Dutch context provided a specific and relevant case study, the unique regulatory, economic, and environmental conditions in the Netherlands may not be directly comparable to other contexts, potentially affecting the broader applicability of the recommendations.

3. **Lack of Empirical Validation**: While the study proposed several recommendations for enhancing ROA adoption, these recommendations have not been empirically tested in real-world settings. The theoretical nature of some suggestions, without practical validation, means that their effectiveness in actual decision-making processes remains uncertain. Future research should focus on implementing these strategies in real projects to evaluate their practicality and impact.

4. **Methodological Constraints**: The reliance on qualitative research methods, primarily through semi-structured interviews, while providing rich insights, also introduces subjective biases. The interpretation of interview data can be influenced by the researcher's perspective, and the qualitative nature of the analysis may limit the ability to quantify the impact of identified barriers and enablers.

5. **Complexity and Understanding of ROA Concepts**: The inherent complexity of ROA posed challenges in ensuring a uniform understanding of its principles and applications among participants. Despite efforts to simplify and clarify the methodology during interviews, varying levels of familiarity may have influenced the accuracy and consistency of their responses, potentially leading to discrepancies in the data.

6. **Researcher and Participant Subjectivity**: Conducted entirely by a single researcher, this study is susceptible to biases stemming from individual judgment and interpretation, particularly in the selection of quotations, categorization of data, and attachment of relevant elements to the transcripts. This reliance on one person's perspective may compromise the overall integrity of the findings. Additionally, subjectivity may also arise from participants, as they might provide socially desirable responses rather than those that accurately reflect their real practices, further skewing the results.

7. Conclusion & Recommendations

This chapter presents thorough answers to the sub-questions that have guided this research, culminating in a comprehensive response to the main research question. It concludes with recommendations for future research, identifying key areas for further exploration to advance the applicability of ROA in infrastructure projects.

7.1 Answering the Sub-Questions

7.1.1 Sub-Question 1

The 1st Sub-Question: What is currently known about the Real Options Approach (ROA) and its applicability & application in infrastructure projects?

Originating from financial markets, ROA has been adapted to real assets. It provides a structured way to quantify flexibility, enabling better uncertainty management and more dynamic decision-making than traditional methods like CBA, which often overlook evolving project environments. Typically, ROA can be applied in two ways: as a strategic mindset and as an analytical tool. As a mindset, it helps frame decision-making by emphasizing flexibility and adaptability. As an analytical tool, ROA employs methods to value flexibility, assess the optimal timing of decisions, and develop models tailored to specific projects. For ROA to be applicable, key conditions must be met: significant uncertainty, managerial flexibility, irreversibility, and asymmetric payoffs. ROA is particularly useful for long-term projects with high volatility and the potential for new information to arise. Common options include deferring, expanding, or abandoning projects, ensuring adaptability to market changes. ROA can be applied to both "on" and "in" projects. "On" projects refers to applying ROA at a macro level, focusing on investment and portfolio management in response to market uncertainties. "In" projects involve integrating flexibility into the project's design and operations, allowing for adjustments as uncertainties arise. This distinction highlights how ROA can be used at different stages of project management.

ROA offers more accurate investment valuations by incorporating flexibility, making it vital for adapting to changing conditions. It provides strategic insights by evaluating multiple project pathways and translating abstract benefits into financial terms. Its customizable nature allows for tailored applications to specific project needs. However, ROA's limitations include an incomplete view of megaproject complexity, as it narrows focus on uncertainty and flexibility, potentially overlooking critical risks. Additionally, ROA can be prone to heuristics and decision biases, leading to suboptimal outcomes. Adoption is further hindered by challenges in valuing real asset options due to ambiguous market variables and the assumption that decision-makers possess advanced quantitative skills. Political, organizational, and institutional constraints, along with the multi-agent complexity of public projects involving economic, political, and stakeholder negotiations, also limit its implementation.

ROA has been explored in various infrastructure sectors globally, including transportation, energy, and urban development, with applications in toll roads, airports, and rail systems. While its theoretical benefits are well-documented, practical implementation remains limited, with most studies focusing on theoretical cases or ex-post evaluations rather than real-world evidence. In the Netherlands, ROA adoption has been slow, particularly in the railway sector, with isolated examples such as the Maasvlakte 2 expansion. Its potential to manage uncertainties and improve decision-making is hindered by the complexity of the methodology, time demands, rooted standardized frameworks, and the political pressure for swift results, limiting its broader use in public infrastructure projects. Finally, it is important to emphasize that ROA neither replaces nor excludes traditional evaluation methods. Instead, it complements and enhances these approaches by integrating its principles into existing frameworks. This integration creates a new valuation paradigm that strengthens the ability of traditional methods to address uncertainty and improve long-term planning.

7.1.2 Sub-Question 2

The 2nd Sub-Question: What types of uncertainties are prevalent in Dutch infrastructure decision-making, and how do existing evaluation methods address these uncertainties?

Four main categories of uncertainty were identified in the Dutch context including Organizational and Administrative Uncertainty encompasses issues such as political shifts, stakeholder expectations, and inefficiencies within institutional processes, all of which can lead to fragmented decision-making and delays in project execution. Political uncertainty, driven by changes in government policies and elections, can alter project scopes and timelines, while stakeholder uncertainty arises from varying demands and expectations, often leading to extended project timelines due to the need for continuous communication and adjustments. Additionally, administrative inefficiencies and complexities within institutional frameworks further exacerbate these uncertainties, making project management more challenging. Financial and Market Uncertainty encompasses the unpredictability of budgeting, market conditions, and economic factors, which are critical in infrastructure projects. Market uncertainty, particularly fluctuations in material costs and labour availability, was frequently mentioned by interviewees as a significant concern. The dynamic nature of market conditions and the impact of external factors such as geopolitical events further complicate financial planning and long-term project stability and force project managers to continuously adapt their strategies.

