Processing complexities in conjunction with risks to support the project risk management

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DREES & SOMMER

TU Delft

Investigation of relationships between complexities and risks in complex construction projects for usage during the project risk management process

by

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Preface

Before you lies the report *"Processing complexities in conjunction with risks to support the project risk management"*, which is the result of my 8-month lasting graduation. It has been written to fulfill the requirements of a Master of Science in Construction Management and Engineering (CME) at the Delft University of Technology. I was engaged in researching and writing this report from June 2020 - January 2021. The research has been executed in collaboration with Drees & Sommer. The graduation journey was an unique opportunity to keep learning and exploring my ambitions while gaining scientific insights and knowledge into how theories are transferred into practice.

As a child I always worked on solving puzzles. In doing so, I learned that solving a problem is not only about finding the right answer, but also about the way to approach this problem. I continued to pursue my interest in solving problems even further while studying the BSc Civil Engineering, where I fell in love with solving major challenges the world is facing. However, besides the infrastructure, I also became interested in the organizational, logistictical and external complexity of projects. So that is why I decided to continue my track with the MSc CME. Additionally, the topic of my graduation research is in close relation to my fields of interest as it combines the worlds of civil engineering and the tactical and strategical decision-making that comes along with risk management.

I would like to thank my graduation committee from the Delft University of Technology. Without their guidance and support, I would not have delivered the report as it lies in front of you. Especially, since they helped me to complete my research with all the ambitious plans that I had imposed on myself. A special thanks goes out to Önder who was daily available and willing to answer all my queries while supporting me in my decision-making throughout the process. He really showed me that hard work pays off. Furthermore, I would like to thank my supervisors Martijn and Hans for always being critical and challenging me. They helped me to enhance the academic quality and clarity of my report, which helped me to understand my research even better.

Second, I would like to thank Drees & Sommer for the opportunity to apply my knowledge and gain more insights in my fields of interest and have the possibility to experience this in a working environment. By talking with current Drees & Sommer employees, I learned about the open, ambitious and dedicated culture at Drees & Sommer. This is an environment in which I would thrive. A special thanks goes out to Nick for the constructive and clear feedback during every meeting and for providing directions. Thanks to him I had the opportunity to present and discuss my research topic to the Risk Management Competency Group of Drees & Sommer, with nationalities varying from German, English, Norwegian, Swedish and Danish. The Risk Management Competency Group covers the setting up of appropriate structures within the project, and the application and further development of appropriate (IT based) tools. This was also one of the most educational and interesting parts of the study. I also wish to thank all of the respondents from Drees & Sommer, without their cooperation I would not have been able to conduct this assessment and gain knowledge into the practice. Overall, graduating as a student at Drees & Sommer has taught me to value open-minded thinking and has shaped my analytical mindset and I consider all the lessons learned as very useful knowledge in my future career.

To finalise, I would like to thank my roommates, family, friends and fellow CME students for supporting me throughout this process, without which I would not have been able to conduct this study. I hope you enjoy reading this report.

L. Andringa
Delft, January 2021

Executive summary

Currently, there are many examples of failures as a result of the growing size and complexity of construction projects. The complexity of projects is related to the increasing number of interfaces and dynamic character over time. The causes are the uncertainties and unpredictabilities that play a role and evolve in projects. Grey (2014) states the rise of complex projects represents an opportunity as well as a need for fresh thinking within risk management. Although there were many benefits to the use of the traditional risk management procedure, it appeared to be based on the impractical assumption of complexities being independent from risks. As a result, managers are unable to accumulate the knowledge necessary for understanding of the probability and impact of the risk-factors and their sources. However, this is inadequate for complex construction projects, since in order to investigate the total effect of uncertainty, the perceived complexity need to be assessed. Therefore, the research question of this study is as follows:

In what way can practitioners process the complexities in construction projects more consistently during the implementation of risk management?

The goal of this research is to provide insights into the different types of relationships between complexity elements and risk-factors to be used in risk analysis and management of complex construction projects. On the basis of the reviewed literature, two essential insights into the interdependency between complexity elements and risk-factors were observed. Firstly, complexity elements are considered to create an unexpected event or risk-factor (direct inducement of risk-factors from complexity elements). Secondly, unexpected events are believed to influence the project objectives (indirect inducement of risk-factors from complexity elements). Based on this, it is concluded that complexities may trigger a causal effect for risks, while the risks affect the project objectives. Overall, the interdependency between project complexity and risks is observed as: *Complexity-induced events seem to be a major source of risks whose effect for the project are uncertain.* However, it is noticed that only establishing the relationship between complexities and risks is not enough to guarantee a successful project. The traditional risk management process need to succeed a complexity assessment process in case of a complex construction project, differently from ordinary projects.

In this research, a theoretical framework and empirical research are conducted to answer the research question. In preparation of the exploratory survey, a literature study is performed to review the available knowledge on project complexity, the influence of project complexity on project risk management and the interdependency between project complexity and risks. Subsequently, an exploratory survey is organised with twenty project managers and twenty risk managers from the company Drees & Sommer. The survey aims to investigate how the causal relationship between complexity elements and risk-factors is perceived and managed in complex construction projects. The survey consists of two parts, both focusing on whether the different viewpoints and attitudes of the experts have overlap with the theoretical findings. First, the previously developed Technical-Organisational-External (TOE) framework by Bosch-Rekveldt et al. (2011) is used to explore the causal effect between complexity elements and risk-factors. In doing so, the participants are asked to score the complexity elements that caused or contributed to additional risks based on their last completed complex project. After that, a questionnaire is used to evaluate the limitations of the current risk management process of Drees & Sommer.

Despite the divergences in literature, most practitioners see the causal relationship between complexity elements and risk-factors as an important contribution to the risk management process. However, they also recognize challenges such that practitioners prefer to manage risks in a rather personalised and inefficient way. Therefore, the risk management procedure is to be improved by an increased orientation towards the results, by requiring less time, better alignment and encouragement of original thinking and interactions within the team. Besides this, other practitioners link the expansion of the risk management process to including logical steps, suppress unnecessary details and to pay more attention to the elements that contribute to the complexity of a specific project and the integration of experiences from previous projects.

On the basis of the literature study and exploratory survey, it can be concluded that there is need for a better understanding of the causal relationship between complexity elements and risks. Project managers need to accept the complexities of a project and try to appreciate the dynamic behaviour, rather then reducing the complexities and

risks. As a consequence, the idea of processing complexity more consistently during the implementation of project risk management is conceived. In addition, the *Complexity Based Risk Assessment Technique (CBRAT)* is designed to provide the first steps in capturing the cause-effect mechanisms between complexity elements and risk-factors.

The CBRAT strengthens the risk assessment capability by introducing the following three tools; the *TOE framework*, the *Risk Breakdown Structure (RBS)* and the *risk-influence diagram*. As described in the practical implications of the CBRAT in Figure 1, the TOE framework provides an extensive list of categories where complexities could be expected to arise. The aim is to enable scaling and putting more or less emphasis on certain complexity elements. In doing so, a project managers is able to come up with a risk management approach that is the most suitable for a project, given the unique circumstances of that project (incl. the industry requirements). After the complexity assessment, the traditional risk register is combined with a RBS. This enables to structure and decompose the risk-factors into sub-categories. Besides this, the RBS aims to record generic risk-factors which occur frequently as lessons learned for future reference. Finally, the CBRAT prefers to benefit from the risk-influence diagram in order to trace the direct and indirect inducement of risk-factors from complexity elements. The visualisation of the causal effect enables to understand how the causalities are likely to interact and their consequences on the project objectives.

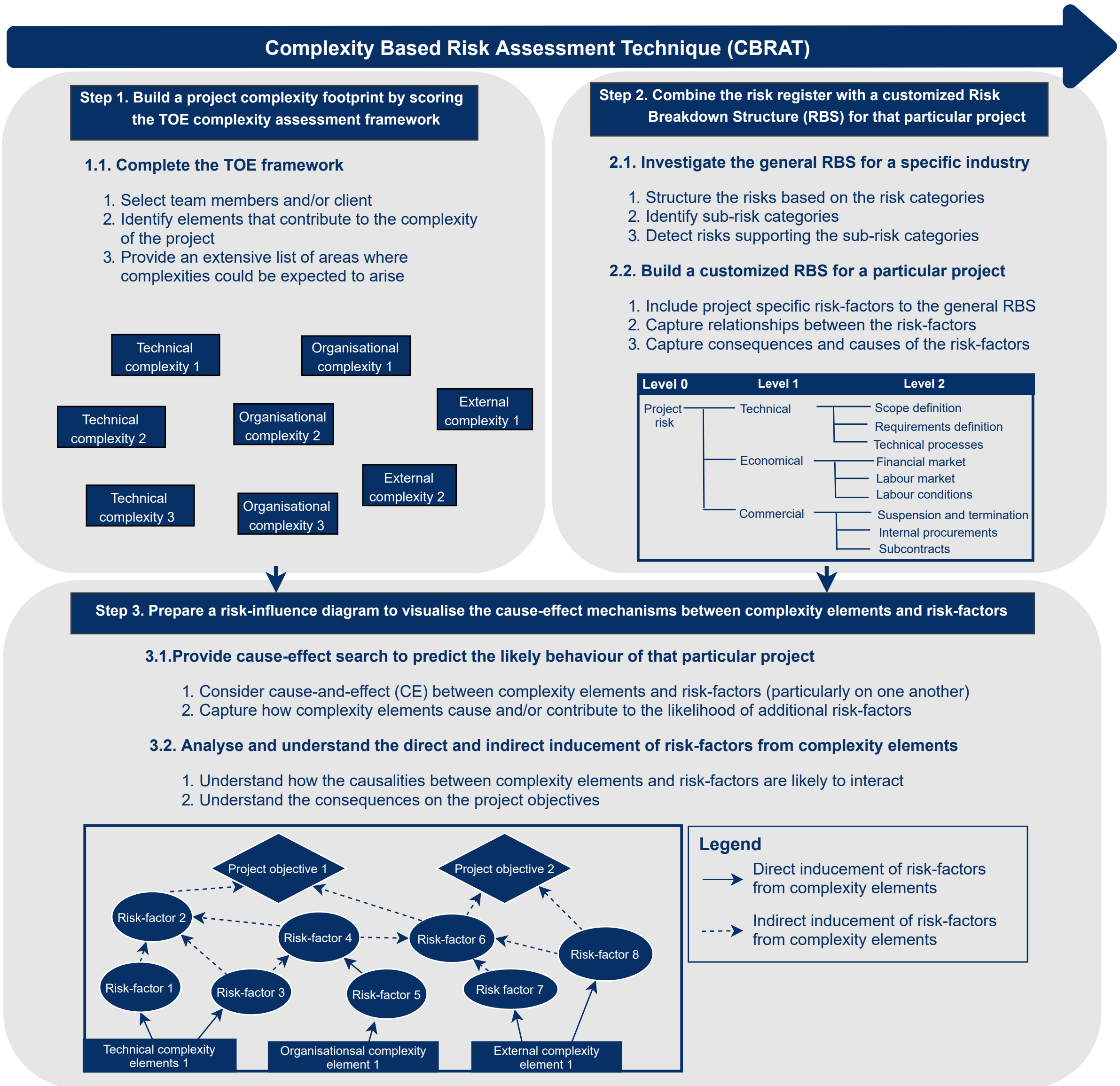

Figure 1: Practical implications of the Complexity Based Risk Assessment Technique (CBRAT) in the risk management process

Next, the applicability of the CBRAT was tested on the FA Terminal 3 project. Based on the results of the pilot study, the conclusion is drawn that the CBRAT would have supported the risk management procedure of Drees & Sommer. The reason for this is that the risk-factors, could have been linked to the complexity elements that are known at the early phase of the project. Based on this, there seem to be a cause-effect mechanisms between complexities and risk-factors in complex construction projects so during risk management these two concepts should be handled together. As a consequence, the CBRAT strengthens the risk assessment capability by identiying the causal relationships between complexities and risks. It is expected that once the causal relationship is understood, the impact and probability of the risks can be better analysed. Therefore, the CBRAT can be called a risk assessment technique.

In general, it can be concluded that it is of importance to define the complexity of a project early and clearly for successful risk management. The aim is to enable scaling and putting more or less emphasis on certain complexity elements. In doing so, a project manager is able to come up with a risk management approach that is the most suitable for a project, given the specific and unique circumstances of that project. Otherwise, risk analysis and management would not include especially complexity-induced risks, which in turn lead us to incomplete and misleading conclusions regarding the risk mitigation actions. Additionally, it is expected that once the relationships between complexities and risks are better understood, the impact and probability of the risk-factors and their sources can be better analysed.

With those insights, the practitioners can develop a strategy to process the complexities in construction projects more consistently during the implementation of risk management. For this, the CBRAT can be used as a tool within the traditional risk management process, as shown in Figure 2. Depending on the characteristics unique to a particular project, the project manager can come up with a risk management approach by focusing attention on those risk-factors and causalities that have the highest potential to create negative consequences on the project objectives. Nonetheless, in the end, being aware of the relationships between complexities and risks in a particular project would be one of the most important success factors of managing risks.

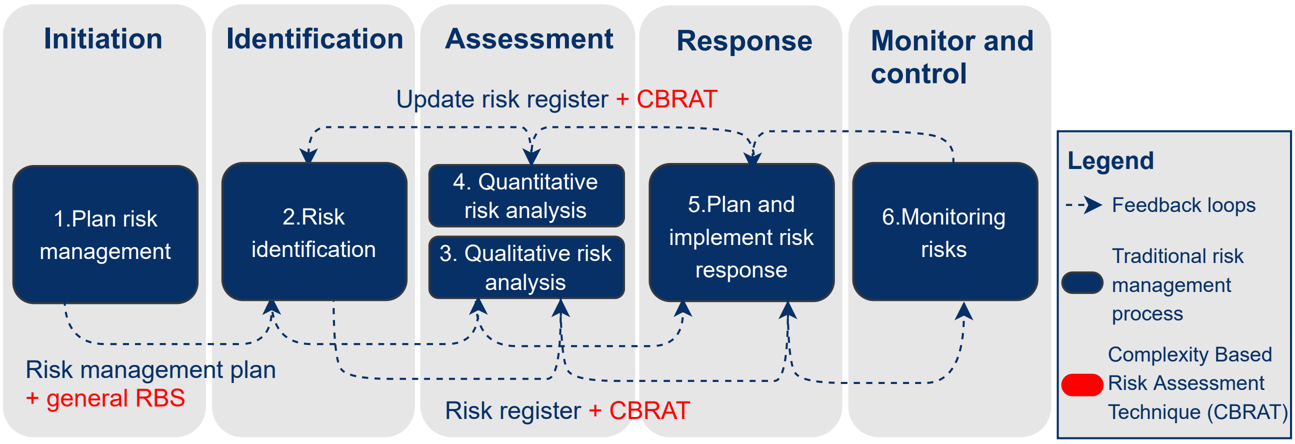

Figure 2: The CBRAT (visualised in red) is positioned within the traditional risk management process (visualised in blue) and the dashed lines indicate the feedback loops.

However, one has to question whether it is realistic that practitioners are willing to change their risk management approach, since it is already difficult enough. Because of this, the CBRAT is designed in such a way that it does not provide time-consuming input information or unnecessary details. Therefore, the CBRAT is easily to incorporate during the implementations of risk management and fits well in the busy work schedules of average users of the concept.

Altogether, the contribution of this study consists of four main parts: it explored an important research theme that has potential to support the implementation of risk management, it conduced an empirical study to provide insight on how the causal relationship between complexity elements and risk-factors is perceived and managed within the construction industry; it proposed the CBRAT to capture the cause-effect mechanisms between complexity elements and risk-factors and finally, through a pilot study the CBRAT is shown to work well on a real life construction project.

Keywords: Project complexity, project risk management, complexity-induced risks, causal relationship, cause-effect mechanisms, Complexity Based Risk Assessment Technique (CBRAT), Technical-Organisational-External (TOE) framework, Risk Breakdown Structure (RBS), risk-influence diagram

Samenvatting

Op dit moment zijn er veel voorbeelden van problemen als gevolg van de toenemende omvang en complexiteit van bouwprojecten. Onder de complexiteit van bouwprojecten wordt het toenemende aantal interfaces en dynamische karakter over tijd verstaan. De oorzaak hiervan blijken de onzekerheden en onvoorspelbaarheden die een evoluerende rol spelen in projecten. Grey (2014) constateert dat de opkomst van complexere bouwprojecten zowel een kans biedt als een behoefte aan nieuwe ideeën voor het managen van risico's. Hoewel de traditionele risico management procedure veel voordelen met zich meebracht, bleek deze gebaseerd te zijn op de onpraktische aanname dat complexiteiten onafhankelijk zijn van risico's. Dit is echter onvoldoende om de oorsprong en het totale effect van de risico factoren in complexe bouwprojecten volledig te begrijpen. Daarom is de onderzoeksvraag van dit onderzoek als volgt:

Op welke manier kunnen professionals de complexiteitskenmerken van bouwprojecten consequenter verwerken tijdens de implementatie van risicomanagement?

Het doel van het onderzoek is om inzicht te geven in de verschillende soorten relaties tussen complexiteitskenmerken en risico factoren die gebruikt kunnen worden bij risico analyse en beheer van complexe bouwprojecten. Door middel van de gereviewde literatuur worden twee essentiële inzichten in de onderlinge afhankelijkheid tussen complexiteitselementen en risico factoren waargenomen. Ten eerste worden complexiteitskenmerken verwacht om een onverwachte gebeurtenis of risico factor te creëren (complexiteitsopwekkende activiteiten). Ten tweede wordt aangenomen dat onverwachte gebeurtenissen de projectdoelstellingen beïnvloeden (indirect geïnduceerde risico's door complexiteit). Hierop wordt geconcludeerd dat complexiteitskenmerken een causaal effect kunnen hebben op risico factoren, terwijl de risico factoren de projectdoelstellingen beïnvloeden. Om explicieter te maken; *Complexiteitsopwekkende activiteiten lijken een belangrijke bron van risico's te zijn waarvan het effect voor het project onzeker is.* Het is echter opgemerkt dat alleen het opbouwen van de relaties niet voldoende is om een succesvol project te garanderen. Het traditionele risicobeheerproces moet ook een complexiteitsbeoordelingsproces uitvoeren in het geval van een complex bouwproject, anders dan bij gewone projecten.

In dit onderzoek wordt een theoretisch kader en een empirische studie uitgevoerd om de onderzoeksvraag te beantwoorden. Ter voorbereiding van de informatieve enquête wordt een literatuurstudie uitgevoerd naar de beschikbare kennis over de invloed van project complexiteit op projectrisicomanagement en de onderlinge afhankelijkheid tussen project complexiteit en risico's. Vervolgens wordt een informatieve enquête georganiseerd onder twintig projectmanagers en twintig risicomanagers van het bedrijf Drees & Sommer. Het doel van het enquête is om te onderzoeken hoe de onderlinge afhankelijkheid tussen de beoordeling van complexiteit en management van risico's wordt waargenomen en beheerd in complexe bouwprojecten. De enquête bestaat uit twee delen, beide gericht op de vraag of de verschillende standpunten en attitudes van de experts overlappen met de theoretische bevindingen. Ten eerste is het eerder ontwikkelde Technical-Organisational-External (TOE) framework van Bosch-Rekveldt et al. (2011) gebruikt om het causale effect tussen complexiteitskenmerken en risico factoren te onderzoeken. Daarbij worden de deelnemers gevraagd om de complexiteitskenmerken te scoren die extra risico's veroorzaakten of daaraan hebben bijgedragen op basis van hun laatst voltooide complexe bouwproject. Daarna wordt een vragenlijst gebruikt om de beperkingen van het huidige risicomanagement proces te evalueren.

Ondanks de verschillen in de literatuur zien de meeste specialisten de causale relatie tussen complexiteit kenmerken en risicofactoren als een belangrijke toevoeging aan het risicomanagement proces. Ze herkennen echter ook uitdagingen, zoals dat specialisten de risico's liever op een tamelijk persoonlijke en efficiënte manier identificeren. Daarom werd de verbetering van het risicomanagement proces gekoppeld aan een grotere oriëntatie op de resultaten, minder tijdrovend, betere afstemming en aanmoediging van origineel denken en interacties binnen het team. Daarnaast koppelden andere specialisten de uitbreiding van het risicomanagement proces aan het opnemen van logische stappen, weglaten van onnodige details en meer aandacht voor de complexiteitskenmerken van een specifiek project en het opnemen van ervaringen.

Op basis van de literatuurstudie en de enquête kan worden geconcludeerd dat er behoefte is aan een beter begrip van de causale relatie tussen complexiteitselementen en risico's. Projectmanagers moeten de complexiteit van een

project accepteren en proberen het dynamische gedrag better te begrijpen in plaats van te complexiteiten en risico's te verminderen. Op basis hiervan ontstond het idee om complexiteit consistenter te verwerken tijdens de implementatie van projectrisicomanagement. Bovendien is de *Complexity Based Risk Assessment Technique (CBRAT)* ontworpen om de eerste stappen te bieden bij het bepalen van de oorzaak-gevolg mechanismen tussen complexiteitskenmerken en risico factoren.