Environmental and Regulatory Uncertainty primarily stems from stringent and evolving environmental regulations, particularly those related to emissions and protected areas, which can delay or alter project plans. Additionally, the unpredictability of climate change impacts, such as sea-level rise and extreme weather events, complicates long-term infrastructure planning, necessitating adaptive and flexible strategies. Technological and Innovation Uncertainty reflects the challenges associated with adopting new technologies and innovations in infrastructure projects, ensuring compatibility with existing systems, and predicting long-term viability. The conservative nature of the infrastructure sector, particularly in areas like railways, often delays the adoption of proven innovations from other industries. The regulatory requirements for new technologies can further complicate their implementation, leading to increased uncertainty. The success of innovations is also unpredictable, which can impact decision-making processes and necessitates thorough evaluation and pilot testing to mitigate risks. Lastly, the lack of reliable historical data on infrastructure assets intensifies uncertainty and complicates maintenance-related decisions. Finally, from a ROA perspective, addressing all uncertainties can lead to an overly complex model, highlighting the necessity for simplification.

The existing evaluation methods in Dutch infrastructure projects are CBA, LCA, MCA, VE, and TCO. Each method offers unique strengths, including project assessments of costs, benefits, and impacts, yet they also present limitations. The methods struggle with addressing uncertainties, particularly in long-term projects and areas requiring integration and coordination across different departments. Traditional CBA, for example, relies on discounting cash flows, which can lead to unrealistic outcomes, especially for long-term projects where future costs are heavily minimized. Additionally, these methods often apply broad, hypothetical uncertainty ranges without a solid foundation, resulting in decisions that do not connect to actionable outcomes. The static nature of these evaluations further limits their ability to adapt to dynamic real-world conditions. However, experts critiqued the emphasis on discounting as a major limitation, arguing that while it complicates long-term evaluations, it is essential for accuracy and is widely used across methods, including ROA and MCA. They concluded that the issue is rooted in the evaluators' mindset, how the methods are applied, not the methods themselves, suggesting that traditional methods can be improved by revisiting decisions when new information arises. A key insight is ROA's ability to manage uncertainty through its multidimensional approach, integrating all scenarios into a single decision tree. This simplifies decision-making, uncovers overlooked opportunities, and offers substantial benefits.

7.1.3 Sub-Question 3

The 3rd Sub-Question: What are the key reasons and barriers that have prevented the widespread adoption of ROA in the Dutch infrastructure sector?

ROA adoption in the Dutch infrastructure sector faces several key barriers. Standardized decision-making processes within organizations favour familiar methods due to their perceived simplicity, speed, and control, creating resistance to new approaches like ROA. This resistance is compounded by political influence, where decisions are often driven by short-term public approval rather than long-term benefits, misaligning with ROA's strategic focus. The general unfamiliarity with ROA, alongside a preference for traditional methods like CBA, and the lack of clear policy support, further limits its exploration. Moreover, ROA is seen as requiring substantial time and financial investment, which, in an environment constrained by tight budgets and a focus on maintaining existing infrastructure, makes its adoption less appealing.

The complexity of decision-making in Dutch institutions, marked by segmented responsibilities and bureaucratic inertia, complicates the application of ROA, as it requires a holistic perspective that is often lacking. Additionally, ROA is viewed as complex and intimidating, requiring specialized skills that are not always available. This lack of expertise, coupled with insufficient motivation and a skills gap, impedes its effective use. The statistical demands of ROA create a psychological barrier for practitioners who feel unprepared to apply the approach. Further challenges include difficulties in benchmarking and quality assessment due to the absence of comparative studies, adding to uncertainty about ROA’s benefits and reliability. Moreover, a general dislike of uncertainty among practitioners hinders ROA adoption, driven by, among others, concerns over accountability and fears of losing control due to ROA’s transparency and detailed analysis. This highlights the psychological barriers to ROA implementation suggesting that adoption is more challenging than previously thought. Even when individuals overcome their aversion to uncertainty, they often resort to linear, non-adaptive approaches.

Common misconceptions about ROA, such as its perceived universal applicability, high costs, and complexity, further restrict its adoption. ROA is most effective for large-scale, long-term projects and, while resource-intensive initially, can be adapted for limited budgets through flexible options and simplified for strategic use without complex calculations. Its adoption is also challenged by a lack of long-term perspective in some organizations, added complexity, and extended timelines in phased approaches, which increase bureaucratic burdens. Maintaining political and financial support, along with legal concerns around transparency, also complicates implementation. Practical challenges like political pressures and expiring permits further impact the use of defer options. Additionally, the absence of user-friendly software to support ROA implementation prevents its practical use.

7.1.4 Sub-Question 4

The 4th Sub-Question: What recommendations can be provided to facilitate the adoption and implementation of ROA in the Dutch Infrastructure Sector?

To facilitate ROA adoption in the Dutch infrastructure sector, six key enablers were identified. First, effective communication and awareness-building are essential, using clear, straightforward language and visual tools to highlight ROA's benefits and overcome resistance to unfamiliarity and complexity. Second, active stakeholder engagement, including cross-departmental collaboration and appointing ROA champions, promotes buy-in and broader integration. Third, simplifying and standardizing ROA processes with clear documentation increases accessibility and trust, while aligning it with existing frameworks. Fourth, gradual integration, with decision milestones, eases the transition and reduces resistance to change. Fifth, fostering a cultural and organizational shift through structured change management and training equips employees to apply ROA effectively. Finally, leveraging empirical evidence and success stories demonstrates ROA's practical value and encourages its adoption. Moreover, differentiating enablers for organizations (focused on fostering a supportive culture and building practical frameworks) and ROA promoters (focused on advocacy and engagement) ensures successful integration. The findings emphasize that ROA adoption requires strong organizational commitment and a shift from traditional practices, supported by infrastructure managers and consultants.

To maximize ROA's potential, it should be applied in the pre-implementation phase of projects with high uncertainty, irreversibility, significant investments, managerial flexibility, and asymmetric payoffs. ROA is especially valuable in large-scale projects where detailed analysis is justified, helping to navigate volatile conditions with varying outcomes. It is most effective when projects can be segmented, allowing flexible, phased decision-making as new information emerges. Recommended options for ROA include phase options, which break projects into manageable stages for better risk management, and expansion options, useful for scalability but less relevant for energy transition and climate adaptation. Accelerated options may be more suitable in this context. Defer options delay investments until more information is available, especially beneficial for aligning transportation projects with market conditions, while pre-invest options secure future opportunities, and abandon options mitigate losses in case of underperformance.

The research highlights the importance of adopting ROA as a strategic mindset over complex quantifications. Focusing on strategic options enhances decision-making, drives cultural change, and aligns projects with long-term goals. While quantification can provide additional insights, it should complement the strategic approach, not overshadow it. ROA's true value lies in its strategic application, with simplified decision tree analysis offering support when needed. Key areas for ROA application include climate adaptation, long-term planning, adaptive management, and strategic planning. ROA addresses climate-related uncertainties, such as sea-level rise and extreme weather, by enabling incremental and adaptive decision-making. It enhances long-term planning by providing a framework to evaluate scenarios and adjust investments over time. Additionally, ROA supports adaptive management through continuous strategy adjustments based on new data, while in strategic planning, it helps align stakeholder interests and ensures regulatory compliance.

7.2 Answering the Research Question

Why has the Real Options Approach (ROA) not been widely adopted in the Dutch Infrastructure Sector, and how can it be used to enhance investment decision-making under uncertainty?

ROA has not been widely adopted in the Dutch infrastructure sector due to several key factors. Traditional evaluation methods dominate decision-making processes because of their perceived simplicity and familiarity. ROA's complexity, the time required to implement it, and the need for specialized quantitative skills create major barriers. Additionally, political and organizational constraints, such as the pressure for quick results, resistance to change, and segmented decision-making within institutions, limit the exploration and use of ROA. There is also a general aversion to uncertainty among decision-makers, who often prefer linear, predictable approaches, which further hinder the adoption of ROA.

However, ROA could enhance investment decision-making under uncertainty by allowing for more flexible and adaptive strategies. It is especially useful in managing long-term projects with high uncertainty, providing a structured framework to integrate managerial flexibility and optimize decision timing. ROA's strategic mindset promotes better adaptability by framing decisions in terms of evolving conditions, offering a dynamic alternative to static methods like CBA. For wider adoption, simplifying ROA's application, aligning it with existing frameworks, and promoting a shift in organizational culture is essential. Clear communication of its benefits, alongside the integration of phased decision-making, would allow ROA to better support infrastructure projects in navigating uncertainty.

7.3 Recommendations for Future Research

- **Empirical Validation of ROA in Infrastructure Projects**: Conduct more empirical studies to validate the practical benefits of ROA in real-world infrastructure projects, particularly within the Dutch context. This would bridge the gap between theoretical advantages and practical application, providing concrete evidence of ROA's effectiveness.

- **Overcoming Organizational and Institutional Barriers**: Investigate strategies for overcoming the organizational and institutional barriers that hinder the adoption of ROA. Research could focus on developing frameworks for integrating ROA into existing decision-making processes and addressing the resistance to change within bureaucratic environments.

- **Simplification and Standardization of ROA Methodologies**: Explore ways to simplify and standardize ROA methodologies to make them more accessible to practitioners. Future research could focus on developing user-friendly tools and documentation that demystify the approach and facilitate its broader adoption.

- **Longitudinal Studies on ROA's Impact**: Conduct longitudinal studies to assess the long-term impact of ROA on project outcomes. This research could track infrastructure projects over time to evaluate how ROA's flexibility and strategic options influence project success under varying conditions of uncertainty.

- **Sector-Specific Applications of ROA**: Investigate the application of ROA in specific sectors within infrastructure, such as climate adaptation, transportation, and urban development. This would help identify tailored approaches that maximize the benefits of ROA in addressing sector-specific challenges and uncertainties.

7.4 Recommendations for Practice

To bridge the gap between the theoretical advantages of ROA and its practical application within the Dutch infrastructure sector, the following recommendations are proposed:

1. **Develop Comprehensive Training Programs:** Enhance the proficiency of decision-makers and practitioners in applying ROA by implementing specialized training workshops and certification programs. These programs should focus on both the strategic and analytical aspects of ROA methodologies. Collaborate with academic institutions and industry experts to design a curriculum that addresses the specific needs of infrastructure projects.

2. **Simplify and Standardize ROA Methodologies:** Make ROA more accessible and easier to implement across various projects by developing standardized ROA frameworks and guidelines tailored to the Dutch infrastructure context. Additionally, create user-friendly tools and software to streamline the ROA application process, thereby reducing complexity and minimizing the time required for implementation.

3. **Engage Stakeholders Early and Continuously:** Secure stakeholder buy-in and collaboratively identify critical uncertainties by conducting regular consultations and workshops. These engagements will gather valuable insights, prioritize key uncertainties, build consensus, and demonstrate the value of the ROA in addressing diverse stakeholder concerns.
4. **Align ROA with Existing Decision-Making Frameworks:** Seamlessly integrate ROA into current organizational processes by identifying and mapping its components to existing evaluation methods and decision-making frameworks. Ensure that ROA complements established practices, facilitating smoother integration and enhancing overall decision-making effectiveness.