De CBRAT ondersteunt het managen van risico's door de volgende drie technieken te introduceren; het *TOE framework*, het *Risk Breakdown Structure (RBS)* en het *risico-beïnvloedingsdiagram*. Zoals beschreven in de praktische implicaties van de CBRAT in Figuur 3, biedt het TOE framework een uitgebreide lijst met categorieën waarin complexiteit kan worden verwacht. Het doel is om schaalvergroting mogelijk te maken en meer of minder nadruk te leggen op bepaalde complexiteitselementen om zo tot een risicomanagementaanpak te komen die het meest geschikt is voor een project, gegeven de unieke omstandigheden van dat project (incl. De branche-eisen). Na de complexiteitsbeoordeling wordt het traditionele risicoregister uitgebreid door het te combineren met een RBS. De combinatie van deze tools heeft tot doel de risico factoren op te splitsen en te structureren in subcategorieën. Daarnaast heeft de RBS tot doel algemene risico factoren vast te leggen die vaak voorkomen als lessen die zijn geleerd voor toekomstig gebruik. Ten slotte profiteert de CBRAT van de risico-beïnvloedingsdiagram om de directe en indirecte aanleiding van risico factoren uit complexiteit kenmerken op te sporen. De visualisatie van het causale effect maakt het mogelijk om te begrijpen hoe de causaliteiten hoogst waarschijnlijk op elkaar inwerken en wat hun gevolgen zijn voor de projectdoelstellingen.

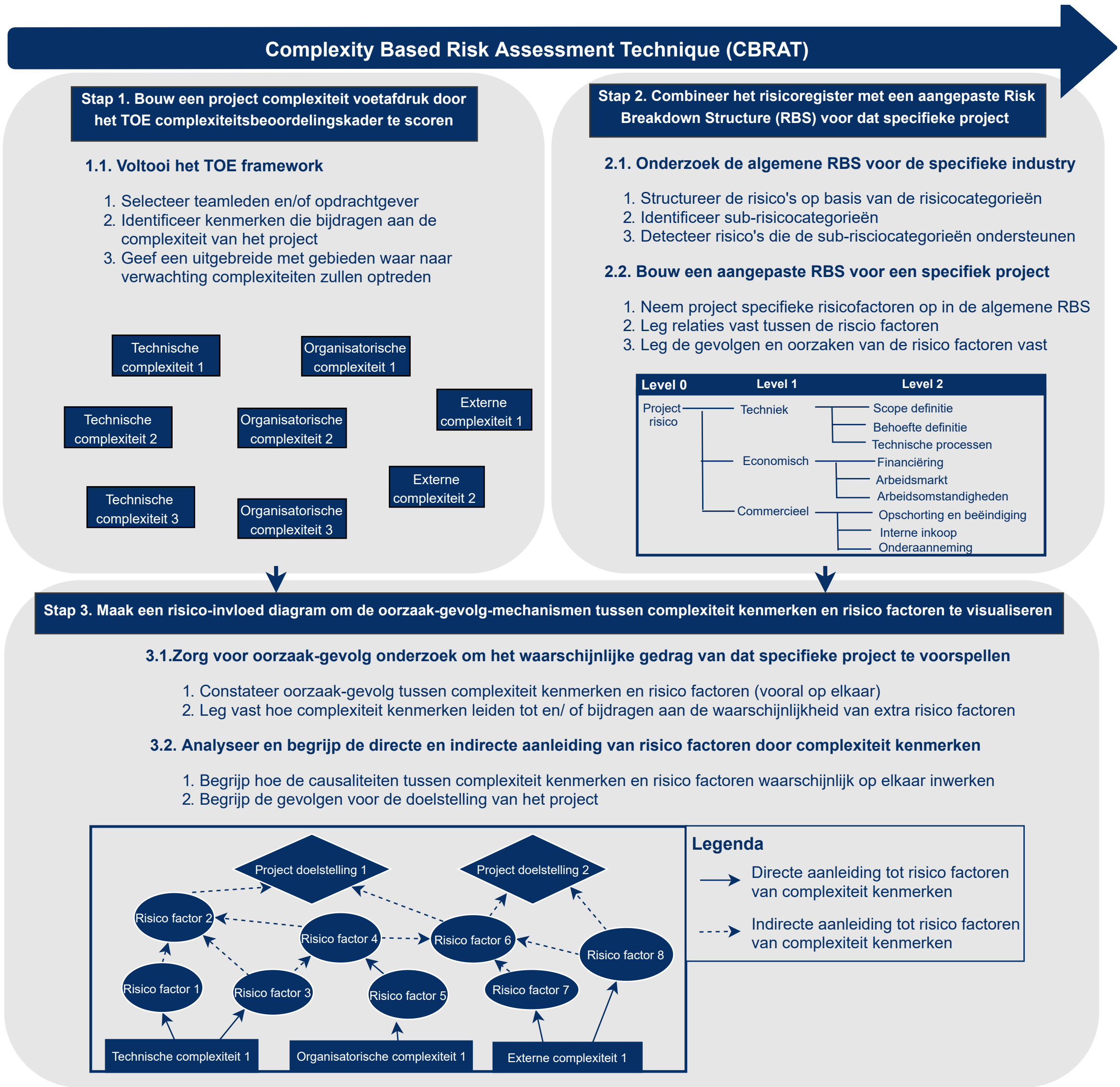

Figure 3: Praktische implicaties van de Complexity Based Risk Assessment Technique (CBRAT) in het risicomanagement proces

Vervolgens werd de toepasbaarheid van de CBRAT getest op het FA Terminal 3 project. Op basis van de resultaten van de pilot studie wordt geconcludeerd dat de CBRAT de risicomanagement procedure van Drees & Sommer zou hebben ondersteund. De reden hiervoor is dat de risicofactoren (voorziene risico's en onvoorziene risico's) verband hadden kunnen houden met de complexiteitselementen die bekend zijn in de vroege fase van het project. De reden hiervoor is dat er een oorzaak-gevolg-mechanismen lijkt te bestaan tussen complexiteit en risicofactoren bij complexe bouwprojecten, dus tijdens risicomanagement moeten deze twee concepten samen worden behandeld. Als gevolg hiervan versterkt de CBRAT het vermogen tot risicobeoordeling door de causale verbanden tussen complexiteit en risico's te identificeren. De verwachting is dat als het oorzakelijk verband eenmaal is begrepen, de impact en waarschijnlijkheid van de risico's beter kunnen worden geanalyseerd. Daarom wordt de CBRAT een risicobeoordelingstechniek genoemd.

In het algemeen kan worden geconcludeerd dat het van belang is om de complexiteit van een project vroegtijdig duidelijk te definiëren voor succesvol risicomanagement. Het doel is om schaalvergroting mogelijk te maken en meer of minder de nadruk te leggen op bepaalde complexiteitselementen. Daarbij is een projectmanager in staat een risicomanagementaanpak te bedenken die het meest geschikt is voor een project, gegeven de specifieke en unieke omstandigheden van dat project. Anders zouden risicoanalyse en -beheer geen cruciale door complexiteits beinvloedende risicofactoren omvatten, die ons op hun beurt tot onvolledige en misleidende conclusies leiden met betrekking tot de risicobeperkende maatregelen. Bovendien wordt verwacht dat zodra de relaties tussen complexiteit en risico's beter worden begrepen, de impact en waarschijnlijkheid van de risico's beter kunnen worden geanalyseerd.

Met die inzichten kunnen de experts een strategie ontwikkelen om de complexiteitskenmerken van bouwprojecten consistenter te verwerken tijdens de implementatie van risicomanagement. Hiervoor kan de CBRAT als richtlijn gebruikt worden binnen het traditionele risicomanagementproces, zoals weergegeven in Figure 4. Afhankelijk van de kenmerken die uniek zijn voor een bepaald project, kan de projectmanager een risicomanagementbenadering opstellen door de aandacht te richten op die risico factoren en causaliteit die negatieve gevolgen kunnen hebben voor de projectdoelstellingen. Desalniettemin is de bewustwording van de relaties tussen complexiteit en risico's in een bepaald project uiteindelijk een van de belangrijkste succesfactoren voor het beheersen van risico's.

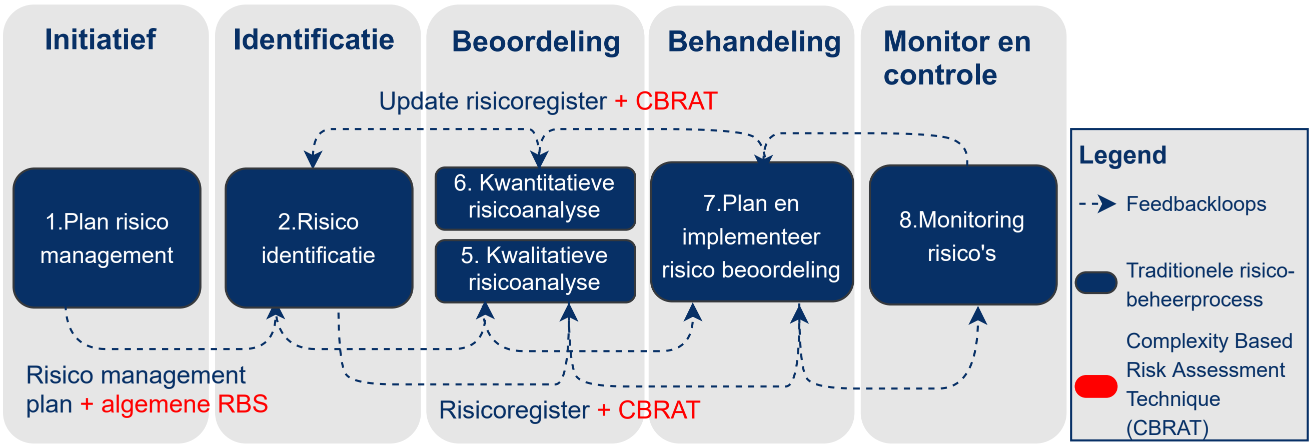

Figure 4: De CBRAT (weergegeven in rood) wordt gepositioneerd binnen het traditionele risicobeheerproces (gevisualiseerd in blauw)

Men moet zich echter afvragen of het realistisch is dat specialisten bereid zijn om hun risicomanagementaanpak te veranderen, aangezien het al gecompliceerd genoeg is. Daarom is de CBRAT zo ontworpen dat deze geen tijdrovende invoerinformatie of onnodige details bevat. Hierdoor is de CBRAT makkelijk te gebruiken en te betrekken bij het traditionele risicobeheerproces en past hij goed bij de drukke werkschema's van gemiddelde gebruikers van het concept.

Al met al bestaat de bijdrage van dit onderzoek uit vier onderdelen: het onderzocht een belangrijk onderwerp dat de potentie heeft om de implementatie van risicomanagement te ondersteunen, een empirische studie om inzicht te geven in hoe de causale relatie tussen complexiteiten en risico factoren worden waargenomen en beheerd binnen de bouwsector; het stelde de CBRAT op om de oorzaak-gevolg mechanismen tussen complexiteitskenmerken en risico factoren vast te leggen en tot slot, op basis van een proef studie blijkt de CBRAT goed te werken op een bouwproject.

Trefwoorden: projectcomplexiteit, projectrisicomanagement, complexiteit-geïnduceerde risico's, causaal verband, oorzaak-gevolg mechanismen, Complexity Based Risk Assessment Technique (CBRAT), Technical-Organisational-External (TOE) framework, Risk Breakdown Structure (RBS), risico-beïnvloedingsdiagram

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Acronyms

BREEAM	Building Research Establishment Environmental Assessment Method
CBRAT	Complexity Based Risk Assessment Technique
CE	Cause-and-Effect
CME	Construction Management and Engineering
COVID	CoronaVirus Disease
CSRAM	Correlated Schedule Risk Analysis Model
EN	European Norms
FA	Frankfurt Airport
FAS	Fraport Aufbau Süd
Fraport	Frankfurt Airport Services Worldwide
HSSE	Health, Safety, Security and Environment
ICAO	International Civil Aviation Organisation
ID	Identification
IQRA	In-project Quantitative Risk Analysis
LCM	Lightweight Communications and Marshalling
LED	Light Emitting Diode
MCS	Monte Carlo Simulation
NACO	Netherlands Airport Consultant
ORAT	Operation
PMBoK	Project Management Body of Knowledge
PMI	Project Management Institute
PRINCE2	PRojects IN Controlled Environments 2
ProCrim	Project Complexity and Risk Management
RBS	Risk Breakdown Structure
RM	Risk Management
TOE	Technical-Organisational-External

I

Research Phase

1
Introduction

1.1. Context

Construction projects are dynamic endeavours and require a manager to keep control of the situation. Unfortunately, the increasing complexities have appeared to be the cause of considerable disasters in projects (Belassi & Tukel, 1996). High failure rates show megaprojects around the world fail by a staggering 65% (Merrow, 2011). The advanced technology, forward-thinking environment, social awareness, shifting market conditions and changing legal and statutory obligations have had unexpected and far-reaching effects on construction projects. Baccarini (1996) claims that an increased awareness of dimensions and levels of project complexity may help to establish the adequate control, coordination and planning. While the project risk management has resulted in various powerful standardised tools, researchers argue that the complexity of a project is an overlooked aspect of managing risks (Burnaby & Hass, 2009).

A study by Cooke-Davies (2011) shows that the complexity of projects has its most significant impact on risk management. The complexity in projects is most often related to dynamic elements, structural elements and the interaction of these elements (Geraldi et al., 2011). In addition, the interdependency between complexities and risks appeared to cause the most problems in projects (Vidal et al., 2011). Although several researchers have investigated different techniques, tools and theories for supporting risk management, there is still a clear gap between practice and theory (Taroun, 2014). With projects growing in interconnectedness, researchers need to investigate suitable and attractive approaches for practitioners to reflect their experience. Particularly, the relationships between complexity elements and risk-factors is worth considering (Grey, 2016). As a consequence, the rise of complex projects represents an opportunity as well as a need for new thinking within risk management (Grey, 2014).

Recently, researches have tried to demonstrate that project complexity is not independent from project risks (Ackermann et al., 2007; Zhang & Fan, 2014; Thomé et al., 2016). A research by Senescu et al. (2013) provided evidence of the existing relationships between complexities and risks by measuring data from 69 test projects. The new perception about project complexity and related risks understanding suggest to link the complexities to risks (San Cristóbal et al., 2018). This enables to understand the consequences of project complexity, instead of only covering risks (Bakker et al., 2010; Jensen & Aven, 2018). Therefore, to define optimal risk mitigation strategies, it is desirable to include elements that contribute to the complexity of that particular project, since they may have potential to cause risks (the so-called complexity-induced risks) (Hartono, 2018).

1.2. Problem Statement

Throughout the years, projects are growing significant in size and duration. The project's ever-increasing complexity is an increasing source of project risks. On top of that, the complexity elements are considered to create unexpected events, while in turn, unexpected events influence the project objectives (Vidal & Marle, 2008). Although project management has received enormous attention, it seems that the risk management procedure is still a debatable issue (Baloi & Price, 2003). The project risk register seems to deal with a slight part of all types of risks. The reason for is that the risk categories are incomplete and the interactions between risks (occurrence of one risk influences other risks) are missing. Subsequently, various problems occur during construction because of an incomplete or unstructured list of risks during the initial design stages of a complex projects (Ökmen, 2016).

In addition, several assumptions are made in the literature study that could clarify the current problem. Most important of all, traditional risk management treats projects rather static and as isolated processes. There exist a distance between those who carry out the project and those who formulate the strategy (Böhle et al., 2016). As a consequence, essential influence factors that produce risks are missing. On top of that, companies seems to be unable to gather the experience and knowledge necessary for dealing with uncertainties. According to Williams (2017), the concepts of active learning and improvement are often left behind due to customer-centric thinking. Besides this, the varying project outcomes hinder the selection of an appropriate risk management approach (Perminova et al., 2008).

From the underlying assumptions, it is expected that it is desirable to support the implementation of risk management. Therefore, changes should be made for project managers to better manage risks under the influence of project complexity. The integration of complexity assessment into the risk management process could be a solution for this, since current risk management fails to examine the presumed relationships between complexity elements and risk-factors. If the risk management processes does not covers a complexity assessment, risk management and analysis would not include the direct and indirect inducement of risks from complexities which in turn lead to incomplete and misleading conclusions regarding the risk mitigation actions. In addition, the problem statement of this research is:

In complex construction projects, complexity elements are not independent from the risk-factors. The literature describes they are supposed to have different types of relationships. Despite this, the traditional risk management process has difficulties processing the larger degree of complexity, which in turn leads to an incomplete understanding of the probability and impact of the risks and their sources.

Although previous studies have tackled risks from various angles, an integrated framework presenting the different types of relationship between complexities and risks is missing (Kardes et al., 2013). However, due to the increasing complexity of projects, there has been a growing concern about the usage of the traditional risk management process (San Cristóbal et al., 2018). In addition, this research outlines the conceptual and practical need to move beyond the linear risk management approach by incorporating the complexity assessment into the risk management process.

1.3. Research Objective

The objective of this research is to investigate how the implementation of risk management can be supported by processing the complexities in construction projects more consistently. Therefore, this research aims to achieve both a theoretical and practical purpose by the following two objectives:

1. Gather and provide academic and empirical data on the relationships between complexity elements and risk-factors in complex construction projects. In doing so, this study aims to capture the cause-effect mechanisms between complexities and risks by building a conceptual framework that links complexity assessment to risk management tasks (the so-called Complexity Based Risk Assessment Technique (CBRAT)).
2. Provide Drees & Sommer with advice on how to improve and/or expand the existing risk management process. Moreover, it is investigated if the CBRAT could be utilized on a real-life project. If the CBRAT was shown to work well on the pilot project, it is recommended for usage in the future for similar projects.

This will be done by reviewing the theory and practice on project complexity and the influence of project complexity on project risk management. The purpose of this is to review the available knowledge on the interdependency between complexities and risks during the implementation of risk management in complex construction projects.

1.4. The scientific and practical relevance of the research

In terms of scientific relevance, the literature proves that a complexity driven approach for risk management provides an interesting opportunity to enhance the understanding of the risks and their sources. Although, the complexity-related risk information is often incompletely identified or even unidentified before, Munthe et al. (2014) suggests that focusing more upon complexity-related risks might function as a lens through which one can gain new and essential insights. The reason for this is that the assessment of complexity enables to scale and put more or less emphasis on certain complexity elements. In doing so, a project manager is able to come up with a risk management approach that is the most suitable for a project, given the specific and unique circumstances of that project. In addition, this research contribute to a better understanding of the inducement of risks by complexities by collecting new empirical data and combining tools.

The aim of developing the CBRAT is conceived to increase the awareness of the relationships between complexities and risks. In addition, the practical relevance of this research is an effective approach that incorporates complexity assessment into the risk management process. The added of the complexity assessment consist of providing an all-encompassing list of areas where risks could be expected. In terms of social relevance, this research creates awareness of the causal effect of complexities on risks. Based on this, project managers are able to improve the understanding of the risk-factors and their sources. As a consequence, the results of this research helps project managers to better deal with critical risks, to select optimal risk mitigation strategies and gain a more realistic view of the impact on their projects. For instance, this information can be useful to take essential decisions to subcontract parts of the project to a contractor, divide the project into manageable parts and whether to proceed with the project.

2
Research Methodology

In this chapter, the research methodology of the study is provided. First, the research scope is discussed. Next, the research questions are laid out. Following that, the strategy of the research and report structure are further explained.

2.1. Research Scope

Project risk management is a broad topic, therefore this report is limited in scope. The boundaries of the research are displayed in Figure 2.1, and the main aspects are highlighted below.

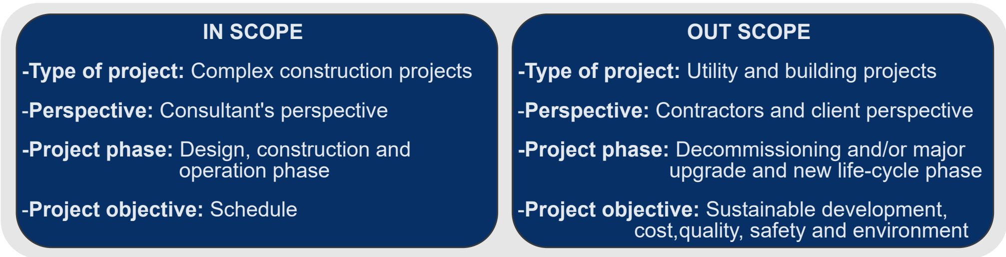


Figure 2.1: Scope of the research

- *Complex construction projects:* The chosen unit of analysis consists of the complex construction industry. To be more specific: projects with the aim to develop and/or construct a complex asset or facility.
- *Consultant's perspective:* The research is executed in collaboration with the engineering company Drees & Sommer, who provided part of the resources for the study. For this reason, all participants of the exploratory survey were employees from Drees & Sommer. The company is an international partner for consultancy and project management. The decision to perform the research within this company, is made because of its positive mindset towards further professionalisation of project risk management. Thereby, the size of the company enables the inclusion of different types of projects and the involvement of different nationalities.
- *Design, construction and operation phase:* The research focuses on the design, construction and operation phase, as visualised in Figure 2.2. These three phases are also the scope of Risk Management (RM). To achieve effective risk management, PMBOK Guide (2013) highlights to repeat the risk management process several times within the project life cycle. The reason for this is the changing nature of the risks throughout the project.
- *Schedule:* The central performances of projects are sustainable development, Health, Safety, Security and Environment (HSSE), scope, time, cost and quality (Bakker & de Kleijn, 2014). Most of the times the performance are measured according to the iron triangle; schedule, cost and quality (Bakker et al., 2010). For managing risks, it is important to be precise on what the project objective is, therefore this research focuses on the schedule.