5. **Implement Pilot Projects to Demonstrate ROA Benefits:** Provide tangible evidence of ROA's effectiveness by selecting and executing pilot infrastructure projects that incorporate ROA. Thoroughly document the outcomes and lessons learned from these projects, and utilize these case studies to highlight ROA's practical advantages. This approach will build confidence among potential adopters by showcasing the real-world benefits and successful application of ROA.

6. **Foster an Organizational Culture Embracing Flexibility:** Cultivate a mindset that values adaptability and strategic flexibility by promoting cultural change initiatives within organizations. Encourage openness to new methodologies like ROA through internal communications and leadership endorsement, highlighting the long-term benefits of flexible decision-making.

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Appendix A: Semi-Structured Interview Guide

Interviews questions

1. Can you briefly describe your role and experience

Uncertainty and Current Evaluation Methods (general questions)

No.	Questions
2	In your opinion and based on your experience, what is the role of uncertainties in infrastructure investment decision-making? How important is addressing these uncertainties?
3	What types of uncertainties (e.g., market, technological, regulatory) have you encountered in the Dutch infrastructure sector? Which do you consider most critical to investment decision-making and why?
4	What are the current evaluation methods used in the sector for investment decision-making?
5	How do these methods address the uncertainties you've mentioned? Are there any limitations?
6	To what extent do you consider it important to maintain flexibility in investment decisions, given the potential for changes in conditions within the infrastructure sector? Could you also explain why you feel this way?
7	When making investment decisions, what do you value (prioritize) more: ensuring the decisions are precise and accurate, even if stakeholders don't fully understand how they were made, or making the decision-making process transparent so that everyone involved understands how the decisions are arrived at? In other words (Which is more important to you—the outcome of the decision or the process used to arrive at it?)

ROA Familiarity

No.	Questions
8	How familiar are you with the Real Options Approach (ROA) in the context of infrastructure investment? If the respondents are unfamiliar with the terminology but may have applied the method or its principles unknowingly: The Real Options Approach (ROA) involves evaluating investment opportunities in infrastructure projects as flexible options, rather than fixed commitments. It allows decision-makers to adapt to changes over time, by considering the value of future choices like expanding, delaying, or abandoning projects based on evolving conditions. **If the respondents are familiar, proceed with Table A** **If the respondents are unfamiliar, move to Table B**

Table A for respondents familiar with ROA

9	Have you or your organization ever applied ROA in decision-making processes? If so, could you describe the project and the outcomes?
10	Can you recall any times when current methods didn't handle uncertainties well, showing where Real Options Analysis (ROA) might be useful?
11	If yes, how do you perceive the potential benefits of ROA compared to traditional evaluation methods?
12	Several options could arise for transport infrastructure decisions. Which of the following forms of flexibility, options, have you encountered? • Decision to defer • Decision to expand • Decision to phase (stage) • Decision to switch • Decision to abandon
13	There are generally two ways to use ROA. In which of the two do you see the most potential? • Real option as a way of thinking (insights into flexibility options) • Real option as a quantitative method (calculations of exact accurate figures that express the value of flexibility)
14	In your opinion, what are the barriers or challenges to adopting ROA in the Dutch infrastructure sector (reasons for the limited application of ROA)?
15	Previous studies reveal several barriers to the application of ROA, which of the following barriers do you think is more relevant? • Unfamiliarity • The complexity of ROA methodologies • The extra time and effort needed for ROA execution • The challenges posed by existing standardized decision-making frameworks • The urgency for swift decision-making, along with political pressures and the desire for tangible results (political barriers)
16	Can you suggest any strategies or steps that could facilitate the incorporation of ROA into investment decision-making processes?
17	Do you anticipate a growing need for the Real Options Approach (ROA) as circumstances change?
18	How do you think different stakeholders (e.g., government agencies, contractors, financiers) perceive the application of ROA in the sector?
19	Does your organization have the ability to adopt complex methods like ROA? What changes or improvements would be needed?

Table B for respondents unfamiliar with ROA

9	In your role, how do you approach uncertainty in decision-making in infrastructure projects? What tools or methods do you use to manage these uncertainties?
10	Can you recall any times when current methods didn't handle uncertainties well, showing where a new approach could be useful?
11	How do you currently handle flexibility in investment decisions? Can you give examples of when you had to adapt or change decisions based on new information?
12	Could you recall any decisions or projects where having the flexibility to adapt to changing conditions would have been beneficial?
13	In managing project risks and uncertainties, how valuable would it be to assess options like postponing, adjusting, or redirecting project resources based on emerging information or market changes?
14	Are you aware of any alternative methods to evaluate infrastructure investments that might offer more flexibility compared to traditional methods? What are they?
15	Would you be interested in learning about new methods that could potentially offer better ways to handle uncertainties and make more informed decisions?
16	The Real Options Approach to decision-making views investment opportunities as options, similar to financial options in the stock market. This approach allows businesses to make investment decisions as flexible responses that can adapt based on evolving business environments and changing circumstances, rather than committing to fixed, irreversible courses of action upfront. Given the dynamic nature of markets and technologies, having the ability to alter, defer, or abandon investment decisions can be crucial. **How does this concept sound to you, and do you think it could be useful in your work?** The Real Options Approach treats investment decisions like options in everyday life. It suggests that instead of making a fixed decision from the start, you can adjust your plans as situations change and new information becomes available. This means you have the flexibility to delay, modify, or even drop investment plans based on how things unfold, much like deciding to buy a house or not based on changing personal circumstances or market conditions.
17	Have you or your organization ever applied principles similar to ROA in decision-making processes, perhaps without using the term 'Real Options Approach'?
18	Does your organization have the ability to adopt complex methods like ROA? What changes or improvements would be needed?