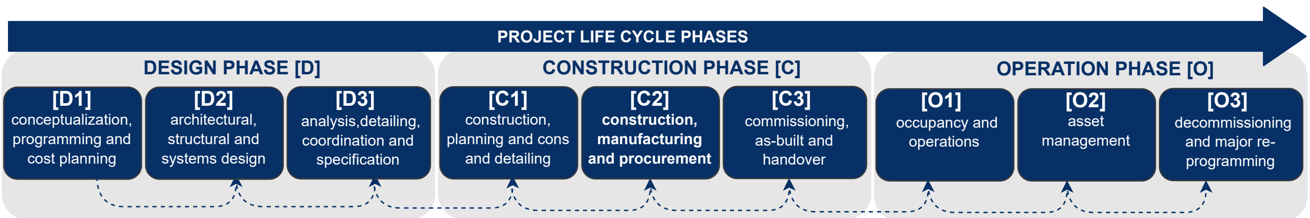


Figure 2.2: The project life cycle refers to the path a construction project takes from the beginning to its end (PMBOK Guide, 2013)

2.2. Research Questions

In order to support the implementation of risk management, the objective of this research is to investigate how the complexities can be processed more consistently. Therefore, this research investigates the different types of relationships between complexity elements and risk-factors. In doing so, the study tries to refine the link between complexity assessment and risk management tasks. The research question to achieve this objective is:

In what way can practitioners process the complexities in construction projects more consistently during the implementation of risk management?

The following sub-questions have been defined to contribute to the understanding of the subject and analyze the practical elaboration in support of this main research question:

1. *How is the interdependency between project complexity and risks treated in the literature?*
2. *How is the causal relationship between complexity elements and risks perceived and assessed in the risk management process?*
3. *What effective technique can be applied by practitioners to capture the cause-effect mechanisms between complexity elements and risks in the risk management process?*

2.3. The methodology of the research

This study sought to answer these research questions through both a theoretical framework and an empirical research. The research design, which is shown in Figure 2.3, consists of four parts to answer the main research questions.

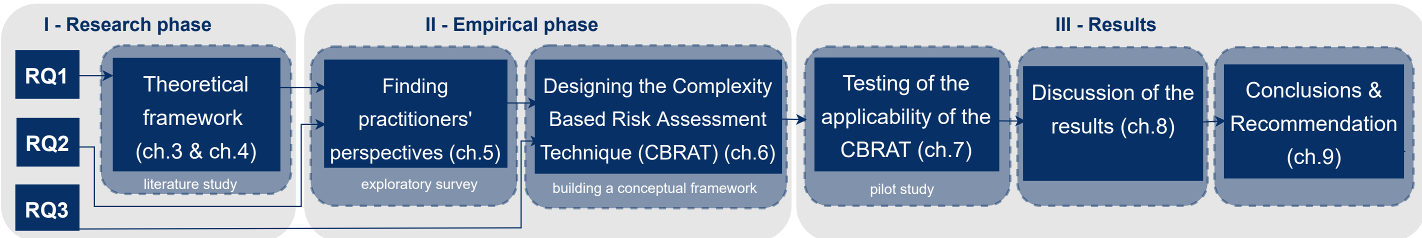


Figure 2.3: Flow diagram of the research design

This section further elaborates on the method by first discussing the theoretical context of the research. Next, the theoretical data is linked to the empirical data, followed by the evaluation of the final results, as visualised in Figure 2.4

Part I: Research phase

Theoretical framework
The goal of the first part is to establish a theoretical context of the interdependency between project complexity and risks. The data collection will be obtained by a literature study for which searches in the Repository of the Delft University of Technology, Google Scholar and Scopus will be used to review the available knowledge on the subject. The reports and papers will be selected based on their relevance to the scope of the study, the year of publication, the number of times cited and recommendations from articles or committee members and fellow students.

The literature study concerns the first sub-question. In doing so, available knowledge on project complexity and the influence of project complexity on project risk management will be reviewed. At first, the concept of project complexity in general will be examined and next, project risk management and risk assessment techniques are studied. After that, the focus shifts to the link between project complexity and project risks and adaptive studies are studied. Finally, the interdependency between complexity elements and risk-factors is observed. From the problem statement, it became clear that the traditional risk management process has problems in dealing with the larger degree of complexities. Therefore, the existing risk management plan and risk management tools of Drees & Sommer will be investigated to provide the appropriate information to execute the exploratory analysis.

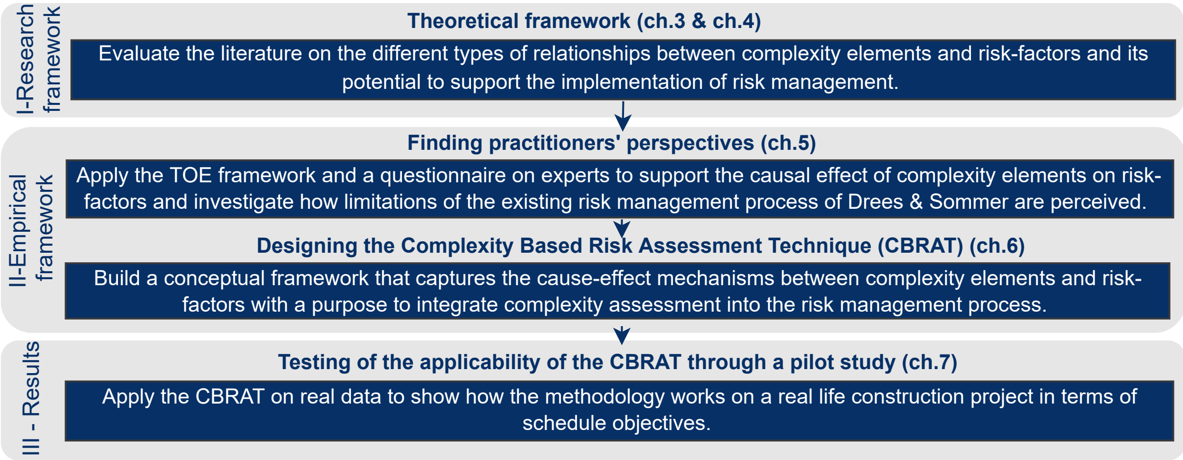


Figure 2.4: Strategy to support the implementation of risk management by processing the complexities in construction projects more consistently

Part II: Empirical framework

After the research framework has been set up, the focus shifts to the empirical framework. The link between the theoretical findings and the empirical data is analysed through an exploratory survey.

Finding practitioners' perspectives
The aim of this part is to answer sub-question two. The data is collected through a exploratory survey, performed in two parts; the Technical-Organisational-External (TOE) framework and a questionnaire. To verify whether the common practice has overlaps with the theoretical findings, both parts focus on the different viewpoints and attitudes of experts within Drees & Sommer. Firstly, the scoring of the TOE framework will explore the causal effect result between complexity elements and risk-factors. This will be done by asking the participants to score the complexity elements that caused the additional risks based on their last completed complex project. Next, the questionnaire will evaluate the current risk management process of Drees & Sommer. The structured questions will be relatively open to ensure the relevant data is extracted from the respondents.

Designing the Complexity Based Risk Assessment Technique (CBRAT)
Based on the theoretical and exploratory findings, the third sub-question will be answered by proposing a complexity driven risk management approach that aims to capture the cause-effect mechanisms between complexity elements and risk-factors. The CBRAT will be designed by first summarizing the limitations of the existing risk management procedure, followed by the theorectical and practical objectives and requirements to end with the starting points.

Part III: Results

Testing the applicability of the CBRAT through a pilot study
The objective of the pilot study is to test the methodology and examine if the CBRAT can be facilitated in a real-life complex construction project. The application will be focused on the Frankfurt Airport (FA) Terminal 3 project, in which Drees & Sommer is involved as competition coordinator and program planner. The feasibility and practicality of the CBRAT are believed to be met if a cause-effect mechanisms between the complexity elements and risk-factors can be captured. Testing the CBRAT through a pilot study, fits perfectly to optimize the implementation of risk management.

2.4. Report Structure

The report is structured into the following three parts; research phase, empirical phase and results. Chapter 1 introduces the context of the research concerning the interdependency between project complexity and risks. In Chapter 2, the research methodology is described to reach the goals defined in the introduction. After that, a literature study concerning project complexity and the influence of project complexity on project risk management are conducted in Chapter 3 and Chapter 4. Next, the practitioners' perspectives are presented in Chapter 5. After that, the CBRAT is designed in Chapter 6. In Chapter 7, the application of the CBRAT is performed on the FA Terminal 3 project of Drees & Sommer. The findings of the research are discussed in Chapter 8. Finally, the conclusions, recommendations for practice and future research and a reflection are presented in Chapter 9.

3
Project Complexity

This chapter describes the available knowledge on project complexity. Section 3.1 defines project complexity. After that, Section 3.2 focuses on the understanding of project complexity and Section 3.3 on the causes of project complexity. Next, the assessment of project complexity is elaborated in Section 3.4. Finally, the chapter is concluded in Section 3.5.

3.1. Defining Project Complexity

The topic of project complexity has been extensively researched, resulting in many different definitions. Despite this, there is still a lack of consensus on how to conceptualise project complexity (Vidal & Marle, 2008; Qureshi & Kang, 2015; Padalkar & Gopinath, 2016; San Cristóbal et al., 2018). In the early days, complex systems were considered as a large number of interrelated components (Herbert, 1962). This idea was followed by the systems theory of Waldrop (1993), which characterizes a complex system as the interaction between various actors within a technical or physical environment. Additionally, one of the first efforts to describe project complexity is proposed by Turner and Cochrane (1993):

> *"Degree of whether the goals and methods of achieving them are well defined"* (p.93).

In general, it is difficult to define project complexity. The reason for this is that complexity is an evolving, overarching and abstract concept that changes considerably(Hartono, 2018). To get an idea on how the concept of project complexity evolved through the literature, Figure 3.1 summarizes the key developments (Bakhshi et al., 2016).

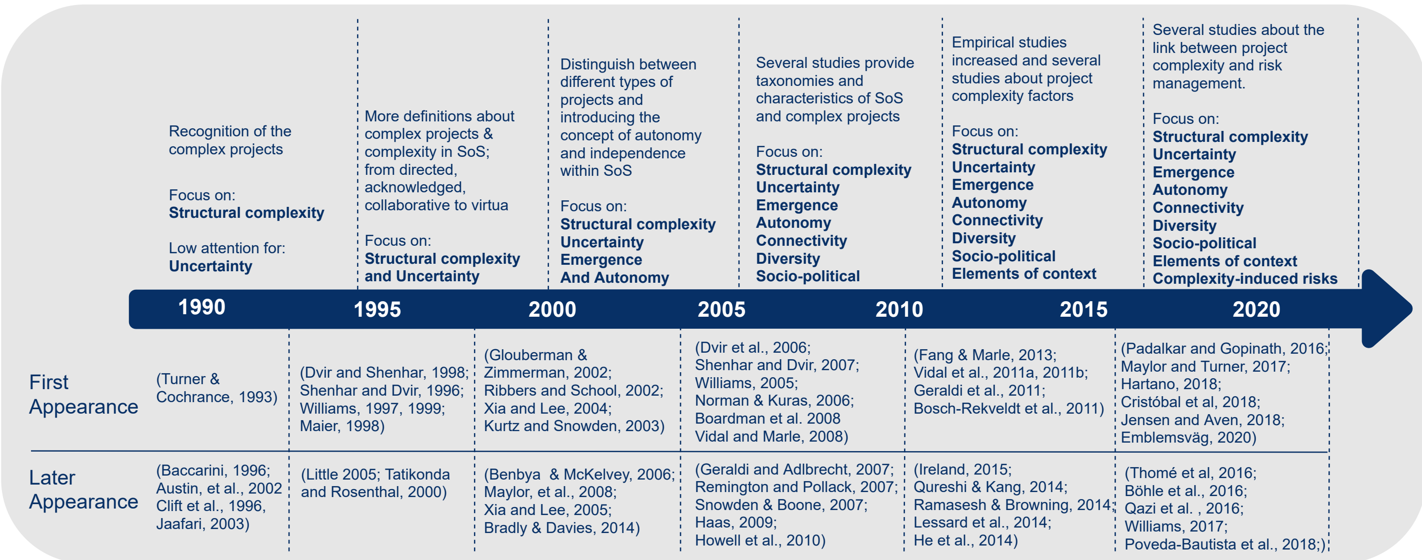


Figure 3.1: Milestones of project complexity history, adapted from Bakhshi et al. (2016)

Later on, the systematic approach by Baccarini (1996) is one of the first foundations of the Project Management Institute (PMI)'s further practice and study. It highlights uncertainty, sociopolitical complexity and structural complexity (Geraldi et al., 2011). Even tough, most researches followed the PMI perspective, others believe that there are more factors contributing to project complexity. These researches emphasize project complexity as the uncertainty of understanding the objectives and methods, the connectivity and differentiation or the ambiguity and multiple stakeholders (Project Management Institute, 2013). As for this study, the most reputed definition according to Vidal and Marle (2008) and Vidal et al. (2011) and Poveda-Bautista et al. (2018) and Hartono (2018) is followed, as defined by Baccarini (1996):

> *"Project complexity consists of many varied interrelated parts and can be operationalized in terms of differentiation and interdependency "* (p. 202).

3.2. Understanding Project Complexity

From the previous section, it became clear that an universally accepted definition of project complexity is missing. The reason is an incomplete understanding of what project complexity really is and how to deal with it (Bosch-Rekveldt et al., 2011; Cooke-Davies, 2011; Geraldi et al., 2011; Vidal et al., 2011; Maylor & Turner, 2017; Padalkar & Gopinath, 2016). To give an example, some people may relate complexity to the size or costs of the project, while others argue the growing number of interfaces and their dynamic nature over time make a project complex (Bakker & de Kleijn, 2018).

To deal with project complexity, a project manager needs to understand the complexity that is likely to play an important role in the project. Especially, since a project manager needs to emphasize the total uncertainty and reality of the project to be able to correspond to actions and make adequate decisions (Jaafari, 2001; Vidal & Marle, 2008). Several studies have provided valuable insights on how to act on the complexity of a project (Maylor & Turner, 2017). This study follows a research by Vidal and Marle (2008), who suggest to link the following two traditional views:

1.**Descriptive way**. An example of the objective vision on project complexity is the study of Baccarini (1996). He associates organisational complexity and technical complexity as the core components of project complexity. This idea is extended by Williams and Hillson (2002), as visualised in Figure 3.2. In their research, the authors attribute project complexity to two dimensions; uncertainty and structural complexity, each of them consists of two sub-dimensions; the size and number of elements and interdependence of elements and uncertainty in goals and uncertainty in methods.

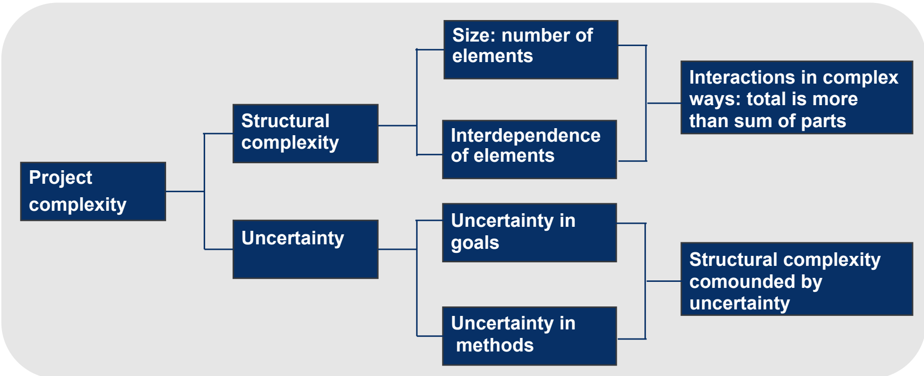


Figure 3.2: Overview of dimensions of project complexity (Williams & Hillson, 2002)

2. **Perceptive way**. The perceived complexity can be described as the more realistic view of dealing with project complexity. To give an example, project managers associate complexity with the challenges of managing projects (Vidal & Marle, 2008). These challenges may consist of how to come up with practical decisions or understand the complicated source of uncertainty caused by complexity. In addition, the perceived complexity is crucial to discuss, since it is not the same for everybody (Maylor & Turner, 2017). The subjective view is created by the collection of certain complex elements followed by an adjudication of these elements. To make more explicit, an inexperienced project manager might have a different idea of the complexity of a project than a more practiced one. In the end, the difference in the perceived complexity seems to depend on: experience, the specific project context and the observed impact of that element and the influence one has on that element (Bakker et al., 2010).

Besides the different views, there are also negative and positive influences of project complexity. The negative influence consists of the difficulty to control a construction project. For example, due to interactions, behaviour and unfamiliarity within the project, some elements can not be predicted (San Cristóbal et al., 2018). On the other hand, the positive influences are based on the opportunities that can arise as a result of the complex environment of a project. To better deal with the complexity of a project, a project manager need to reduce and/or avoid the negative effect of project complexity, seize the opportunities emerging from project complexity, create a shared perception and common goal and consider the evolution of project complexity through the project life cycle (Bakker & de Kleijn, 2018).

To conclude this section, from the aforementioned it is expected that every project manager has its own reference of the complexity of a project. The reason for this is that project managers perceive the environment and reality through a filter that depends on their own representations, mental models, personal experiences and personal culture (Jaafari, 2001). Consequently, this study suggests to create more awareness of the complexity of projects in the construction industry, since a wrong and/or incomplete perception or interpretation negatively influences the project performances.

3.3. Causes of Project Complexity

In this section the causes of project complexity are emphasised to provide a better view of the project characteristics that contribute to the complexity. Unfortunately, the literature lacks a commonly-agreed or standardized list of causes of the complexity of a project. Based on the researches of Vidal and Marle (2008), Vidal et al. (2011) and Hartono (2018), this study distinguishes the following five dominant causes of project complexity: size of the project, variety of the project system, interdependency, context-dependence and uncertainty in goals and methods.

Size of the project
To start with Baccarini (1996), who divided the size of the project into the number of elements and the interdependencies between these elements. Later on, Lee and Xia (2006) emphasizes the importance to consider the multiplicity of organizational elements. Thus, when considering the size, the structural differentiation needs to be managed throughout the different phases of the project (San Cristóbal et al., 2018). In doing so, the elements of the organizational structure need to be interrelated over a minimum critical size. Based on the aforementioned studies, this research characterises size as a cause of project complexity by associating it to the number of locations and tasks (Bosch-Rekveldt et al., 2011).

Variety of the project system
Next, the variety of the project system seems to emerge when projects have unclear and indefinite objectives. The reason for this can be found in the different philosophical and methodological expectations (San Cristóbal et al., 2018). As a consequence, this study relates the variety of the project system to the diversity and ambiguity in methods and goals (Hartono, 2018). Thus, to better understand the variety as a cause of project complexity, the technology or process novelty must be properly and adequately defined (Bosch-Rekveldt et al., 2011). Both at operational and strategic level.

Interdependency
Interdependency as a cause of project complexity gives a widely list of factors. Mostly it is characterized as follows: *"parts interacting in non-simple ways"* (Sommer & Loch, 2004), *"decomposition of units that are connected by monitored links* "(Perrow, 1999) , *"interfaces between locations and humans"* (Geraldi, 2008) and *"the number of systems and subsystems that integrate the project* "(San Cristóbal et al., 2018). Consequently, this study associate interdependency as the interrelations influence or the link between different type of entities. To make more explicit, an unexpected event in an interrelated structure can cause or contribute to an effect on another event inside the structure.

Context-dependence
The dependence of the context also appears to contribute to the level of complexity too, since it attributes to a common measure of any complex project (Chu et al., 2013). Together with globalization, context-dependence boots complexity by higher mobility, dynamics and the erosion of boundaries. This statement is confirmed by several authors, who associate context-dependence as: *" the practices and context that apply to one project are not directly transferable to other projects with different cultural configurations and institutional"* (Koivu et al., 2004), *" hierarchical framework of systems and subsystems"* (Tatikonda & Rosenthal, 2000) and *"upgrading, retrofitting works and globalization as an essential feature of complexity "* (San Cristóbal et al., 2018). Thus, from the literature it became clear that project complexity cannot be managed or analysed without reflecting the environment and characteristics on it (Vidal & Marle, 2008).

Uncertainty in goals and methods
Finally, project complexity cannot be either analysed or managed without considering the uncertainty in goals and methods. In the early days, Williams (1999) already added uncertainty to the system properties of Baccarini (1996), namely differentiation and interdependence. In doing so, he stated project complexity should be operationally understandable and practically useful (Grey, 2016). This statement to consider uncertainty in goals and methods as a cause of project complexity is also followed by: *"technology interdependence between product and process"* (Tatikonda & Rosenthal, 2000), *"complex information interdependencies among activities"* (McLain, 2009) and *"comprehensible and comprehensive* "(Maylor et al., 2013). Through the literature, uncertainty in goals and methods can be linked to the changing or evolving requirements initiated by technological advancements or clients (San Cristóbal et al., 2018).

As shown above, different causes of project complexity could play a role in a project. The five dominant causes are defined as the the number of connections, diversity of components, diversity of the connections, the context and the degree to which the differentiation and interdependence is uncertain to the manager. However, besides the causes of project complexity, it is expected to be crucial to determine more specific in which areas of the project (potential) complexity could arise. Therefore, Section 3.4 further elaborates on the assessment of project complexity, since an increased awareness of anticipated complexities enhances shared understanding about the project. Especially, if complexities are recognised early in the project, because this provides a clear vision where risks could be expected.

3.4. Assessment of Project Complexity

This section aims to classify the broad concept of project complexity by assessing it. Several ways have been proposed in the literature to assess characteristics that contribute to the complexity of a project. However, to define the specific source of project complexity (including the five main causes of Section 3.3), this study refers to the dimension of Bosch-Rekveldt et al. (2011). The authors of this research developed a framework that provides an extensive list of categories where complexities could be expected in the project. Section 3.4.1 describes the three primary forms of sources, where all elements are assigned to either the technical, organisational or external category. The elements of each complexity category are further elaborated on in Appendix B.

3.4.1. Project complexity characteristics of the TOE framework

The complexity elements from the Technical-Organisational-External (TOE) classification enable to identify aspects of the project that contribute to the complexity. Particularly, with regard to where the complexity is foreseeable in the project. The TOE framework is developed based on primary data from interviews conducted on the nature of the complexity of the organization in engineering projects and the secondary data originates from existing literature. The three dimensions are distinguished as: technical, organisational and external complexity. This is visualised in Figure 3.3. The second layer comprises 47 elements that are each allocated to either the T, O or E dimension. The TOE classification aims to increase the awareness of specific complexity elements at the start of the project (Bosch-Rekveldt et al., 2011).

Figure 3.3: Visualisation of the TOE framework (Bosch-Rekveldt et al., 2009)

When looking at Figure 3.3, the Williams' model of Figure 3.2 mainly covers the technical category due to the structural character like; number of tasks and uncertainties in goals. Further, the social aspects of a project seems to be part of the organisational and external categories; like the stakeholders involved and the variety to the structural complexity.

Technical Complexity
When looking to the technical category, Dewar and Hage (1978) state the diversity of the task to achieve as the most crucial part of the complexity of technology. Later on, Baccarini (1996) compounds technical complexity in terms of differentiation and interdependencies by the degree of reciprocity between tasks and teams. In doing so, differentiation refers to diversity and variety of aspects of functions, the diversity of tasks and number of inputs and outputs, whereas inter dependencies between tasks is related to the inputs, project team and functions within a network. Kardes et al. (2013) suggests the geology, supply-chain, design and engineering of aspects of projects all concern the technology.

In general, technical complexity is linked to the procedure which changes inputs into outputs by using skills, techniques, means, materials and knowledge (San Cristóbal et al., 2018). Furthermore, a study by De Bruijn and Leijten (2008) suggest technical complexity is also related to social complexity, including the interactions between the participating people and the size of the project. According to them, when a project faces many social and technical uncertainties, the manager should focus on managing people who can deal with the technical challenges rather than managing the technical difficulties. In other words, the manager's attention should shift from a well-defined project to a process of interaction. From this it is concluded there is need for a given level of specialization and variety of technology in each project, also indicated as the horizontal and determinant differentiation of technical complexity.

In this research, the technical complexity of construction projects is expected to result mainly from the diversity and amount of in- and outputs, the diversity and amount of tasks to produce the presumed outcome of the project and the expertise required for the project. As a result, technical complexity can be found in construction projects which have inexperienced or unfamiliar technical aspects or design characteristics. Besides this, technical complexity is also expected to evolve as a result of the uncertainties of the multiple independent design solutions of the project.

Organisational Complexity
Organisational complexity from interdependency is best identified as the complexity arising from reciprocity of organisational units (Baccarini, 1996). A further study by De Bruijn and Ten Heuvelhof (1997) suggests organisational complexity increases as a consequence of longer duration or an increased scale of the project. This statement is confirmed by Vidal and Marle (2008), who emphasize roughly 70% of the complex elements of current projects are organizational. Reasons for this can be found in the fact that most construction projects consist of a coupling of projects with different functions of purposes and multiple clients (Hertogh & Jacques, 1997). Consequently, it is expected that organisational complexity results primarily from organisational differentiation and interdependencies. In doing so, organisational distinction seems to be dependent on the number of formal organisational units and hierarchical levels.

From the literature it became clear that a lot of complexities can be found in the organisational dimension. To give some examples of these organisational elements; goals and objectives (both on strategic and operational level), management practices (organizational and interactive management) , division of labor (structure of the organization), structural complexity (break down structure of tasks and seperate contracts), directional complexity (change in projects due to problematic situation) and operative complexity (independency of projects in achieving goals, self-reflection, organizational culture, sense-making processes or emergence of identity) (San Cristóbal et al., 2018).

External Complexity
This brings us to another important source of project complexities, the external factors of a project. The external complexity is expected to result mainly from difficulties as a result of the project location, relevant market conditions and the number and diversity of stakeholders (Bosch-Rekveldt et al., 2011). To give an example, the project's location can influence the practices and methods applicable to a project, if it may not be possible to translate them due to cultural, language or institutional differences. Other examples of external complexities are; conflicting agendas of various stakeholder management processes and strategies as well as the information flow between the parties and number of project participants. Besides this, another critical factor that affects external complexities can be found in globalization due to improved mobility, increased dynamics and enhancement of boundaries (San Cristóbal et al., 2018).

In other researches, external complexity is also linked to the factor of time, since current complex construction projects have a relative life span of 10 to 15 years from initiation to execution. As a consequence, a lot can happen in these years due to rapid changes in technology or even unexpected legislative changes. On top of that, the concept of time may also contribute to changes on requirements or wishes of parties or stakeholders involved (Hertogh & Westerveld, 2010). Based on this, it is expected that to deal with the fast-changing and dynamic environment, these projects need to reserve a large amount of money. To make more explicit; a level of financial complexity need to be included in the budget to deal with the potential changes as a result of uncertainties or unexpected events that arises during the project.

Furthermore, project complexity may increase as result of high visibility and politically sensitivity (San Cristóbal et al., 2018). Hertogh and Westerveld (2010) suggest law and regulation complexities is a crucial element of project complexities. Reasons for this can be found in the fact that politics get involved in every detail of complex construction project and in many cases regulations and rules are not well aligned (Hertogh & Jacques, 1997). This may cause rapid and unexpected legislative changes or delays as a result of the number of political parties and the amount of permits or the long waiting list to provide an approval to continue the project (Hertogh & Westerveld, 2010). Besides the changes on requirements, external influences may also effect external risks, such as the wishes of parties or stakeholders.

3.5. Conclusions

To conclude this chapter, the causes of complexity from Section 3.3 provide an overview of the present complexities in projects, whereas the TOE framework focuses on the sources of project complexity. Additionally, the breakdown of complexity elements into T, O and E create awareness of where the potential complexities can be expected to arise in the project. In doing so the, TOE framework considers risks as a natural source of the complexity of a project.

4
Influence of Project Complexity on Project Risk Management

Every project is unique and involves risks, and therefore, risk management is a vital part of every project's business. First, project risk management is defined in Section 4.1. However, to understand project risk management, the interesting relationship with project complexity must not be forgotten. Therefore, the interdependency between project complexity and project risks is further discussed in Section 4.1.2. Next, studies on adapting project risk management to project complexity are elaborated on in Section 4.2. After that, two qualitative assessment techniques are introduced in Section 4.3 to end with the final conclusions in Section 4.4 by answering the first sub-question of this research.

4.1. Project Risk Management

In the construction industry, risks emerge in small-scale, complicated settings, highly interrelated networks, and different phases (Böhle et al., 2016). Due to the importance of managing risks, several guides are defined that involve project risk management processes. The most familiar ones are the International Standard ISO31000, PRojects IN Controlled Environments 2 (PRINCE2) and the Project Management Body of Knowledge (PMBoK) guide. This study refers to the PMBoK Guide, which is developed by the Project Management Institute (PMI), as illustrated in Figure 4.1.

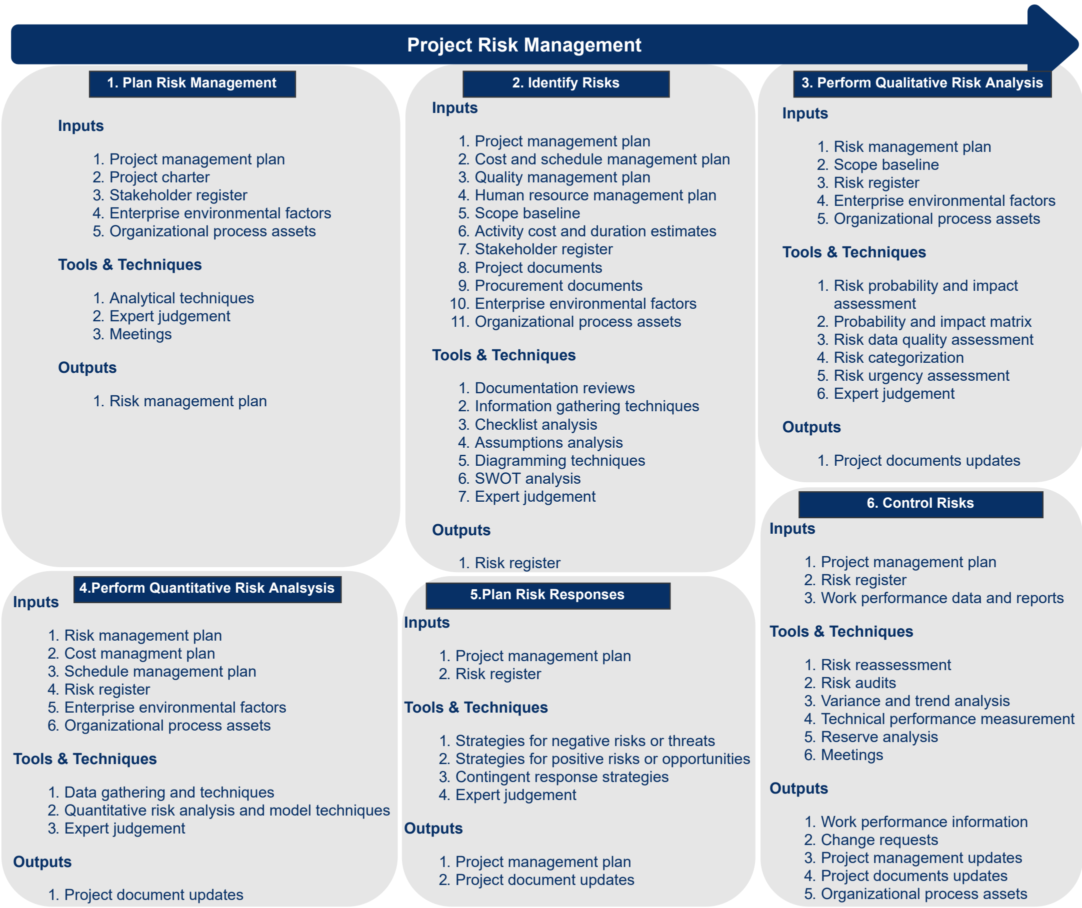


Figure 4.1: Project Risk Management model according to the standard PMBoK Guide (PMBOK Guide, 2013)

4.1.1. Uncertainties and project risks

Projects involve both uncertainties and risks. The uncertainties can not be measured, since they are expected to be uncontrolled and not totally understood situations with regard to potential outcomes and causal influences. On the other hand, project risks can be measured. This can be done by linking the probability and impact scores as a form of uncertainty. As a consequence, uncertainty is considered to be a much broader concept for the reason that not all uncertainties are risks (Raz & Hillson, 2005). Other forms of uncertainty for example include variability or instability.

There are different assumptions on how to define uncertainty in complex construction projects. In literature, uncertainty in projects is most commonly dealt with as an inevitable and normal phenomenon (Vidal & Marle, 2008). Additionally, uncertainty is expected to be the lack to objectively relate sufficient knowledge to probabilities (Williams, 2017). As for this study, uncertainty is defined as the instability of the properties of operation of socio-cultural and technological-material conditions (Böhle et al., 2016).

In addition, uncertainty plays an essential role in every phase of the project for the reason that unpredictable events have the potential to create a risk (Bosch-Rekveldt et al., 2011). To give an example: the weather conditions of one month ahead on a construction site. When depending on this uncertainty, one month later the labour productivity on-site may vary in an adverse or favourable direction. In other words, the uncertainty in weather conditions creates risks on labour productivity. Therefore, risks are expected to have two paths; positive (favourable) and negative (adverse).

In the modern literature, the standard definition by PMBoK appears to be the most specific and complete way to define risks (Nicholas & Steyn, 2017). In doing so, Hillson (2002) extensively researched the concept of risks based on experiences and uniqueness of projects, and therefore, his definition is used in this research to define project risks:

> *"..an uncertain event or condition that, if it occurs, has an effect on at least one project objective such as time, cost, scope or quality. A risk may have one or more causes and, if it occurs, one or more impacts."* (p.11).

In practice, project risks are often calculated with the product of the probability of their occurrence and the impact (Williams & Hillson, 2002). In doing so, probability is considered as the likelihood of an event occurring, whereas the impact indicates the effect and consequences of an event on the project (Nicholas & Steyn, 2017). Additionally, the combination of probability and impact enables a project manager to decide on which risks to treat and which risks to take. Furthermore, Figure 4.2 illustrates the cause-event-effect definition of risks (Bakker & de Kleijn, 2014), which refers to an event (or condition) with a related effect (or impact). In other words, a project risk that exists today gives rise to the probability of an event happening that has multiple effects in its turn.

Figure 4.2: Cause-event-effect structure of a risk, based on the causes, event for the risks and the consequences (Raz & Hillson, 2005)

However, it is important to notice that project managers should not only qualify risk as to the possibility of unfavourable performance. Particularly, since project risks might include excellent opportunities, as well as threats or hazards (Williams, 2017). Thus, instead of coupling risks with its negative consequences only (threats or downside risks), the opposite outcomes of the same phenomenon (opportunities or upside risks) should be seen (Ward & Chapman, 2003).

To conclude this section, it became clear that project complexity may trigger or contribute to external causes for risks (Bosch-Rekveldt et al., 2011). To make more explicit, the increasing complexity of projects (e.g. number of interfaces in a project) result in more interactions and dynamics, which contributes to project risks (Bakker & de Kleijn, 2014). This complexity-based perspective of dealing with risk management is also in line with a study of Geraldi et al. (2011). In this research, risk-factors are assessed by including the human reactions and the socio-political affect within the project risk management. Based on the aforementioned researches, this study builds further on the idea that project complexity is a source for project risks. Next, Section 4.1.2 further elaborates on how the interdependency between project complexities and risks are treated in the literature, since they are expected to have different types of relationships between them.

4.1.2. Interdependency between project complexity and risks

This section provides a brief outline of the views concerning the relationships between project complexity and risks. The opinions in literature are outlined in Table 4.1 to investigate whether the authors take risk into account in the treatment of complexity. All the authors recognize a level of interdependency between project complexity and risk.

View on the interdependency between project complexity and risks	Literature
Interdependency between project complexity and risks is not taken into account in the research.	Baccarini (1996), Williams and Hillson (2002), Sommer and Loch (2004), Vidal and Marle (2008)
Interdependency between project complexity and risks is taken into account in the research.	Turner and Cochrane (1993), Ackermann et al. (2007), Perminova et al (2008), Bosch-Rekveldt et al. (2011), Geraldi et al (2011), Fang and Marle (2012), Williams (2017)

Table 4.1: Matching the primary schools of thoughts concerning the interdependency between project complexity and risks

Based on the philosophical stance of Baccarini (1996), the interdependency between project complexity and risks is not included in several kinds of research (Williams & Hillson, 2002; Vidal & Marle, 2008). Later on, the difference between the two terms is further explained by Sommer and Loch (2004) as:

> *"Complexity has two dimensions: system size and number of interactions among influence variables. Unforeseeable uncertainty refers to the inability to recognize influence variables or interactions at the outset"* (p.1337).

Currently, the complexity of a project is often seen as an essential contributor to project risks (Turner & Cochrane, 1993; Fang & Marle, 2012; Williams, 2017). According to Bosch-Rekveldt et al. (2011), the complexity of a project can be considered as a vital part of project risks. The reason for this is that risks seem to be caused by complexities, since complexity is a tangible system property (Perminova et al., 2008; Hillson et al., 2006). Hartono (2018) states the conceptual enhancement of project complexity to risk enables to consider risks as a network of interrelated possible events. This is confirmed by Emblemsvåg (2020), who considers complexity as an inherent property of real-life projects which leads to risks.

In addition, there seems to be some agreement in the literature that complexities and risks are not mutually exclusive. Several researches claim complexity causes risk and uncertainty and they are therefore interdependent (Grey, 2014). Especially, since external influences of risks may include market-related complexities, technological complexities and changes in industry standards and legal regulation (Böhle et al., 2016). Thus, better integration of the different types of relationships between complexity elements and risk-factors can present reality as well as reliability. Based on this, it is concluded that a holistic appreciation of project complexity is crucial for obtaining realistic risk management results (Ackermann et al., 2007). Therefore, this research builds further on the idea to bring the two statements of Table 4.1 together. (Taslicali & Ercan, 2006).

To give a better idea on the direct and indirect inducement of risk-factors from complexities, this study outlines two examples. Firstly, the process of the difference in perception is directly adjusted by real project complexity. For instance, information can be changed because of cultural variety, staff interdependencies or diversity. Secondly, complexity indirectly influences the impact of decisions and the following actions, since complexity entails the project manager's lack of ability to predict the project evaluation and impact of its decisions.

4.1.3. Risk management process

Next, it is crucial to discuss the implementation of risk management. In general, the risk management process aims to help project managers to modify the risk with the purpose to make them understandable, controllable and achieve beneficial outcomes. As a result, PMBOK Guide (2017) defines the risk management process as follows:

> *"Systematic process of identifying, analyzing and responding to project risks"* (p.237)

The implementation of risk management requires several sub-processes (Thamhain, 2013). As can be seen in Figure 4.3, PMBOK Guide (2013) illustrates the continuous cycle for initiating, identifying, assessing, responding and monitoring risks. Some challenges are expected to arise concerning the order of the sub-processes, since they overlap and react with each other. Therefore, it is crucial for an organisation to allocate resources efficiently, establish clear contractual agreements, align cultures, build trust with partners and provide transparent information flow (Grey, 2014). This is also confirmed by Kardes et al. (2013), who state the success of the implementation of the risk management process depends on the underlying mechanisms of a project. Besides this, it seems to be curcial to incorporate the process in the early stages of the project (Ward & Chapman, 2003; Zou et al., 2007), and repeat throughout every phase (PMI, 2017). The reason for this is that risks evolve during the project's life cycle due to the emergent nature and dynamic environment of projects.

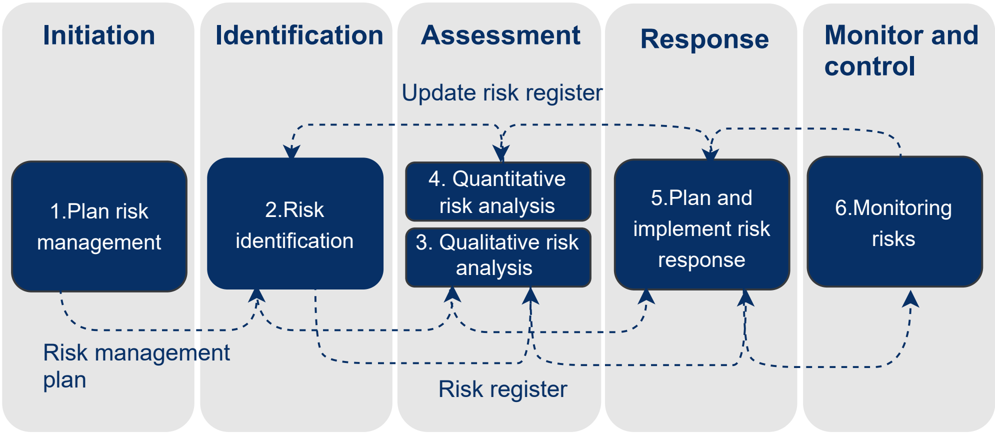


Figure 4.3: The risk management process, whereas the dashed lines indicates the feedback loops (PMI, 2017)

Risk initiation
The risk management process starts with the initiation and definition of risks. In doing so, it establishes the context by explaining the dynamic characters of a project through team members and stakeholders. Even though the number and importance of risks within a risk category can variate depending on the project, each category should be based on both endogenous risks as well as exogenous risks (Kardes et al., 2013). On the one hand, the endogenous risks suffer from factors related to the social environment, operation, resources and stakeholders (Miller & Lessard, 2007). While on the other hand, exogenous risks are associated with factors related to the industry, economy, politics, etc.