Closing Thoughts

19. Is there anything else you would like to say or add?

Appendix B: Validation Interview Guide

1. **Uncertainty in Decision-Making for Dutch Infrastructure Projects**

- How do the identified categories of uncertainties resonate with the challenges you face in Dutch infrastructure projects? Can you think of any additional categories or specific uncertainties that might have been overlooked?
- In what ways do these identified uncertainties reflect the real challenges in infrastructure projects? Are there any specific examples that come to mind?

2. **Evaluation Methods Used in Infrastructure Projects**

- What are your thoughts on the evaluation methods identified (CBA, LCA, MCA, etc.)? Are these the ones most commonly used in your experience, or are there other methods you find more relevant?
- What other evaluation methods do you believe are currently in use in practice?
- How do the limitations of these evaluation methods align with your experience, particularly when it comes to handling uncertainties? Can you share examples of where these methods succeeded or fell short?

3. **ROA's Barriers to Implementation in the Dutch Infra Projects**

- Do the barriers identified reflect your experience, or are there other challenges you find more pressing?
- What other challenges would you encounter when considering or attempting to implement ROA in your organization?

4. **Steps or Strategies to Facilitate ROA Adoption**

- What strategies do you believe would be most effective in facilitating the adoption of ROA in your organization or sector? Do the enablers identified here resonate with your experience, or would you suggest different approaches?

5. **ROA's Recommendations - Application Conditions**

- How appropriate do you find the recommended conditions for applying ROA in practice? Are there any conditions you would add or adjust based on your experience?

6. **ROA's Recommendations - Application Areas & Utilization Approaches**

- To what degree do these utilization approaches and application areas of ROA reflect practical and strategic considerations in infrastructure projects?
- How well do the recommended utilization approaches and application areas of ROA align with the strategic considerations in your infrastructure projects? What practical examples can you share that support or challenge these recommendations?

7. **ROA's Recommendations - Future Infrastructure Project Options**

- In your view, how valuable are the identified options (phase, expand, defer, etc.) for future infrastructure projects? Are there other options you believe should be considered, or do you see any limitations in the ones identified?

Appendix C: Informed Consent Form

Opening Statement (Interview)

You are being invited to participate in a research study titled Real Options Approach for Uncertainty Management in the Decision-Making Process. This study is being done by Ahmed Al Darwish from the TU Delft. The purpose of this research study is to provide an understanding of the application and applicability of the Real Options Approach in the Dutch railway sector, and will take you approximately 45 minutes to complete. The data will be used for the master thesis of Ahmed AL Darwish. We will be asking you to provide information related to your understanding or opinion of the Real Options Approach in the Dutch railway sector, including its benefits and barriers to implementation.

As with any online activity, the risk of a breach is always possible. To the best of our ability, your answers in this study will remain confidential. We will minimize any risks by keeping your answers and personal information strictly confidential. The interview results published in the thesis will be coded and completely anonymous. Personal information, such as name, contact information, and occupation, will only be collected for thesis-related purposes (e.g., informing the study's supervisor). With your permission, the interview will be recorded and if via online meeting, the text will be automatically transcribed using Microsoft Teams. I will manually adjust the automatic transcription to match the original interview. The original transcripts and recordings will only be available to the thesis supervisors, will not be published anywhere, and will be removed approximately two years after the completion of the study, at the latest. Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

Below you can find the informed consent form of the research. Please tick the boxes to indicate your consent. The contact details of the researchers are as follows.

Corresponding Researcher
Ahmed Al Darwish

Responsible Researcher
Martijn Leijten

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information above or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: • The interview will be semi-structured with open-ended questions related to the application of the Real Options Approach in the Dutch railway sector. • A recorded interview will be conducted via Microsoft Teams or Face-to-Face. • If via Microsoft Teams, the recording will be transcribed as a text directly from Microsoft Teams and the researcher will edit the text by listening to the interview recording and adjusting the written transcription to the original spoken text. • The interview recording will be stored on the personal storage of Ahmed Al Drawish on the TU Delft OneDrive and will be destroyed for a maximum of two years after the study has been completed.	☐	☐
4. I understand that I will not be financially compensated for my participation.	☐	☐
5. I understand that the study will end in September 2024		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. I understand that taking part in the study involves the following risks. • The risk of leaked business/organisation strategies. • The risk of leaked information. • The risk of reputation damage from leaked information. I understand that these risks will be mitigated by storing the important data, such as personal information and original interviews securely, will not be made available publicly and only available to the thesis supervisors, and will be removed after the research is finished. The interview results will be published in the thesis only in the form of aggregated data (e.g., coded interviews, codebook, and combination of analysis of all the interviews). Furthermore, I can choose how to respond to each question that may be detrimental to me or my organisation. I may choose not to respond to any of them and I have an option to end the interview at any time.	☐	☐
7. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) (name, occupation, contact information) and associated personally identifiable research data (PIRD), with the potential risk of my identity being revealed, the risk of re-identification and the subsequent risk of affecting my public or professional reputation.	☐	☐
8. I understand that some of this PIRD is considered as sensitive data within GDPR legislation, specifically job positions and political, economic, social, technological, or environmental views.	☐	☐
9. I understand that the following steps will be taken to minimise the threat of a data breach and protect my identity in the event of such a breach. The interview will be conducted anonymously. Personal information of the interviewees will not be published to anyone who is not involved in	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
the research. After the research is completed, the personal data will be deleted.		
10. I understand that personal information collected about me that can identify me, such as my name and contact information, will not be shared beyond the study team.	☐	☐
11. I understand that the (identifiable) personal data I provide will be destroyed after the research has ended, which will be conducted a maximum of two years after the graduation of the researcher.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. I understand that after the research study, the de-identified information I provide will be used for the following purposes. The anonymised interview results will be published along with the master thesis on the TU Delft Repository, including the anonymised coding of the interviews.	☐	☐
13. I agree that my responses, views or other input can be quoted anonymously in research outputs.	☐	☐
D: (LONG-TERM) DATA STORAGE, ACCESS AND REUSE		
14. I give permission for the de-identified interview results that I provide to be archived in the TU Delft repository (https://repository.tudelft.nl/) in the form of anonymous coded interviews so it can be used for future research and learning. The original transcribed interviews will not be made available to the public or stored on the TU Delft repository.	☐	☐
15. I understand that access to the repository where the master thesis is stored is openly available on the internet.	☐	☐
16. I understand that the collected data may be reused for future scientific publications and educational activities on the topic of the Real Options Approach in the decision-making process.	☐	☐