Risk identification
After the initiation, the identification of risks set the tone for control of uncertainty. The risk identification procedure indicates how to manage the project and its inherent risks. The identification is constituted of previous experiences in the construction industry and can entirely rely on the judgement of experts in the very context (Ruthankoon & Ogunlana, 2003; Perera et al., 2014). Additionally, several studies have regarded the identification of the risks as the most critical stage of the risk management procedure (Zaghloul & Hartman, 2003; Banaitienė et al., 2011).

In current construction projects, the outcome of the risk identification procedure is often assisted by a risk register. The dashed arrows of Figure 4.3 illustrates the feedback loops, which in turn indicates the importance of the risk register within the risk management process. The loops start at the beginning of the process and has to be updated continuously during the process. The maintenance of the risk register is one of the minimum requirements of the PMBoK standards (PMBOK Guide, 2017). As a consequence, the risk registers have been extensively used for many years in practice (Ackermann et al., 2007).

Furthermore, the risk register supports decision-making by determining the required risk response strategies. The risk register records risks information in a standard format, including; the risk description, causes, probability and impact, mitigation and control actions, back-ups, status and responsibility (Raz & Hillson, 2005). However, to benefit from the risk register as a communication tool and enable relevant risk response, everyone needs to understand and formulate the risks in the same way. Therefore, it is crucial to describe the causes of the risks as facts. Even though there may be multiple causes to an event, only one cause should be identified per entry to avoid confusion in response. Next, risk events need to be considered as a chance by using "may", "might" or "could". Further, consequences need to be emphasized as "will happen", for the reason that if the event occurs, the consequence will happen.

Risk assessment
Next, the analysis of risks aims to provide valuable knowledge on how to deal with risks and their outcomes (Öztaş & Ökmen, 2004). The difference between qualitative and quantitative consist of the way to approach the process. The qualitative risks analysis is more subjective, whereas the quantitative risk analysis is more objective. There are several methods in practice to analyse project risks. Most of the methods and tools can be linked to one of the following classification: checklists, structured brainstorming and evaluation, risk indicator scales, probabilistic modelling of costs, cash flows, schedules, probability/impact calculations and by informal experienced judgement (Grey, 1996).

Risk response

The risk response phase purposes to create awareness of the allocated risks (Zou et al., 2007). In doing so, an appropriate strategy is formulated to combat and deal with the analysed risk (Kardes et al., 2013). These strategies concern the measures taken by construction managers and build on the prediction of the impact, probability, the reduction of the effect and likelihood of risks (Fan et al., 2008). As a consequence, different response strategies can be eliminated, retention, reduction, avoidance and transfer of risks (Lyons & Skitmore, 2004; Kardes et al., 2013).

Risk monitor and control

The level of monitorring and control over risks is most often based on the amount of project-specific risks (Miller & Lessard, 2007). In addition, the following six strategies are distinguished; instilling flexibility (e.g. balancing cohesion), the assessment and the mitigation of risks (e.g. probabilistic models, quantitative sensitivity analysis), diversifying risks through portfolios (investing in different countries, partnering), building strategic systems (e.g. allocating of resources, information gathering, using laws and regulation) and embracing residual risks.

To conclude, the study on the different sub-processes in project risk management is done to select a sub-process that can be linked to the complexity assessment process. From the literature, it is expected that the risk assessment procedure is most appropriate to refine the link between the complexity assessment process and risk management tasks.

4.2. Studies on adapting project risk management to project complexity

From the previous section, it becomes clear that their exists a level of inderdependency between the concepts of project complexity and project risks. To learn from past research results, this section outlines some earlier assumptions in the literature that aim to manage project complexity and risks adaptively. As for this study, the focus is on developing a new approach to risk management based on the complexity assessment process.

In the literature, there are numerous approaches proposed to support the implementation of risk management. To start with a study by de Carvalho et al. (2005), in which the researchers established a conceptual model to link project success to project risk management while considering the effect of project complexity. At the same time, Poh and Tah (2006) used influence maps to capture the interdependency among the risk-factors impacting the cost and duration of an activity in a construction project. Further, Petit and Hobbs (2010) state the assessment of relevant contextual uncertainty by means of environmental scanning is an integral part of project risk management.

Hartono (2018) supports the practical and conceptual extension of project risk to project complexity by introducing an original matrix to categorize extant works of In-project Quantitative Risk Analysis (IQRA). According to him, it is essential to develop a practical and integrated framework to assess complicated and risky decision-making. In doing so, he introduced five project risk modelling categories from the literature study, as visualised in Figure 4.4. Jensen and Aven (2018) proposed a risk framework that incorporates system knowledge and uncertainty. The developed method is valuable for this study to understand how the project system is supposed to work.

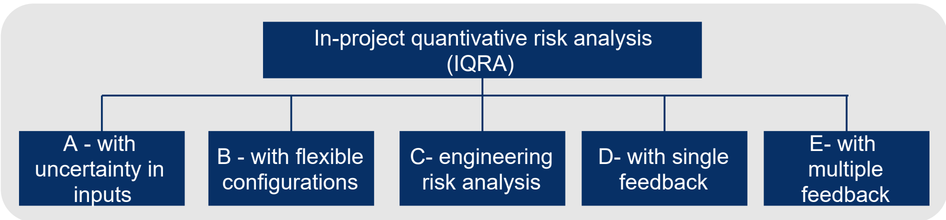


Figure 4.4: Categories of IQRA (Hartono, 2018)

Furthermore, Ackermann et al. (2007) and Ackermann et al. (2014) support the idea of risk mapping. In doing so, these researches demonstrate that the information of a risk map is valuable to identify likely effects of the complex environment of projects on risk management outcomes. In addition, Thomé et al. (2016) introduced a framework that combined uncertainty and the indirect impact of the perceived complexity on risk management. These findings are used in this research to get a better view of the direct and indirect inducement of risks from complexity.

In addition, the concept of influence mapping is also followed by Williams (2017). From the results of his research, as visualised in Figure 4.5, some examples of the inducement of project risks from project complexity are found; changes to the project parties, contracts between the project parties, inter-personal relationships between the project parties, culture within the project parties, individuals within the parties and the combination of risks and human reaction. Based on the above assumptions, an increased focus on the evaluation of complexity combined with an understanding of complexity-induced risks, is expected to assist decision-making when managing complex projects.

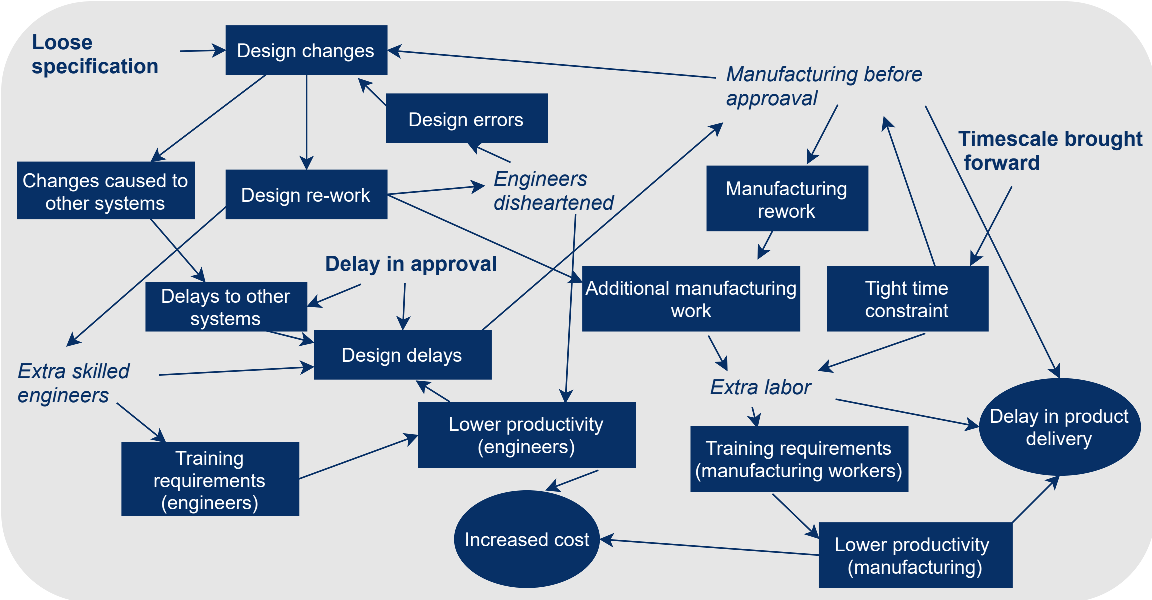


Figure 4.5: An example of a simple risk map with three risks (with no border). The map is based on; causing chains of consequences (rectangle border), four human responses to the risks (italic with no border) and two outcomes (two oval borders) (Williams, 2017)

A further study by Thamhain (2013) proposed the risk-impact-on-performance model by classifying the dimension of risk management into the degree of project complexity. Besides the model, he outlines the importance to increase the awareness of these risks early in the project life cycle. Based on this and an earlier assumption by Bosch-Rekveldt et al. (2011), this study emphasizes the need to increase the awareness of project complexity by recognizing early where (potential) complexity can be expected to arise in the project. Together with the assumption of Maylor and Turner (2017), in which they suggest to distinguish the objective and subjective perception (experience of practitioners) of complexity, this study expects that incorporating personal experience, intuition and judgement supports the management of risks.

Moreover, Qazi et al. (2016) propose a new process to manage project complexity together with risk management, namely Project Complexity and Risk Management (ProCrim). The results provide valuable insights into understanding the critical complexity elements and risks with the associated interdependency. The inputs and outputs of ProCrim are illustrated in Figure 4.6. The study results demonstrate that the assessment of complexity according to the TOE framework developed by Bosch-Rekveldt et al. (2011), is efficient to achieve a better understanding of the project areas where complexity could be predicted to arise and therefore in which areas project risk could be expected.

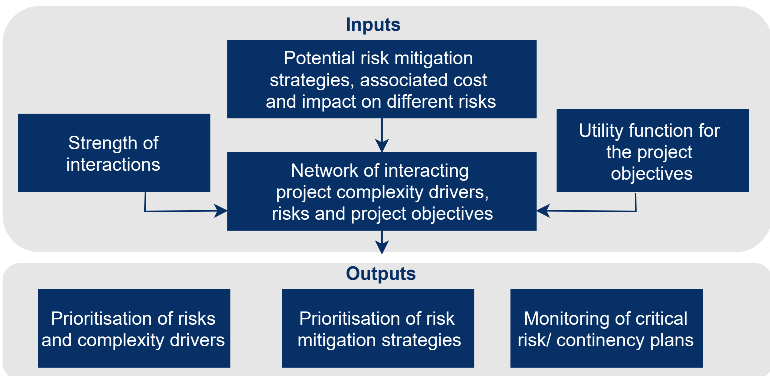


Figure 4.6: Project Complexity and Risk Management process with associated inputs and outputs (Qazi et al., 2016)

4.3. Qualitative risk assessment techniques

Based on the adaptive approaches in Section 4.2, this section introduces the Risk Breakdown Structure (RBS) and the risk-influence diagram. These techniques are useful to understand how the relationships between complexity elements and risk-factors are likely to interact and to evaluate the consequences on the project objectives.

Risk Breakdown Structure (RBS)
The RBS is a hierarchical system that aims to guide the risk management process. The RBS enables to approach the risk register on different levels by relating multiple risk-factors to causes. In doing so, the RBS evaluates high-level risks to show the factors that influence its probability of occurrence (Raz & Hillson, 2005). Thus, instead of only classifying individual risks, the RBS provides the opportunity to structure the relationship with other risk categories. The tool is widely recognized in several risk standards and included in the guidelines of PMI (2017). According to Hillson (2002) and Hillson (2003), the RBS can be defined as follows:

> *"A source-oriented grouping of project risks that organises and defines the total risk exposure of the project. Each descending level represents an increasingly detailed definition of sources of risks to the project"* (p.87).

In Figure 4.7, an example of small segment of a RBS for generic construction projects is visualised. When describing the types of risk faced by the project, the RBS often distinguishes three or four hierarchical levels (Hillson et al., 2006).

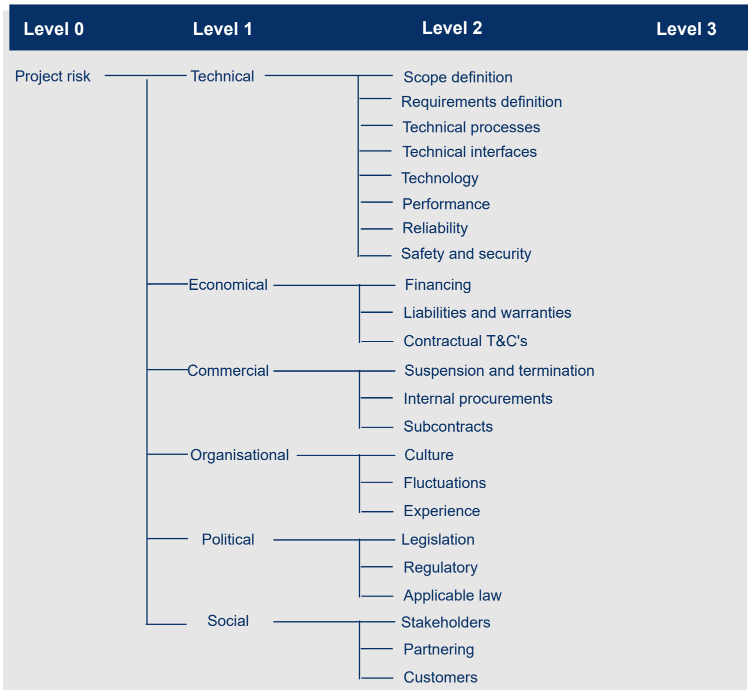


Figure 4.7: An example of a small segment of a RBS for generic projects, adapted from Hillson (2003)

To make the RBS practically useful, it should not be totally redeveloped for every new project. Instead, a general RBS enables to record generic risks which occur frequently for future. These risks are based on previous experiences and lessons learned. This allows project managers to add specific characteristics unique to the project to the general RBS. In doing so, a general RBS for a specific type of construction industry can be customized for a particular project.

Overall, the RBS enables to strengthens the risk assessment capability as listed below Hillson et al. (2006):

- *Cluster and structure:* The RBS is a powerful tool to decompose the risk and their sources into sub-categories. This enables a project manager to better analyse the probability of the risks, as well as their impact on one another. Thus, various conclusions can be drawn based on the sub-categorization, including identifying: where risks have more associated risks, the most important single sources and the interconnections between risks.
- *Understanding of the risk-factors and their sources:* The division of the lower level risks into layers of increasing details ensure complete coverage of the risks and stimulates proactive and lateral thinking (Bartlett, 2004). On

top of that, the decomposition of risks into layers of increasing detail assists a project manager to determine the vulnerable points of the risk-factors.

- *Risk reporting:* The RBS supports the communication and understanding of the risks with their management. Especially, since the standard structure of the risk information enables a consistent demonstration to reduce potential misunderstandings as a result of cross-project reporting or differences in communication for the risk.
- *Experienced-based:* The structured lists of risks that record generic risks (risks that occur frequently), which can be used as knowledge repository with lessons learned for future reference.
- *Risk-balanced portfolio:* The standard terminology and structure of the associated risks provide input to trade-off research. As a consequence, the RBS ensures a more comprehensive view to examine alternative investment options or development decisions, because it can be translated into a lower or higher level of detail.

Risk-influence diagram
The risk-influence diagram aims to provide valuable insights into the sources of critical risks. In doing so, risk-influence diagram records collective experience and the specified effects. Other visualisations of Cause-and-Effect (CE) analysis models are for instance the Ishikawa or fishbone diagram. If CE search is implemented in a logical way, the risk-influence diagram encourages the management of the causality of relationships between complexities and risks.

The action of CE search is, in essence, a way to reduce the difference on how project complexity is perceived. The purpose of this is to better understand project complexity (Vidal & Marle, 2008). CE search can be applied in two ways. On the one hand, to identify the outcome (effect) that determines the sources (causes). On the other hand, to provide a risk source (cause) that helps to identify consequences that might ensue (effect) (Nicholas & Steyn, 2017). As a consequence, the visualisation of the influence that the causes have on one another, encourages the project manager to think original (Nicholas & Steyn, 2017). The influence diagram is therefore comparable with the causal loop diagram.

An example of a risk-influence diagram in Figure 4.8 expresses the direct and indirect influences. This is done by breaking the complexities down into more risks. In doing so, a solid arrow indicates an immediate effect and a dashed arrows shows an indirect effect. The logic behind the paths is explained as follows; *As a result of* use of innovative technology (definite complexity or events that exist in the project environment and which give rise to the uncertainty), the new technology is not fully tested and might not hold up to the requirements (uncertain events or set of circumstances that, if they occur, would affect the project objectives) *may occur which would lead to* Design has security vulnerabilities, *which leads to* delays in design approval (unplanned variations from project objectives).

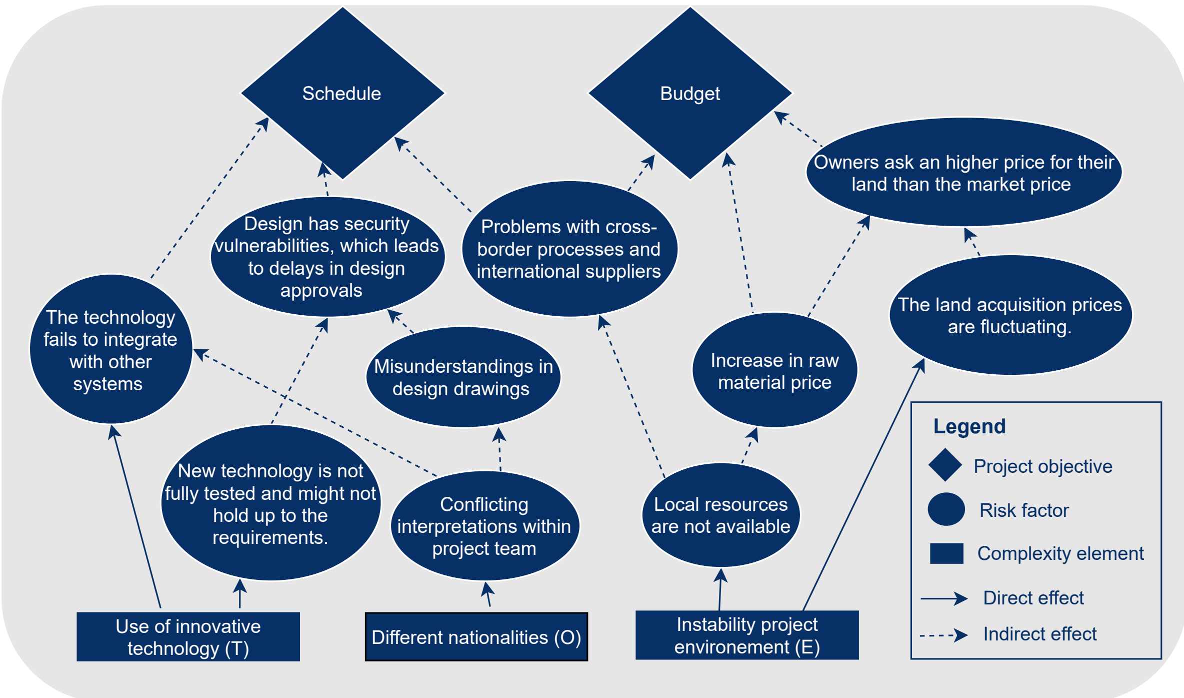


Figure 4.8: An example of a small segment of a risk-influence diagram

4.4. Conclusions

As mentioned earlier, literature stresses the importance of refining the link between project complexity and project risk management. In addition, there are several thoughts on the interdependency between these two concepts. For the purpose of this study, Chapter 3 and Chapter 4 aim to answer the first sub-question:

RQ1: How is the interdependency between project complexity and risks treated in the literature?