Signatures

__________________________ __________________________ ________

Name of participant [printed] Signature Date

I, as a researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands what they are freely consenting.

________________________ __________________ ________

Researcher name [printed] Signature Date

Study contact details for further information:

Ahmed AL Darwish

+31634562100

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Appendix D: Additional Barriers to ROA Implementation

Other Barriers Noted by the Participants (each mentioned by one interviewee):

Lack of Policy Prescription: The absence of policy prescriptions means there is no formal requirement to develop the expertise or infrastructure necessary to support ROA. This leads to a skills gap, with organizations lacking trained personnel to implement ROA effectively. Without policy mandates, there is little incentive for organizations to invest in the tools and resources needed for ROA. Traditional methods like CBA are well-understood, have clear guidelines, and enjoy regulatory support. In contrast, ROA lacks this structured backing, making it less attractive to decision-makers who prioritize compliance and risk mitigation. This highlights organizational inertia in adopting new methodologies without clear policy directives. The reluctance to move beyond established practices stems from the additional effort and perceived risks associated with implementing complex methods like ROA. Therefore, to facilitate the broader adoption of ROA, it is crucial to develop and prescribe clear policies that integrate it into standard decision-making processes, ensuring it becomes a recognized and required practice.

"Real Options is not prescribed. So nobody is going to do more than he has, or she has to do or is getting paid for"

Bureaucratic Obstacles: Implementing ROA in large infrastructure projects faces bureaucratic challenges that impede its smooth application. The necessity to restart administrative procedures at each project stage adds complexity and discourages the use of ROA. These administrative barriers lead to delays and increased project costs due to the extensive documentation, approvals, and compliance checks required at each phase. The lack of streamlined processes forces project teams to navigate various bureaucratic hurdles, including regulatory approvals and inter-departmental coordination. This complexity often makes stakeholders prefer traditional methods that are more familiar and perceived as less administratively burdensome. For example, the Maaslandkering project in Rotterdam, a major investment of nearly €1 billion, illustrates the lengthy administrative processes involved. The timeline from initial decision to completion can span 15 to 20 years, with numerous bureaucratic barriers potentially causing delays or necessitating project restarts.

Overcomplexity in Implementation: Another barrier to ROA adoption is the tendency to make the methodology overly complex by attempting to cover all possible scenarios and variables. This overcomplication overwhelms practitioners, deterring them from using ROA due to its perceived difficulty. Although the basic principles of ROA are straightforward, unnecessary layers of detail hinder its practical application and accessibility. Interviewees recommended simplifying ROA by focusing on its most relevant aspects and avoiding excessive details. Providing practical training and clear guidelines can help practitioners apply ROA more effectively. By streamlining the methodology and emphasizing core principles, organizations can make ROA more user-friendly, overcoming the barrier of overcomplexity and facilitating broader adoption.

Challenges in Coordination and Alignment: Interviewees identified the difficulty of aligning and coordinating various experts and stakeholders as a barrier to implementing ROA. This challenge is primarily organizational rather than technical, involving the unification of diverse individuals and teams. Integrating varied skill sets and perspectives can be daunting, especially in large organizations where departments may have conflicting priorities or work styles. One interviewee emphasized that while technical expertise is available, effectively organizing and managing these resources is the real challenge. Difficulties in coordination and alignment can lead to delays and inefficiencies, as synchronizing different teams often requires substantial time and effort.

Focus on People Management Over Performance Metrics: Interviewees noted that the organization's focus on people management rather than performance metrics hinders the implementation of ROA. This governance approach limits the development of professional project management practices by emphasizing employee satisfaction and capacity management over evaluating project performance through key performance indicators (KPIs). The lack of systematic performance measurement leads to insufficient accountability and overlooks areas for improvement in project management. This people-centric model often prioritizes immediate personnel concerns over long-term project outcomes, making it difficult to adopt advanced methodologies like ROA that require structured data analysis and decision-making. To overcome this barrier, organizations need to integrate performance metrics into their governance framework, balancing people management with systematic evaluation of project outcomes. This shift would enhance professional project management practices and support the effective implementation of ROA.

"Our managers are people managers. They're not into KPIs or anything like that. They're not measuring how well we're performing projects. They're putting people on projects, managing the capacity, and trying to keep people happy. But it's not about setting the bar at this level, growing towards the next level, and evaluating performance. They're not doing that"

High Data and Modelling Requirements: Another barrier to the effective implementation of ROA, as noted by interviewees, is its high data and modelling requirements. The methodology demands extensive, precise data, such as volatility information, which can be difficult to obtain. Without reliable data, ROA outputs risk being misleading, undermining their credibility in decision-making. Additionally, building models that accurately reflect the complexities of real-world projects, with multiple variables, is challenging and often overwhelming. These factors deter practitioners from adopting ROA due to the complexity and high resource demands involved.

"also a good model to model the problem is very difficult. Only simple problems can be well-modelled. And I mean, simply, that there are a limited number of alternatives and hopefully one main variable and a certain variable. Okay. If there are too many variables, then well, the programmer gets lost"

Satisfaction with Existing Methods: There is a belief among some interviewees that current evaluation methods, such as CBA, are sufficient, which makes the adoption of ROA seem unnecessary. This perception is rooted in the familiarity and established reliability of traditional methods, which stakeholders often find adequate for decision-making processes.

Divergent Preferences in Decision-Making Approaches: Conflicting decision-making approaches within organizations pose challenges to the implementation of ROA. While some practitioners prefer data-driven methods like ROA, others rely on personal judgment and intuition, creating friction and slowing its adoption. This divide reflects a broader challenge where some favour analytical rigor, while others prefer experiential approaches. The presence of diverse opinions within organizations means ROA may be applied selectively, and its broader adoption remains uncertain. This issue is especially pronounced in large organizations with departments that vary in comfort and experience with advanced analytical tools.

"Within our organization, you have a lot of people who want to calculate everything, but there are also people who want to decide by their own judgment"

Dependence on Client Tools and Limited Policy Influence: Private consultancy firms face challenges in adopting ROA due to their dependence on client-preferred tools and limited influence on policy. Clients, particularly in the public sector, often prefer traditional methods like CBA, restricting firms' flexibility to implement ROA despite recognizing its benefits. The urgency of public sector investments further limits opportunities for methodological experimentation. To overcome this, consultancy firms must build strong cases for ROA, provide empirical evidence of its advantages, and foster open communication to shift client preferences towards more adaptive decision-making tools.

"Well, as a consultancy firm, we are strongly dependent on the tools our clients use, that's one part. Also, we don't make policy, we're not policymakers, so we cannot influence policy in that way"

Lack of Vision & mission: A lack of coherent vision and mission within organizations and the broader ministry was identified as a barrier to ROA implementation. Without clear long-term goals and strategic direction, it becomes difficult to apply ROA, which depends on contextualizing decisions within a broader framework. The responsibility for establishing this vision lies with the ministry, not individual companies, leading to fragmented project execution. For ROA to be effective, it must be integrated into the policy-making process at the ministry level, ensuring that long-term objectives guide decision-making.

"And I think that we're lacking the bigger picture. So if you talk about roadblocks, this is kind of it. If you don't have a vision, then it's really hard to do the real option kind of thing. Because you need like the goals above the mission kind of statements where you say, okay, so the different ways to do this, and then the real option part comes in and you make like a sensible decision there."

Lack of Urgency: The absence of a sense of urgency hinders the willingness to adopt new methodologies like ROA, which are perceived as non-essential or secondary to immediate operational concerns. This is particularly problematic in organizations where the focus is predominantly on short-term goals and maintaining the status quo.

Slow Organizational Maturity: One participant identified "Slow Organizational Maturity" as an impediment to implementing ROA, stating that the gradual pace at which organizations develop and evolve hinders the adoption of new methodologies. This slow maturation creates a structural barrier, as organizations often lack the agility and readiness to incorporate innovative approaches like ROA into their existing frameworks.

"But on the other end, it's also about organizational growth. It's about maturity. And sometimes I think that we have a slow maturation. It's done like that. We don't mature so very quickly, in a sense. And so there's always like a ceiling"

Misaligned Focus In Decision-Making Stages: Another barrier to ROA adoption is the misalignment of focus during decision-making stages, where decision-makers prioritize the wrong issues at critical junctures. This reactive approach neglects the early and integrated application of ROA, diminishing its effectiveness. Decision-makers often focus on short-term concerns, missing the long-term benefits of ROA's flexible, proactive planning. Addressing the right issues at the right time is essential for successful ROA implementation.

Appendix E: ROA Mindset vs. Quantitative Method (The Challenge)

As previously discussed throughout the study, the Real Options Approach (ROA) can be applied to infrastructure projects in two distinct ways: as a mindset (also referred to as ROA reasoning or a qualitative approach) and as a quantitative method. The choice between applying ROA as a mindset or as a quantitative method is largely influenced by the availability of data, the nature of the uncertainties involved, and the project's stage of development. Decision-makers may prefer one approach over the other based on these factors, leading to different outcomes. The following sections will outline the specific circumstances under which each ROA approach is best applied.

1. Circumstances for Applying ROA as a Mindset

ROA as a mindset emphasizes strategic thinking and flexibility without relying on detailed financial calculations (Trigeorgis & Reuer, 2016). It is about embedding flexibility in decision-making processes and project designs early on. Its power lies in recognising that projects are processes that take place over time and that can be subdivided into smaller components (Herder et al., 2011).

❖ **Applications scenarios:**

- **Focus on Flexibility & Strategic Adaptability:** When project flexibility & long-term strategic adaptability are more important than precise calculations and the focus is more on keeping options open for as long as possible to adapt to future uncertainties (or exploiting Opportunities) as they arise rather than committing to detailed investments (Trigeorgis & Reuer, 2016).

- **Unquantifiable or Complex Uncertainties:** This applies when uncertainties are high but cannot be easily quantified, or when there are too many variables to create precise financial models. This is often the case with political, regulatory, or environmental uncertainties (Herder et al., 2011).