It can be concluded that the interdependency between project complexity and project risk management is captured in the existing literature. The earlier developed methods are essential to better understand the influence of project complexity on project risk management. To correctly define the different types of relationships between complexities and risks, this research recognizes two essential points. Complexity elements are considered to create an unexpected event or risk-factor (direct inducement of risk-factors from complexity elements), whereas the unexpected events are believed to influence the project objectives (indirect inducement of risk-factors from complexity elements). In other words, complexity elements influence the projects, while the risk-factors affect the project objectives. Overall, the interdependency between complexity elements and risk-factors are observed as: *Complexity-induced events seems to be a major source of risks whose effect for the project are uncertain.*

However, it is noticed that only establishing the relationship between complexities and risks is not enough to guarantee a successful project. The traditional risk management process need to succeed a complexity assessment process in case of a complex construction project, differently from ordinary projects. Besides this, the risk-influence diagram of Figure 4.8 shows that multiple risk-factors can arise from causes and that one risk-factor can have multiple causes. Therefore, before implementing the cause-effect analysis it is advantageous to combine the traditional risk register with the RBS. The reason for this is that the decomposition of risks enhances the understanding of the risks and their sources which in turn provides a more realistic view on the total impact and probability of the risks on the project.

In Chapter 5, the conceptual and practical extension of complexity elements to risk-factors is explored by the opinion of experts of Drees & Sommer. In doing so, the perception of the causal relationships between complexities and risks in the risk management procedure in practice are investigated. The purpose of this is to develop a complexity-driven risk assessment technique in Chapter 6. This technique aims to capture the cause-effect mechanisms between complexity elements and risk-factors. The added value for project managers is the increased focus on the complexity elements in the risk management procedure. The results of the above-studied literature, as summarized in Table 4.2, forms an important basis upon which the theoretical requirements of the proposed technique of Chapter 6 depends.

Theoretical objectives and requirements
Include personal experience, human intuition, knowledge and jugdement of experts
Project complexity and project risks are not independent from each other
Include the different types of relationships between complexity elements and risks
Cluster and structure a wider amount of risk categories and their sources
Distinguish the complexity-induced risks into two main classes: the 'risks directly induced by complexity' and the 'risks indirectly induced by complexity'

Table 4.2: Matching the primary schools of thoughts concerning the scope of the Complexity Based Risk Assessment Technique (CBRAT)

Finally, it is essential to notice that every project is unique and the unpredictable possibilities are the events that eventually happen and have the highest impact on the project. Therefore, managing risks on the basis of a so-called checklist or guideline could create the disadvantages of a tunnel vision. This is especially a weakness if organisations rely too much on guidelines and techniques, while these can only foresee the predictable.

II

Empirical Phase

5
Finding practitioners' perspectives

From the literature study of Chapter 3 and Chapter 4, it is concluded that the current practice fails to manage the different types of relationships between complexity elements and risk-factors efficiently in complex construction projects. Therefore, including the causal relationship may have potential to enhance the risk management procedure. In addition, this chapter introduces the causal effect of complexity elements to risk-factors to experts in the construction industry. In doing so, it gives practical requirements for the CBRAT, as designed in Chapter 6 and recommend Drees & Sommer on how to improve and/or expand the current risk management process in Chapter 9.

This chapter presents the findings of this empirical research. Firstly, the method used, the exploratory survey design and the respondents are further elaborated on in Section 5.1. Subsequently, the findings of the TOE scoring process are presented in Section 5.2 and results of the practical validation in Section 5.3. Finally, the overall conclusions are elaborated on in Section 5.4, including a confrontation with the literature findings to end with a critical review.

5.1. Method elaboration: an exploratory survey

An exploratory approach is chosen to understand the current practice of managing and understanding the causal relationship between complexity elements and risk-factors. To gather the relevant data, a survey is developed and distributed amongst current project managers and risk managers of Drees & Sommer. The advantages of a survey approach are as follows; the gathered data is more objective than when (semi-)structured interviews would be organized, the actual data collection takes less time and it is easy to access targeted respondents and collect a large amount of information (Verschuren & Doorewaard, 1999; Baarda & de Goede, 2006). Despite this, a survey needs thorough preparation to be self-explaining (Blaikie, 2009). For instance, the participants should be able to contribute to the survey without other than written instructions. Due to the fact that the research period is in the middle of the CoronaVirus Disease (COVID)-19 pandemic, the survey method also enabled to keep an appropriate distance from the respondents.

The survey investigates the theoretical context of this research by analysing if experts experienced the cause effect between complexity elements and risks. All respondents participate with an introduction to the concept of project complexity and the TOE framework in advance. This is done to ensure the participants become familiar with the terminology prior to the survey, since complexity assessment is relatively new subject among construction companies.

Furthermore, several measures are taken to ensure the internal validity of the survey method (Tashakkori et al., 1998). Two experts from Drees & Sommer are asked to test the draft version of the survey design. Based on their feedback, the vocabulary and questions are clarified and the number of questions is reduced before the survey is sent. On top of that, the respondents have the opportunity to leave some questions 'unanswered'. Thereby, if the respondents have additional questions, they are allowed to contact the researcher personally to support the data of the survey.

To provide some control on the survey and increase the validity of the answers, some 'general questions' are asked first. These concerned the respondents' most recent completed project, the respondents' role in these projects and the number of years of experience in the field. The focus on the participants' last completed project enlarges the validity of the answers, since this project is still fresh in the respondents mind. On top of that, it enables to generalize inside the sector, because the respondents can not select their most successful or unfavourable project (Tashakkori et al., 1998).

5.1.1. Exploratory survey design

The design of the exploratory survey can be found in Appendix C. The survey is divided into two parts: a TOE framework scoring process and a questionnaire. Firstly, the previously developed TOE scoring model by Bosch-Rekveldt et al. (2011) is used to explore the causal relationships between complexity elements and risk-factors. Next, a broad collection of questions is developed to obtain the perspectives of practitioners within Drees & Sommer. These questions were focused on the existing risk management process. The mixture of a scoring process and open questions in one survey perfectly fits a survey approach (Blaikie, 2009). For the reason of practicality, both parts of the survey are undertaken at the same time and designed to take no longer than a maximum of 30 minutes for each participant.

Part 1: TOE framework
This part of the survey focuses on the practitioners' view concerning the causal effect of the complexity elements according to the TOE framework on risk-factors. Therefore, the respondents are asked to focus on the most recent completed project, typical for the complex construction industry. The focus of the study on the causal effect result is explicitly mentioned in advance as further elaborated on in Appendix C. The decision to use the TOE scoring process is made since the TOE framework considers the technical, organisational and external risks as a natural source of complexity.

In addition, the TOE scoring process enables to explore if the risks that could be included within the complexity frame may cause influences on the project. In doing so, the participants are requested to score the complexity elements that have the potential to induce additional risks, based on their last completed project in the construction field. The respondents are giving scores by using the following scale: No (1), A few (2), Some (3), Several (4), Very much (5).

Part 2: Questionnaire
The questionnaire is developed based on the literary findings of the theoretical framework of Chapter 3 and Chapter 4. All the information obtained from the questionnaire is based on statements made by the practitioners. The total of ten survey questions, as further defined in Appendix C, are divided into three parts to build some structure. Open questions are used to not limit the respondents in their answers. Due to privacy, the sources in the report are not linked to the personal row number of the tables in Appendix C.

The questions of the first part of the survey are used as control variables. For instance, the respondents' background, experience into the field of complex construction projects and the most recent projects involved. The second part of the questions are related to the improvement of the current risk management process and the organizations' need. In this part it is asked if the respondent has ever experienced any lacks that can be linked to the incomplete understanding of the risk categories and/or sources of risks. Finally, the third part focuses the personal attitude of the respondent concerning the expansion of the current risk management process. In doing so, the practitioners are asked if they are willing to change their current risk management strategy when a significant relationship between complexities and risks could be explored. Besides this, the respondents are asked for recommendations on how the complexity elements could be processed more consistently within the boundary conditions of the existing risk management process.

5.1.2. Data analysis

Respondents
In this research, practitioners that are included in the survey are all employees from Drees & Sommer. The respondents are selected based on their background, function, availability and years of experience in the field of complex construction projects. Two approaches are used to select the participants of the exploratory survey: the structured method and snowball sampling. First, two project leaders employed at Drees & Sommer are contacted to set up the list of participants. Next, snowball sampling is applied to focus on those who supposedly have an interesting and clear perspective on the context of the study (Biernacki & Waldorf, 1981; Browne, 2005). In doing so, the selected participants are asked to recommend which employees of Drees & Sommer share a similar or different opinion.

The criteria and list of the participants can be found in Appendix C. Including the name of the respondents, the nationality, function and years of experience in the field. The background information is obtained before the survey started to verify if they meet the predefined participant criteria. Based on the average years of experience of the respondents (15-20 years), it is concluded that the respondents have considerable experience in the field of complex construction projects. Due to privacy reasons, the number of each participant on the list is not in coherence with the respondents numbers used in the analysis of Section 5.2.

Data collection
After defining the criteria, the number of respondents is established. To determine an appropriate amount of respondents, different guidelines are followed in the literature, varying from thirty to hundred respondents Amemiya (1981), Baarda and de Goede (2006) and Jansen (2010). In this research, 45 project professional are approached. With a total of 40 employees of Drees & Sommer that participated, a response rate of about 88.88 % is achieved.

The survey is developed and executed in Excel to create a straightforward and trouble-free survey format. The survey is sent to the participants through email. All data is gathered within four weeks. The survey was available between 1 July 2020 and 31 July 2020. The participants were sent a reminder on 22 July 2020. Before the survey was sent, the practitioners are asked friendly for their participation by a colleague of Drees & Sommer. This is done to increase the response rate and create commitment amongst the participants (Porter & Whitcomb, 2007).

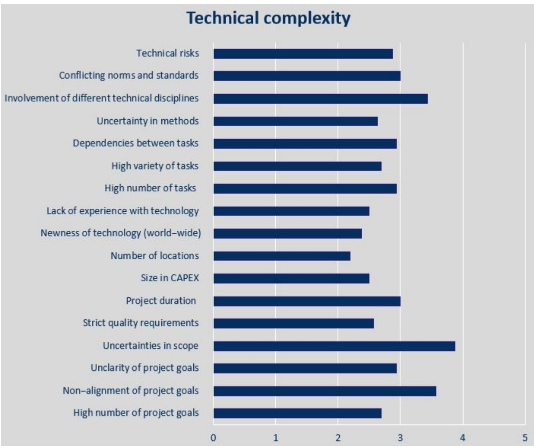
Data treatment

Qualitative analysis methods are used to transmit the gathered data from a written text or individual scores towards more accessible, understandable and precise figures and tables (Miles & Huberman, 1994). The survey data is analysed to support the results from the literary framework, consisting of the statement that complexity elements and risk-factors are supposed to have a causal relationship. After the complexity scores are given, the averages of the scores are calculated and prioritized according to these mean values. Next, the participants are asked if the current risk management process of Drees & Sommer is according to the user's needs and their personal attitude concerning the theoretical context of the study. The survey is not made anonymous to explore the differences between the project manager and risk manager's perspectives.

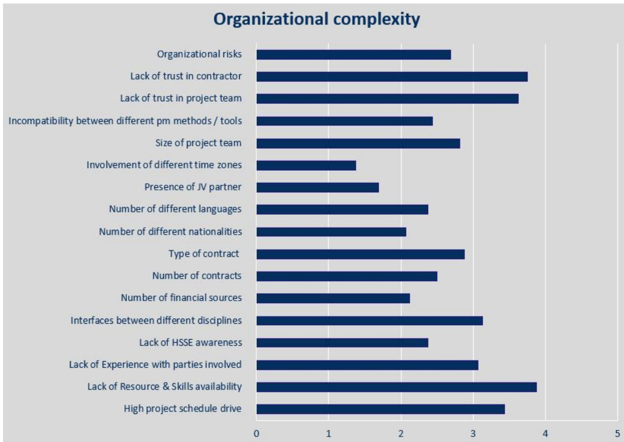
5.2. Using the TOE framework to explore the causal effect result between complexity elements and risk-factors

The results of the survey on the application of the TOE framework are shown in Figure 5.1. To enable a fair comparison, the normalized scores of the complexity elements in the technical, organisational and external categories are presented separately. The explanation of the average complexity scores are listed below:

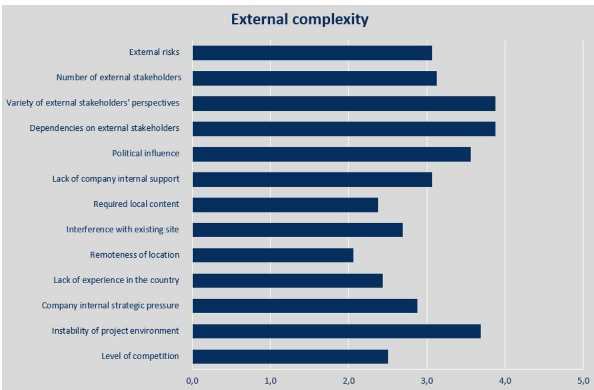
- A score of 1 means that 40 respondents indicated the complexity element induces "no" additional risks,
- a score of 2 means that 40 respondents indicated the complexity element induces "a few" additional risks,
- a score of 3 means that 40 respondents indicated the complexity element induces "some" additional risks,
- a score of 4 means that 40 respondents indicated the complexity element induces "several" additional risks,
- a score of 5 means that 40 respondents indicated the complexity element induces "very much" additional risks.



(a) Distinguishing the scores for the technical category, N=40



(b) Distinguishing the scores for the organisational category, N=40



(c) Distinguishing the scores for the external category, N=40

Figure 5.1: Characterising the survey findings on the application of the TOE framework per complexity category, displayed in averages scores

As can be found in Figure 5.1, the substantial majority of the elements are scored between 2 and 3. None of the respondents indicated that no additional effort was required of these complexity element during the risk management process. Only two elements are scored lower than 2.0 *(involvement of different time zones, presence of JV partner)*. The most often mentioned technical element is related to *Uncertainties in scope*. Next, the most frequently referred organisational element is *Lack of Resource & Skills availability*. The most often mentioned external element includes the elements *Variety of external stakeholder's perspectives* and *Dependencies on external stakeholders*.

Furthermore, the data is divided into a risk manager respondents group (N=20) and a project manager respondents group (N=20). The results of the significant difference between the respondents groups can be found in Table 5.1. Interestingly, project managers consider organisational aspects of complexity as having the highest causal effect on risks. Reason for this could be that project managers are more concerned about the interfaces within a project (e.g. in- and external organisational areas and relationships between people). Due to the fact that the organisation of their own project team is partly determined by the risk areas and capabilities of the project team members. On the other hand, using the higher scores of: *Project duration, dependencies between tasks, uncertainty in methods, interfaces between disciplines, political influence and instability of project environment*, the risk manager were more focused on reducing the probability and mitigating the impact of risks by communicative processes and risk policies.

Technical complexity	Average score Risk manager	Average score Project manager
High number of project goals	2,2	3,3
Non-alignment of project goals	3,8	3,5
Unclarity of project goals	2,7	3,0
Uncertainties in scope	3,3	4,0
Strict quality requirements	2,3	2,9
Project duration	3,4	2,8
Size in CAPEX	2,6	2,4
Number of locations	2,1	2,4
Newness of technology (world-wide)	2,7	2,2
Lack of experience with technology	2,4	2,6
High number of tasks	3,6	2,8
High variety of tasks	3,4	2,7
Dependencies between tasks	3,3	2,9
Uncertainty in methods	2,3	2,6
Involvement of different technology disciplines	3,5	3,7
Conflicting norms of standards	2,9	3,2
Technical risks	3,0	3,2

(a) Cumulative elements scores for the technical category, N=40

Organizational complexity	Average score Risk managers	Average score Project manager
Lack of trust in contractor	3,4	2,9
Lack of trust in project team	3,5	4,0
Incompatibility between different pm methods/ tools	2,2	2,7
Size of project team	2,0	3,2
Involvement of different time zones	1,2	1,5
Presence of JV partner	1,9	1,6
Number of different languages	2,3	2,7
Number of different nationalities	2,0	2,3
Type of contract	2,8	3,0
Number of contracts	2,7	2,4
Number of financial sources	2,3	2,0
Interfaces between different disciplines	3,5	3,0
Lack of HSSE awareness	2,4	2,4
Lack of experience with parties involved	2,9	3,2
Lack of Resource & Skills availability	3,7	4,0
High project schedule drive	2,9	3,1
Organizational risks	2,8	3,3

(b) Cumulative elements scores for the organisational category, N=40

External complexity	Average score Risk manager	Average score Project manager
Number of external stakeholders	3,3	3,0
Variety of external stakeholder's perspectives	3,9	3,9
Dependencies on external stakeholders	3,8	3,9
Political influence	3,8	3,3
Lack of company internal support	2,4	2,5
Required local content	2,5	2,4
Interference with existing site	2,7	2,3
Remoteness of location	2,2	2,2
Lack of experience in the country	2,4	2,5
Company internal strategic pressure	2,7	3,2
Instability of project environment	3,9	3,7
Level of competition	2,4	2,7
External risks	2,6	3,1

(c) Cumulative elements scores for the external category, N=40

Table 5.1: Summary of the survey findings on application of the TOE framework per complexity category, distinguishing the average scores of the Risk manager group (N=20) and average scores of the Project manager group (N=20)

Overall, the perspectives of the risk managers and project managers show small differences. The risk manager perceives the causal effect of complexities on risks generally lower. In doing so, the answers of the risk managers are reflecting the causes rather than the consequences. The reason for this might be that risk managers focus on cause-event relation and not so much on probability and impact of the risk. On the other hand, project managers are more focused on the consequences of the causal relationship, the event-consequence relation.

The validation of the TOE framework in a previous study by Bosch-Rekveldt et al. (2011) shows the importance of treating particular aspects of project complexity with risk management. Based on how the respondents scored and perceived the causality, this empirical study confirms this. All the respondents indicate that the elements that contribute to the complexity also could have the potential to increase the probability of additional risks. This is in line with the conclusions of Section 4.4, which indicates how the interdependency between project complexity and risks are treated in the literature.

5.3. Findings of the practical perspectives

Part 1: Improving the current risk management process of Drees & Sommer
The answers to the open questions provide very varied insights. The questions of this part are related to improving the existing risk management approach of Drees & Sommer. To analyse the perspectives, a categorization is delivered based on rough interpretations of the data and comparisons in the data. Subsequently, all views of the respondents are assigned to the categories in Table 5.2.

Perspectives related to improving the current risk management process of Drees & Sommer	Number of appearances
Create more structure and practical guidance	9
Higher awareness of external sources of risks	9
Make it more user-friendly and efficient	8
Encourage original thinking and interaction within the team	7
Better allignment with different disciplines	4
Repeat the process several times in the project life cycle	3
No opportunities to improve the current risk management process	3
Questions not well understood	2

Table 5.2: Summary of the survey findings on improving the current risk management process of Drees & Sommer

During the survey, most respondents suggest to create more structure and practical guidance by *"Working with standardized tools, so not everyone works with their own methods and documents"*(Participant 15), *"More guidance in identifying risks, since this provides opportunities to determine appropriate measures "*(participant 14), *"It is impossible to foresee risks if a risk management process consists of lots of loose ends, because then the client keeps changing his mind and keeps mingling in the project management issues."*. The potential improvement is also confirmed by *"Everything that makes the management of risks more transparent, comprehensible and touchable is welcome"*(participant 10) and *"The risk management process needs a more structured guide that serves as a filter for the detailed risks afterwards"* (participant 11 and 29).

Other respondents indicate to pay more attention to the external sources of risks by *"Very often only the internal risks are considered as the risk management approach is supported by tools as risk registers and/or dashboard reports"* (participant 2 and 7), *"There is a broad variety of risk-factors missing while discussing the identified risks with the client"* (participant 12), *"We have seen issues coming from missing risk-factors like cutting edge technologies or inexperienced local team"* (participant 3) and *"By adding specific characteristics of the project we should be able to predict better the outcome of our (future) decisions"* (participant 17). Thus, rather than reducing risks, accept the existence and try to enhance the risk data.

A few respondents suggest *"If the risk management process becomes more visually, it is more likely that people actually gonna use it"*(participant 3), *"Create a quick-scan for the graduation in the low and the high risks"* (participant 33), *"Provide an image on each complexity topic and the possible risks "*(participant 27), *"Always good to have a clearer guidance and view on the risks"* (participant 18) and *"Give a better sight of the client's wish"* (Participant 38). Other respondents mention a structured risk management process is missing because *"Internal risk management depends on the experience of the project manager and the project participants rather than providing an overview of potential risks."* (participant 28) and *"Risk management is now very diverse, because it depends on the client's wishes. "*(participant 27). In addition, the potential improvement for a structured guidance are linked to standardization, efficiency, less time-consuming and formalizing the available tool kits (participant 4, 7, 18, 23).

Other respondents see the opportunity to enhance the user-friendliness and efficiency by *"If the process is clear and concise then it is easy for people to understand and react upon it"* (participant 30), *"The risk management process needs to be understandable for everyone and provide a simple input mask of the predefined risks "*(participant 22 and 40). According to participant 8 and 9, the risk management process needs to be more result-oriented, since this encourages the client to spend more resources on risk management and not skip the topic or mitigate the subject.