- **Lack of Complete or Reliable Data:** In projects where the distribution and dispersion of key variables are unknown or unreliable, decision-makers have embraced real option reasoning to define the options attributable to the initial investment following an informal and heuristic process that can lead to future-proof outcomes (Di Maddaloni et al., 2024). In this case, precise valuation of options is not feasible and the mindset approach becomes more useful (Trigeorgis & Reuer, 2016).

❖ **Expected Outcomes:**

- **Enhanced Project Flexibility & Adaptability:** ROA mindset ensures ongoing flexibility and adaptability in decision-making throughout the project lifecycle, allowing adjustments as uncertainties evolve. It makes decision-makers think more about downstream decisions, about breaking down and measuring uncertainty, and about splitting up decisions into several stages (Herder et al., 2011).

- **Agility in Decision-Making:** Decision-makers can stay agile and responsive to changing project demands, ensuring timely adjustments to scope, timing, and implementation.
- **Embedded Flexibility from the Start:** ROA embeds flexibility early in project planning and design, ensuring strategic options are defined and key drivers of option value are identified conceptually (Di Maddaloni et al., 2024; Trigeorgis & Reuer, 2016).

- **Improved Strategic Resilience**: By fostering a more adaptable project structure, ROA leads to increased resilience in navigating uncertainties and enhances the overall understanding and communication of flexibility (Herder et al., 2011).

Key points (Trigeorgis & Reuer, 2016):

- Encourages taking on uncertain projects: Since the value of an option increases with uncertainty, ROR helps overcome biases against investing in uncertain environments, where traditional methods like NPV may undervalue initiatives.
- Staged investments: ROR promotes breaking investments into stages, allowing firms to capitalize on upside potential while limiting losses if conditions change.
- Proactive management: It supports making flexible decisions that can be adjusted in the future as contingent circumstances evolve.
- Portfolio approach: ROR advocates for spreading investments across multiple low-cost, staged projects, which diversifies risk and enhances potential returns.

2. Circumstances for Applying ROA as a Quantitative Method

ROA as a quantitative method involves using formal mathematical models or simulations to value real options and to calculate the value of flexibility and uncertainties, which is more common in economics and finance literature (Trigeorgis & Reuer, 2016). It is typically applied in later project stages when sufficient data becomes available, and financial calculations are feasible to determine the value of real options.

❖ **Applications scenarios:**

- **Quantifiable Uncertainties:** When uncertainties can be quantified, such as fluctuating market prices, demand forecasts, or investment costs e.g., evaluating whether to expand, defer, or abandon an infrastructure project (Dixit & Pindyck, 1994).

- **Projects with High Costs or High Stakes, Where Financial Metrics Are Critical:** When there are high costs or high stakes, such as significant financial investments where managers need precise data to make informed decisions and when managerial flexibility (to defer, expand, or abandon) needs to be analysed and quantified (Trigeorgis, 1996)

- **Suitable for Market-Like Conditions:** ROA was derived from financial options valuation. It therefore works best under conditions that resemble (perfect) financial markets: perfect information, perfect competition (no arbitrage), and liquid assets (Herder et al., 2011). Additionally, it is mostly applicable to market-price-related uncertainty (van Den Boomen et al., 2018). As a result, although the real options technique has been increasingly used in valuing infrastructure investments, most of the published cases focus on projects where the volatility of output prices and cost inputs can be determined or derived with the use of advanced statistical methods, such as Monte Carlo simulations. (Di Maddaloni et al., 2024).

- **Availability of Sensible Data:** When detailed, reliable data (on costs, revenues, and risks) is available, where the volatility of key parameters is unknown (Di Maddaloni et al., 2024), the quantitative approach can be fully leveraged to quantify real options effectively. Valuation can work on real assets provided that there is some sensible information about expectations and uncertainty. The hard part of valuation in the real world is that there often is very limited information on long-term uncertainty. (Herder et al., 2011).

❖ **Expected Outcomes**:

- **Quantifies the Value of Flexibility:** Wang and de Neufville (2005) emphasize that ROA transcends traditional analysis by offering a structured way to understand, organize, and quantify flexibility, making it an indispensable asset in decision-making processes.

- **Optimizes Project Outcomes** (Bos & Zwaneveld, 2014).

- **Supports Data-Driven Decision-Making** (financial Justification): Provides clear financial justification for strategic decisions, optimizing project outcomes by calculating the monetary value of keeping options open, and giving decision-makers concrete numbers to inform their decisions (Trigeorgis & Reuer, 2016).

- **Provide detailed financial analysis** (Trigeorgis & Reuer, 2016).

- **Superior Market Valuation**: it has been shown to outperform traditional Discounted Cash Flow (DCF) models in explaining market valuations and investment decisions in various industries. (Trigeorgis & Reuer, 2016).

- **Explicit Assumptions & Critical Insights**: It makes assumptions explicit, helps identify critical boundary conditions, and allows for the simulation of complex relationships, offering precise, data-driven insights (Trigeorgis & Reuer, 2016).

- **Comparative Statics & Simulations**: its models are useful for developing propositions and conducting numerical analysis to better understand the dynamics of investment decisions (Trigeorgis & Reuer, 2016).

However, ROA is a quantitative method that also has drawbacks (Trigeorgis & Reuer, 2016):

- Restrictive assumptions: To maintain mathematical tractability, models often rely on unrealistic assumptions that may not be practical in real-world settings.
- Disconnect from organizational realities: While rigorous, ROV models can sometimes become too theoretical and may not align with the practical needs and realities faced by managers in strategic decision-making.

In summary, ROA is a quantitative method is valuable for precise, analytical insights but may lack flexibility and practical applicability in complex, real-world situations (Trigeorgis & Reuer, 2016).