Some respondents see the improvements in the alignment within the project team and amongst the stakeholders by *"To avoid post project discussions, create a clear starting point for all parties so those demarcations can be set up against contract value and time "*(participant 18). This is also reflected by participant 15: *"Risks increases due to the many uncertainties within the goals and methods between stakeholders that evolve in projects "*. Only participant 24 pointed out to encourage original thinking by *"Useful to let every manager think further than what they would normally do "*.

During the survey, a few respondents stress the importance to repeat the risk management process more times in the project life cycle by *"We have a solid base with our guideline and special audits, but continuous improvement in the progress is sometimes missing "* (participant 1) and *"Project risk management should be included per phase"* (participant 11). The respondents seem to realize that the management of risks is not only favourable in the early project phases but needs to be repeated several times during the project life cycle. However, in the view of three respondents, no improvement is necessary to the current project risk management process of Drees & Sommer by *"The current risk management process already includes all the required steps. Identifying risks, determining the strategy to handle the risk, carrying out risk strategy, evaluate strategy and if necessary adjust strategy "* (participant 14) *"I would describe our risk management process as very sufficient "*(participant 17). Besides this, two responses are linked to the perspective "Questions not well understood".

Part 2: Expanding the current risk management process of Drees & Sommer
The questions of this part are related on expanding the current risk management approach of Drees & Sommer. To analyse the perspectives, a categorization is delivered based on rough interpretations of the data and comparisons in the data. The answers to the questions are categorized in Table 5.3. All the respondents express a positive view on expanding the risk management process. A few times, it is linked to increasing the attention of risk management at the start of the project. *"There should be more attention to potential sources of risks at the early stage of the project, since this can minimize the (negative) influences and requirements on a project"* (participant 4, 5 and 36).

Perspectives related to expanding the current risk management process of Drees & Sommer	Number of appearances
Include lessons learned from previous projects	16
Integrate elements that contribute to the complexity of the project	11
Integrate with stakeholder management	6
Incorporate systematic attention	4
Increase the attention at the early stage of the project	3
No opportunities to expand the current risk management process	0
Questions not good understood	0

Table 5.3: Summary of the survey findings on expanding the current risk management process of Drees & Sommer

Most of the respondents mention the need to integrate experiences from previous projects by *"There is currently medium attention to integrate experiences"* (participant 3) and *"A checklist and recommendations based on experiences are beneficial for projects "*(participant 11). The missing concept of experiences is also expressed by *"Focusing on horizontal interactions and experiences benefits a project in various ways."* (participant 9), *"The risk management process should more learnfrom previous projects and serve as a tool to identify the risk-factors for new projects"* (participant 16) and *"Internally we should more learn from previous projects, because a client expects you to manage all the risks"*(participant 25). This is confirmed by participant 10 *"Additional information based on experiences are very useful for long, expensive and technically challenging projects with an inexperienced owner and lots of stakeholders."* and participant 21 by *"Most of the time I included an inventory of risks based on my own knowledge and experience, since this is missing in the standard risk management process"* (participant 21).

Some respondents mention they are willing to expand the risk management strategy when a significant relationship between complexity elements and risk-factors was identified by *"The complex characteristics of a project should* *be included in our existing toolings and risk workshops"* (participant 17). This is confirmed by *"The concept of complexity can be easily part of (phase)-reports in the design and construction phase"* (participant 19) and *"We have risk assessment scorecards where crucial complexity details could be included"* (participant 6).

During the survey, some respondents see the benefits of integration with stakeholder management by *"The risk assessment in combination with the pre-design gives us additional information to manage stakeholders"* (participant 23) and *"Managing the external stakeholders early on in the project reduces the negative influences of these stakeholders"* (participant 33). Others suggest *"Give a better indicator on which areas to focus on, before it can be discussed with the client or even internally "*(participant 3), *"If stakeholder management is included in the risk strategy, the output to client or contractor is better to comprehend "*(participant 26) and *"Additional risk information should be implemented within the project kick-off with internal and external stakeholders "* (participant 39).

Some respondents seem to realize that risk management needs systematic attention. *"Uncertainties are very underestimated in projects, and it would be of added value for Drees & Sommer to expand the management of risks prior to the start of the project, but also early on during the realization."* (participant 23) and *"The risk management process needs to be linked to the recurring tasks with a task management tool (e.g. "to-do" planner), so it can be used as a simple regular reminder to check and update the risk management process"*(participant 35). The advantages of this systematic awareness is also confirmed by *"Create an organized approach that reflects the complexity and highlight areas that should be considered with more care "*(participant 18) and *"Make a complete integral plan to finish the process phase by phase and avoid changes"* (participant 28).

Others indicate a better management of risks at the early phases of the projects. To achieve alignment along the stakeholders, the respondents highlight *"When identifying risks at the start of the project it is necessary to determine a strategy with all the internal stakeholders within the project (design team, project manager, client etc.)"* (participant 33). According to participant 8 and 24, a strong focus on the collaboration between the stakeholders, contractor and clients is the solution to deal with increasing complexities. Here, a link is perceived between risk management and stakeholder management.

Finally, it is essential to notice that no respondent did not know the answer to any questions or answered the questions with "No opportunities to expand the current risk management process". In general, the statements derived from the survey show the advances for actual application of expanding the risk management process.

5.4. Overall conclusions

In addition to the literature study, the exploratory survey is performed to explore how practitioners perceive and manage the causal relationship between complexity elements and risk factors. Besides this, it also investigates how the current risk management process of Drees & Sommer can be improved and/or expanded. Therefore, a company survey with experts of Drees & Sommer is organised. In doing so, the different viewpoints and attitudes of experts are obtained. The information collected from the previous sections is linked to answer the second sub-question:

> *RQ2: How is the causal relationship between complexity elements and risks perceived and assessed in the risk management process?*

Previous empirical research has focused on understanding the practices of managing complexity in projects (Koppenjan et al., 2011; Saunders et al., 2015; Qazi et al., 2016). However, the current practice about perceiving and assessing the causal effect between complexity elements and risk-factors of complex construction projects has not been investigated. Furthermore, it is crucial to explore whether the practitioners encourage a potential improvement and/or expansion of the existing risk management process. The empirical findings of this study are original in terms of exploring if practitioners experienced the causal effect of complexity elements on risk-factors in their last completed project.

Overall looking at the routine analysis of the answers in Figure 5.1, all participants seem to experience that complexity elements seem to contribute to additional risks. In other words, the respondents recognize the causal effect of complexity elements on risk-factors. Based on this, it is concluded that the interdependency between project complexity and project risks is supported. In addition, these result are in line with the realisation of several studies by considering complexity elements as a cause of risk-factors and the need for integrating these together (Geraldi et al., 2011; Bosch-Rekveldt et al., 2011; Qazi et al., 2016; Williams, 2017; Emblemsvåg, 2020).

Although the causal effect scoring results indicate that all complexity elements cause or contribute to additional risk-factors, they do so in different levels. Nonetheless, it is expected that one complexity element could induce more additional risk-factors than another in a given project. Despite this, the aim of conducting empirical research is not to provide a list of complexity elements that have the highest potential to induce additional risks repeatedly. The reason for this is that each project is unique and, certain events would influence the strength of the relationship. A more elaborated survey should be organized to build the causal relationship between complexity elements and risk management by taking the opinions of the experts.

During the survey, the perspectives of the risk managers and project managers show small differences. The risk manager perceives the causal effect of complexities on risks generally lower. In doing so, the answers of the risk managers are reflecting the causes rather than the consequences. The reasons for this might be that risk managers focus on cause-event relation and not so much on probability and impact of the risk. When addressing the risks to the response, the risk manager would always try to reduce the probability of risks rather than accepting the probability and just try to mitigate the impact. On the other hand, project managers are more focused on the consequences of the causal relationships and the event-consequence relation. Based on this, it can be concluded that the project manager would try to reflect on the risks and further explain the strategies to reduce the impact.

In view of the practitioners of Drees & Sommer, there is a positive attitude towards further improvement and/or expansion of the current risk management process, as further recommended in Section 9.2.1. In Table 5.4, the statements derived from the questionnaire are formulated into practical objectives and requirements. The purpose of this is to enable the researcher to develop a complexity driven risk management approach in Chapter 6.

Perspectives related to improving and/or expanding the current risk management process		Practical objectives and requirements for the complexity based risk assessment technique (CBRAT)
Create more structure and practical guidance	Make it more user-friendly and efficient	→ Logical steps, user-friendly and suppress unnecessary detail
Encourage original thinking and interactions within the project team		→ Encourage original thinking and interactions within the project team
Integrate elements that contribute to the complexity of the project		→ Integrate elements that contribute to the complexity of the project
Include lessons learned from previous projects		→ Include lessons learned from previous projects
Integrate with stakeholder management	Higher awareness of external sources of risks	→ Create a more realistic view of the impact of the risks on a particular project

Table 5.4: Directions for solving project risk management problems from project managers and risk managers perspectives

During the set up of the survey, attention is paid to the formulation of the procedure to prevent unclear and ambiguous questions. Nonetheless, some comments are made on specific sentences that still consisted too less or too much excess meaning. By giving the participants the opportunity to contact the researcher if the reasoning was unclear, it is expected that the degree of misunderstandings is limited. However, since the researcher describes and interprets each answer, some bias is to be considered. The bias as a result of misinterpretations could have been solved by interviews. On the other hand, the gathered data of a survey is more objective, the actual data collection takes less time and it is easy to access targeted respondents.

A critical note should be made regarding the content of the exploratory survey, it is suggested to better explain what complexity elements and risk-factors of projects stands for, including the theoretical background and examples of the relationships in between. Besides this, it is suggested to add extra focus on the complexity elements: *technical risks , organizational risks and external risks*, since these are considered to be a natural source of complexity. The limitations of the exploratory survey and the validity is further discussed in Chapter 8.

6
Designing the Complexity Based Risk Assessment Technique (CBRAT)

In support of the main research question, this chapter introduces an approach to build a one-way bridge from complexity assessment to risk management tasks. First, the limitations of the existing project's risk management procedure are discussed in Section 6.1. Next, the objectives and requirements are laid out in Section 6.2. Following that, the starting points for the proposed Complexity Based Risk Assessment Technique (CBRAT) are further elaborated on in Section 6.3 to end with the conclusions in Section 6.4 by answering the third sub-question of this research.

6.1. Limitations of the traditional risk management procedure

From the literature study and exploratory survey, it becomes clear that the risk management process has difficulties with processing the larger degree of complexity. Most projects using risk management are likely to assist the risk management procedure with a risk register. Although there are many benefits, the risk registers appear to be based on the impractical assumption of complexity elements being independent from risks. However, this is inadequate for complex construction projects, since the effect of two risk-factors might be more than the sum of the two individual risks. As a result, managers are unable to accumulate the knowledge necessary for understanding all the essential influence factors that produce risks.

Therefore, changes should be made for project managers to provide a more realistic view on the total impact of the risks on a project. The integration of complexity assessment into the risk management process could be a solution for this. The reason for this is that if the risk management processes do not succeed a complexity assessment, risk management and analysis would not include the relationships between complexity elements and risk-factors, which in turn leads to incomplete and misleading conclusions regarding the risk mitigation actions.

6.2. Defining the objectives and requirements of the CBRAT

Using the limitations mentioned above helps to define the scope of the new approach to risk management based on complexity assessment. This is done by distinguishing the results of the literature study of Chapter 3 and Chapter 4 and the exploratory survey of Chapter 5. In doing so, the theoretical objectives and requirements are summarized in Table 4.2 and the practical objectives and requirements are listed in Table 5.4.

Theoretical objectives and requirements
Although several researchers have investigated techniques and theories for supporting risk management, there is still a gap between practice and theory. Therefore, it is required to refine the existing tools that practitioners use to encourage them to apply the new technique. Consequently, the expansion of the traditional risk register is to be included in the new technique (Ackermann et al., 2007). The reason is that the maintenance of the risk register is a requirement of the PMBoK standards and therefore has been used extensively for many years in practice (PMBOK Guide, 2017).

As underlined by Emblemsvåg (2020), the current problem of the risk management approach can be solved by including personal experience, human intuition, knowledge and judgement of experts. This is in line with the findings of this study and the results of several other studies (Uher & Toakley, 1999; Baker & Sinkula, 1999; Raz & Michael, 2001; Lyons & Skitmore, 2004; Dikmen et al., 2004).

Moreover, organisations need to deal with the larger degree of complexity and the increasing risk-factors of future projects. Instead of focusing on individual risk items, it becomes even more important to structure the risk-factors and their sources. The reason for this is that the current technological and economic advances make production, communication and transport ever more complicated. As a consequence, project managers interact with even more organisations, people, systems and objects. Therefore, the new technique needs to decompose the risk-factors into subcategories, since this enables to better analyse the probability of the risk-factors, as well as their impact on one another.

Instead of looking for opportunities to enrich the implementation of risk management with a complexity based perspective, the complexity is treated in isolation in the construction industry (Zhang & Fan, 2014; Fan et al., 2015; Böhle et al., 2016). As a result, an increased focus on elements that contribute to the complexity of a project is required. In doing so, the new technique needs to give project complexity a more prominent position within the risk management process by refining the link between complexity assessment and risk assessment tasks.

Another important requirement consists of including the direct and indirect inducement of risks from complexity (Vidal et al., 2011). The reason for this is that breaking down the complexity features enables to produce more relevant risks. On the one hand, the direct-induced risks are the risk-factors that are considered to be directly inferred from complexity elements and create unexpected events. Most of the time, these risks were already identified in the risk register. On the other hand, the indirect-induced risks are the risk-factors that can be indirectly explained by the means of other risk-factors. These risks are considered to affect the project objectives.

Practical objectives and requirements
From the exploratory survey, it became clear that practitioners do not use the available tools extensively. Instead, they prefer to identify risks in a rather personalised and inefficient way by losing as little as possible of their work time. This problem can be solved by inspiring the client to spend more resources on risk management, rather then mitigating the subject. Therefore, the risk management procedure is to be improved by an increased orientation towards the results, by requiring less time, better alignment and encouragement of original thinking and interactions within the team. Besides this, several practitioners related the expansion of the risk management procedure to including logical steps, suppress unnecessary details and the increased focus on the elements that contribute to the complexity of a specific project. Others mention to pay more attention to the integration of experiences from previous projects. Therefore, the new technique needs to accept the existince of the relationships between complexities and risks and try to understand the dynamic behaviour, rather than reducing the risks.

6.3. Starting points of the CBRAT

Based on the objectives and requirements, the CBRAT is developed. The flowchart of Figure 6.1 gives an overview of the starting points for the combination of steps used in the CBRAT.

Step 1: The CBRAT starts with becoming more aware of the complexity characteristics of a project. To detect the sources of the complexity of a particular project, this study refers to the TOE framework previously developed by Bosch-Rekveldt et al. (2011). The TOE suggests three forms to grasp project complexity, where all elements are assigned to either the technical, organisational or external category. The CBRAT benefits from the TOE scoring process in order to provide an extensive list of categories where complexities could be expected.

After completing the TOE framework, the elements that are expected to contribute to the complexity of the particular project can be dealt with early in the project. Depending on the initial complexity footprint, an extensive list of categories where (potential) risk-factors are expected to arise can be provided. The application of the TOE framework, however, is not limited to exploring (potential) risk-factors. The increased awareness of anticipated complexities of the particular project can also be beneficial to strengthen control and monitoring areas.

Step 2: Once the perceived complexity of a project is assessed, the CBRAT aims to focus on clustering on risks. The reason for this is that the risk register only provides one cause and one relationship, because the risk register only classifies individual risks. However, multiple risk-factors have multiple causes. Thus, instead of solving each individual cause-event relationship with one response, one response can reply for multiple cause-event relationships. Otherwise, only one cause is considered at a time, which in turn leads to incomplete and misleading formulation of the responses.

Due to the requirements that the CBRAT need to be compatible with other widely used risk management tools, the traditional risk register is combined with a RBS. The RBS approaches the risk register on different levels by relating multiple risk-factors to causes. In doing so, the RBS enables to decompose the risks into sub-categories and record generic risks which occur frequently as lessons learned for future reference. Once the relationship is better understood, the probability and impact of the risks and their consequences can also be investigated to improve the project performance.

The use of RBS in combination with a risk register increases the level of detail of the identified risks. The lower level risks form the basis of the risk register which needs further investigation. At the same time, the higher level risks allow to make appropriate interconnections between the risks. Thus, the useful information to investigate the relationship between complexities and risks and vulnerable points of the risks can be found at the highest level of the RBS.

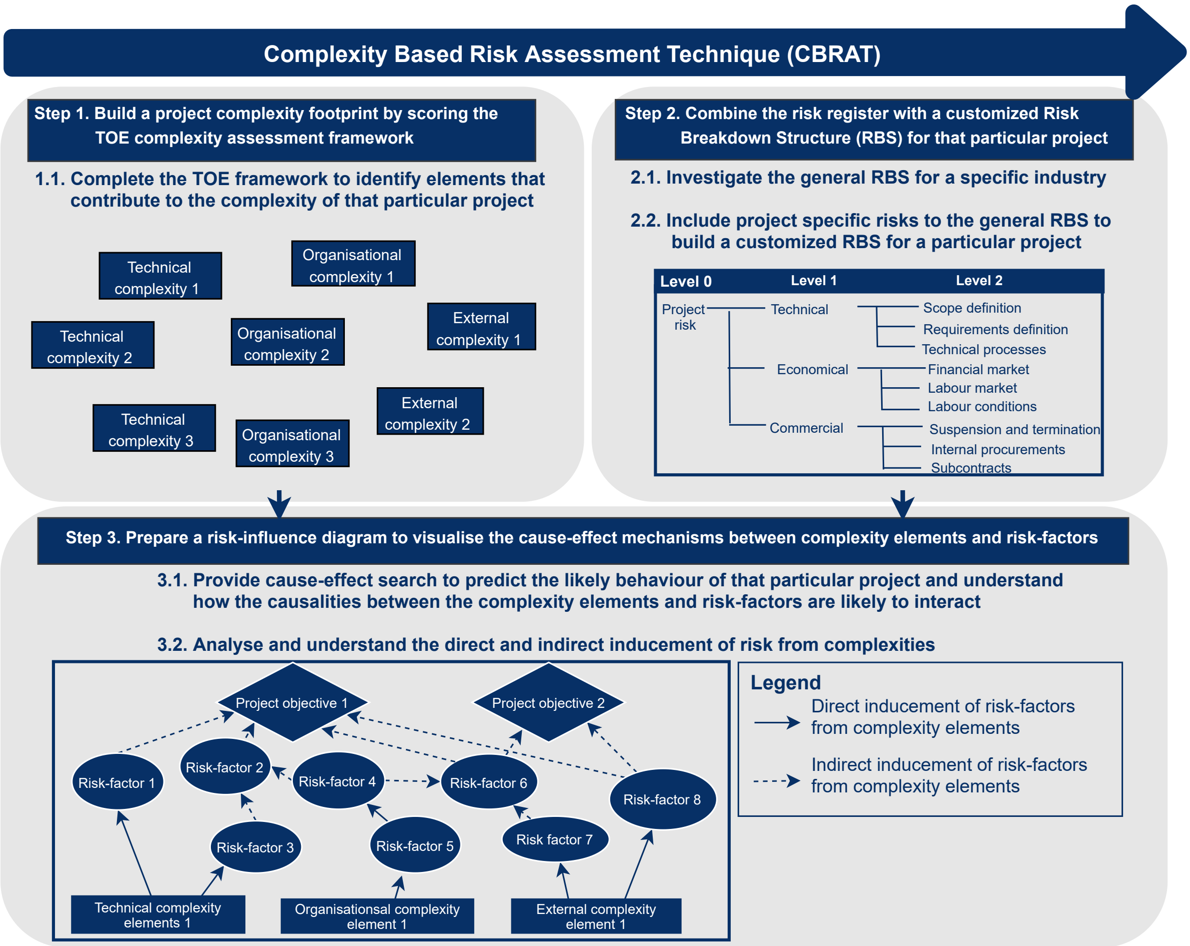


Figure 6.1: Process to introduce a new approach to risk management based on complexity assessment

To continue with the application of the RBS in practice, it is crucial to notice that risk management should not be performed on the basis of one previously developed RBS. However, it is impractical to totally redevelop the RBS for every new project. Therefore, the use of a general RBS for a specific construction industry is more feasible. In doing so, the general RBS enables to record generic risks which occur frequently based on previous experiences and lessons learned.

In addition, the project manager can customize the general RBS by adding specific characteristics unique on the project. In practice this means that the general RBS aims to reveal the risk-factors which frequently occur. While on the other hand, the goal of the customized RBS is to provide unique insights into the effect of the risks on different aspects of the project. Based on the customized RBS, the project manager can detect the risks and their sources that would most probably occur in that particular project.

Step 3: Finally, the CBRAT prefers to benefit from the risk-influence diagramming technique. The idea of an influence diagram is conceived to encourage thinking about the way in which risks can be traced back to their original source. As a consequence, the risk-influence diagram is valuable to provide insights on the critical complexity elements and risks with associated interdependency (Raz & Hillson, 2005). This is beneficial, since some risks are directly inferred from the complexity elements, and some risks are more indirectly inferred. In other words, the impact from the relationships between complexities and risks might compound the impact of other risks.

In addition, the risk-influence diagram provides CE search in order to trace how the causalities are likely to interact. In doing so, multiple risk-factors can be linked to causes and multiple causes to risk-factors. This creates a network of possible interrelated complexity elements and risk-factors. Based on the complexity-risk pairs that cause the same effect, the complexities and risks are expected to have a causal relationship between them. As a result, the risk-influence diagram enables to capture how complexities cause and/or contribute to the likelihood of additional risks and evaluate the consequences on the project objectives.

6.4. Conclusions

Although considerable attention had been paid to consider the complexity of projects as a source of risks and integrating these together in literature, there is no solid framework originating in both theory and practice that captures the cause-effect mechanisms between complexity elements and risk-factors. In order to address the aforementioned issue, the third sub-question of this research is answered:

RQ3: What effective technique can be applied by practitioners to capture the cause-effect mechanisms between complexity elements and risks in the risk management process?

After careful consideration the CBRAT is designed, and it can be concluded that the CBRAT strengthens the risk assessment capability by introducing the following three tools; the TOE framework, the Risk Breakdown Structure (RBS) and the risk-influence diagram. As mentioned earlier, the TOE framework provides an extensive list of categories where complexities could be expected to arise. In doing so, the TOE framework enables scaling and putting more or less emphasis on certain complexity elements in order to come up with a risk management approach that is the most suitable for a project, given the unique circumstances of that project (incl. the industry requirements).

After the complexity assessment, the traditional risk register is also combined with a RBS. The combination of these tools aims to decompose and structure the risk-factors into sub-categories. As a result, this provides the opportunity for a project manager to record generic risk-factors which occur frequently as lessons learned for future reference. Finally, the CBRAT prefers to benefit from the risk-influence diagram in order to trace the direct and indirect inducement of risk-factors from complexity elements. The visualisation of the causal effect enables to understand how the causalities between the complexities and risks are likely to interact and their consequences on the project objectives.

Futhermore, Figure 6.2 shows how the CBRAT can be easily incorporated during the implementation of risk management in practice. The risk management process is defined according to the PMBoK Guide (PMBOK Guide, 2017). The closed control loop start at the beginning of the process, in which the risks identified in the risk identification phase and analysed in the risk assessment phase has to be updated continuously. In case new risks are identified or deviations occur, the feedback loop cycle start a new loop. As a consequence, the combination of the risk register with the CBRAT assists the decision-making and the determination of the risk response and risk monitor strategies.

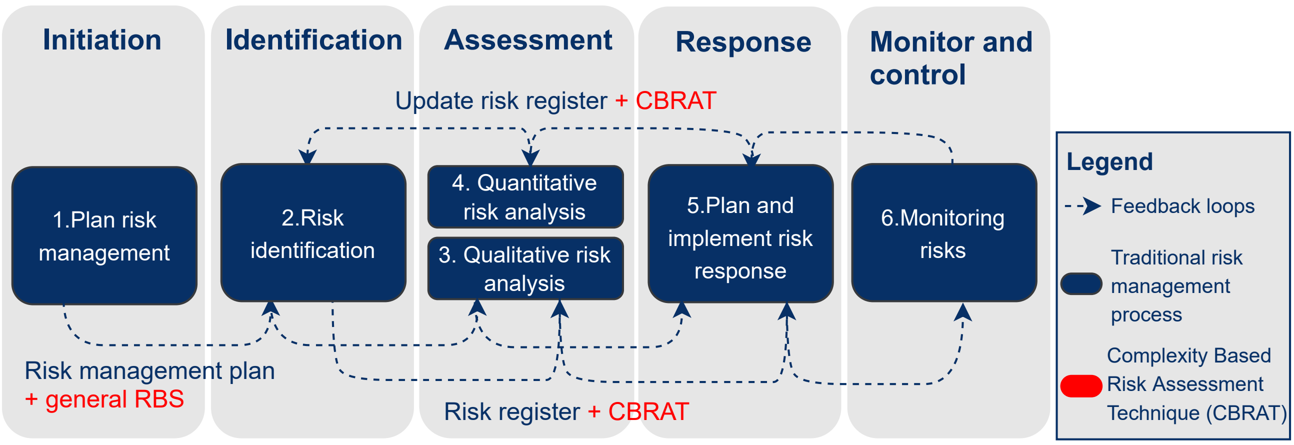


Figure 6.2: The CBRAT (visualised in red) is positioned within the traditional risk management process (visualised in blue) and the dashed lines indicate the feedback loops.

A note should be made that this study does not try to generalise the cause-effect mechanisms between complexity elements and risk-factors. Instead, it tries to develop an effective technique that supports practitioners to trace the direct and indirect inducement of risk-factors from complexity elements within the context of their projects. The reason for this is that each project is unique and therefore certain events would influence the strength of the interconnected variables differently. Further recommendations for implicating the CBRAT in practice can be found in Section 9.2.

In the next chapter, the CBRAT is applied to the FA Terminal 3 project to test the applicability on a real life complex construction project, and in turn prove the feasibility and practicality of the CBRAT.

III

Results

7 Testing of the CBRAT through a pilot study

In this chapter, the CBRAT as designed in Chapter 6 is tested on a real life construction project. First, the pilot project - the Frankfurt Airport (FA) Terminal 3 project - is introduced in Section 7.1. Second, the pilot study is set up in Section 7.2. Next, the pilot study is applied in Section 7.3. After that, the limitations are discussed in Section 7.4. Finally, the achievements in terms of risk management are evaluated in Section 7.5 to end with the final conclusions in Section 7.6.

7.1. Description of the Frankfurt Airport (FA) Terminal 3 project

Today the FA is an infrastructure relic that is more than 80 years old, yet it is the most traveled airport out of Germany and the busiest airport in Europe by cargo traffic. The airport is one of the biggest infrastructure works in Germany and stretches for a total of 2,300 hectares underground. With a usage of 65 million passengers per year and only four runways, it is well past its designed capacity (Zielonka, 2016). Subsequently, the total capacity of the terminal is to be increased with three piers (Pier H, J and G) to assure the Frankfurt location as an international hub.

Figure 7.1 illustrates the two existing terminals of FA with the new terminal 3. With the project being approximately 2 billion euros (incl. infrastructure around the new terminal), it could be characterized as a large scale project. The German transport company Frankfurt Airport Services Worldwide (Fraport) is responsible for the operation of FA and therefore the owner/client of the Terminal 3 project. To ensure integration of such a large project, the future independent project company Fraport Aufbau Süd (FAS) was established by Fraport. As main contractor, FAS is responsible for the overall construction of the FA Terminal 3 project. Furthermore, Drees & Sommer is involved as competition coordinator and program planner through an overall project management contract. The requirements of the tender documents are compiled in collaboration with Netherlands Airport Consultant (NACO).

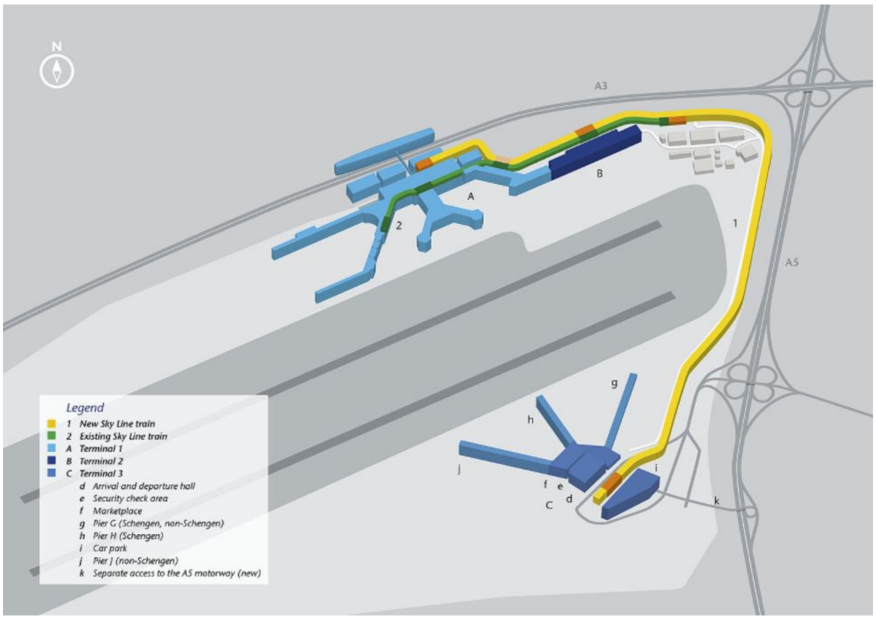


Figure 7.1: The new terminal 3, built on the south side of Frankfurt Airport (FA) (Frankfurt Airport, 2020)

To continue with the progress and the planning recorded up to now. The overall construction contains two phases, which are separately procured under the design-build contract system. The first phase consists of the main terminal building with departure and arrival levels, lounges for a passenger volume of 14 million, automated baggage systems and piers H and J. The start of operations for the first phase is currently projected in 2023 (Frankfurt Airport, 2020). Whereas, the completion of the second phase (construction of pier G) is expected in 2025 (Scheinhütte, 2020).

7.2. The methodology used in the pilot study

The pilot study design, as visualised in Figure 7.2, is established to examine if the CBRAT is effective for practitioners to capture the cause-effect mechanisms between complexity elements and risk-factors. In doing so, the FA Terminal 3 project is selected, since Drees & Sommer has been responsible as competition coordinator and program planner from the initiation phase (2001) to the completion (expected in 2023). The almost completed project has appeared to possess various complexities, as further elaborated on in Appendix D. The information is obtained through project documentation, sources of the internet and from three experts involved in the project.

The approach of the pilot study, as visualised in Figure 7.2, is different in the first step of the CBRAT, as visualised in Figure 6.2. The pilot study only focuses on step 2 and 3 for the reason that the research time is limited and the FA Terminal 3 project is already in the execution phase. Despite this, the complexity characteristics of step 1 are shortly noticed.

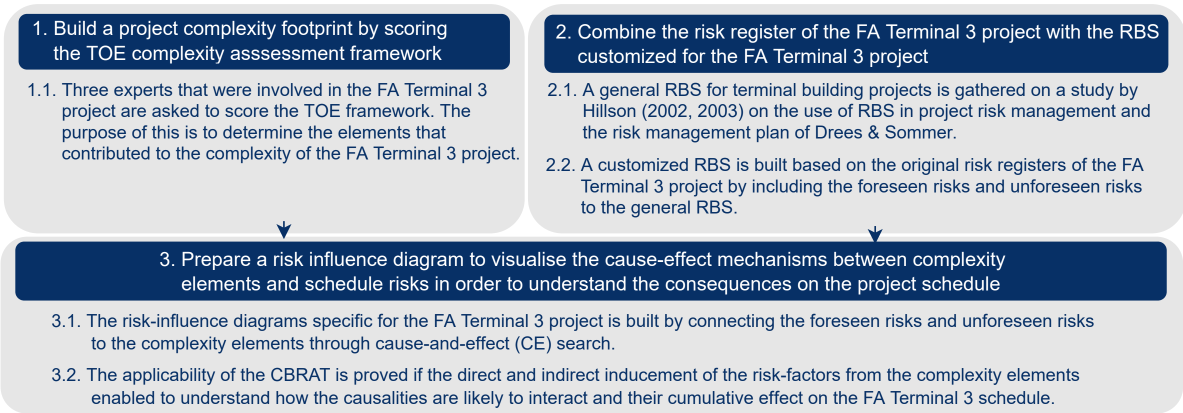


Figure 7.2: Process to test of the applicability of the CBRAT on the Frankfurt Airport (FA) Terminal 3 project

Furthermore, the feasibility and practicality of the CBRAT are believed to be met if a causal relationship between the complexities and risks can be identified. Therefore, the pilot study focuses on the implementation of risk management. In case of the FA Terminal 3 project, the risk identification phase started with brainstorm workshops. After that, the results of the risk workshops were recorded in the risk register, which was valid during the design phase.

To test of the applicability of the CBRAT, the risk register which was valid during the construction phase (see Appendix D) is used. The reason for this is that during the design and construction phase, the risk register was continuously updated by Drees & Sommer. In doing so, several measures were taken against the risks that appeared as negative counterparts in terms of schedule objectives. These measurements and effects on the schedule were listed in the risk register which was valid during the construction phase. Therefore, the risk-factors that were supposed to be valid on the schedule of the FA Terminal 3 project are categorized as follows:

- *Foreseen risks* are the risks that were identified in the design phase and therefore entered to the risk register which was valid during the design phase.

- *Unforeseen risks* are the risks that were not identified in the risk register which was valid during the design phase and therefore entered to the risk register which was valid during the construction phase.

7.3. Application of the CBRAT

The applicability of the CBRAT is tested by implementing each of the steps as further elaborated on in Figure 7.2.

Step 1.1: Complete the TOE framework to identify elements that contribute to the complexity of that project
First, the TOE framework is scored by three experts involved in the FA Terminal 3 project. Based on this, ten complexity characteristics unique to the project are selected. Each of them is further elaborated below:

- *Strict quality requirements*; challenges arose due to the special approval procedure that was required for such an unregulated special construction. To give an example of an unexpected event that influenced the schedule, there were some additional requests to the aircraft mix due to changes in the International Civil Aviation Organisation (ICAO) guidelines and some additional requirements to the infrastructure as a result of Skytrax (global airline quality rating).

• *Long project duration*; other major problems arose due to the long period between the invitation to tender and construction. The detailed planning started in November 2001 and was specified at the end of 2017. The completion is expected in the end of 2023. To give an example of an unexpected event as a result of the long project duration, the construction planned first could not be started on time since legal provisions and framework conditions changed.

• *Multiple tasks*; the number of tasks of such a major airport elevation project could always be extended. One of the major tasks required for successful project completion consisted of as less hinder as possible to the daily operations of FA.

• *High project schedule drive*; all execution work needed to be done in the agreed time spans, since every misalignment or delay would have an effect on later activities. To name a few examples of unexpected events as a result of the high project schedule drive, the required time of flight Operation (ORAT) was incorrectly implemented in the detailed planning and execution needed to be start before all designs were completed and agreed upon.

• *Unavailability of sufficient resources & skills*; with a project of this size, several problems arose as a result of the availability and prices of raw material and the engineering market.

• *Multiple interfaces between different disciplines*; with the large number of awards (150-180) and participating parties, there were several interface gaps. Other problems arose due to an inadequate integration of the planning. Expecially during the course of working through the draft of the technical systems and structural qualities.

• *Large size of project team*; the total control of execution in terms of qualities, deadlines, costs and teamwork was outsourced to one company, namely FAS. In doing so, the project was legalized under a single contract form (design-build). As a consequence, around 500 individual subcontracts for the number of tasks were awarded to small and middle sized construction companies. As competition coordinator, Drees & Sommer was responsible to award tenders to the (sub)contractors

• *Difficult to interfere with existing site*; the impact on the direct and indirect surroundings was significant. The reason for this is that all execution work that interferred with some mode of transportation had an effect on the (air) traffic flow. Therefore, all plans needed to be submitted and assessed by Fraport and the municipality. Besides this, with the construction being a project positioned directly within the area of a large airport, the construction space is very low. This resulted in additional infrastructural work to incorporate the new terminal control mechanism into an already existing location, without influencing the rest of the airport.

• *Political instability*; the other aspects of the project; being situated within the heart of Frankfurt which is a very influencial and crucial city in Germany in political aspect. Due to severe insecurities caused by such a big project, politics meddled with the project and made decisions that lead to a shift in the overall schedule.

• *Dependencies on multiple external stakeholders*; the external stakeholders that were anticipated upfront included the municipality of Frankfurt, politicians, the people living nearby the airport, the businesses which were affected by the construction works and the contractors hired for the construction works. With so many participants, a lot of negotiations and tender rounds were necessary from the start. Apart from the effect on air traffic flow, nuisances of the construction work and interventions in the public space of the airport itself, the access roads in the neighbourhood were also being affected. This caused implications for neighbouring entrepreneurs and inhabitants.

Step 2.1: Investigate the general RBS for a specific industry
After the complexity assessment of the FA Terminal 3 project, a general RBS for terminal building projects was developed in Figure 7.3. The risk data of the general RBS was gathered on a study by Hillson (2002, 2003) on the use of RBSs in project management. The sub-categorization of the risks enabled to relate multiple causes to events. In doing so, the higher levels of the RBS allowed to make interconnections between the risks. Based on this, the general RBS recorded insights into the effect of risks on different aspects specific to terminal building projects.

To continue with a clarification of the sub-categorization of the general RBS for terminal building projects. The general RBS consisted of four hierarchical levels. The risk classification was based on the risk management plan of Drees & Sommer in Appendix A and the results of a study by (Zou et al., 2007). In this research the key risks associated with construction projects were investigated. In the first level, the risks categories were divided into external risks and internal risks. Additionally, the sources of the external risks were dissented into legal, economic, environmental and stakeholders and the sources of internal risks were separated into management, processes and technical.

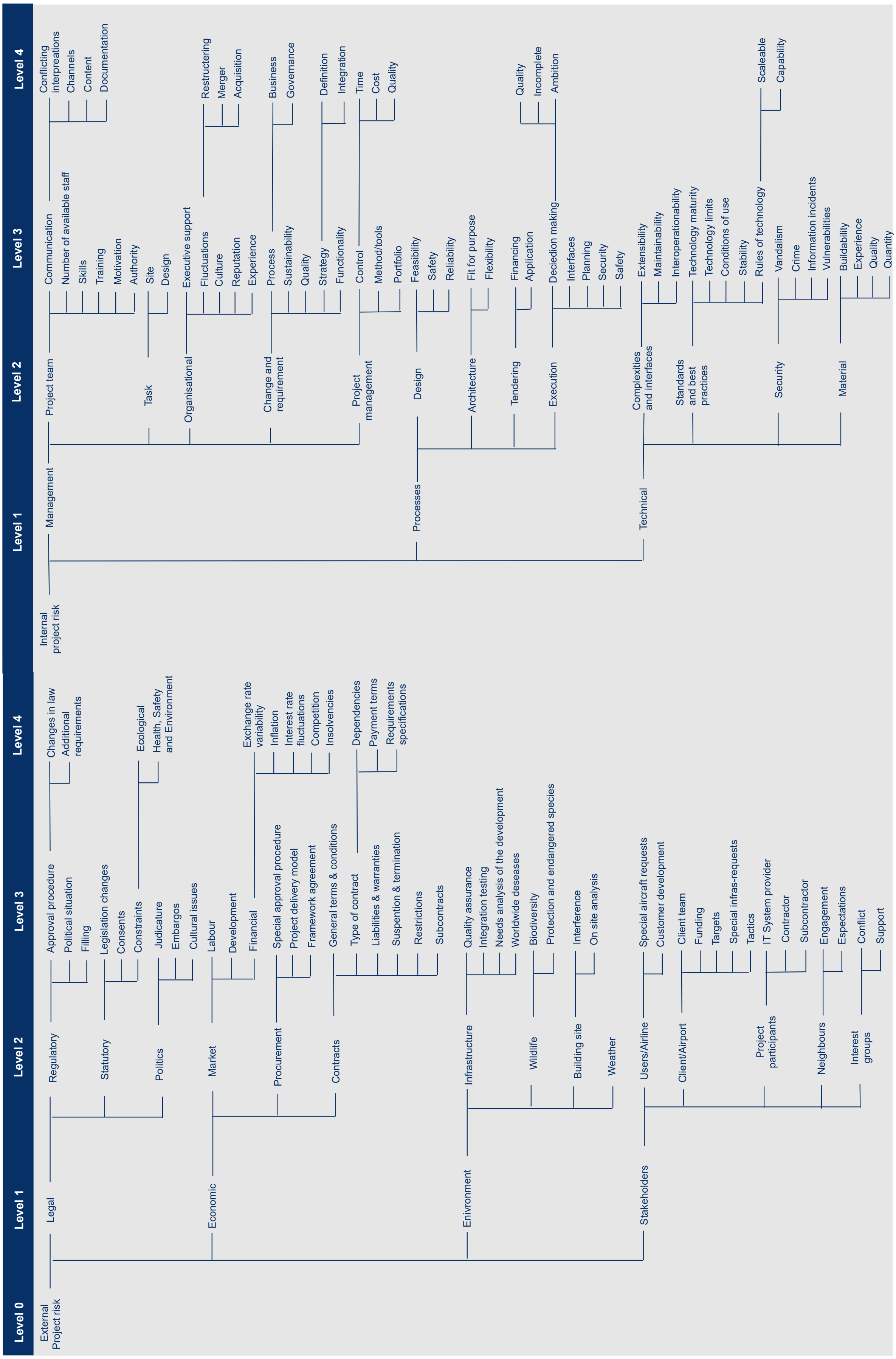


Figure 7.3: RBS for the external and internal risks of generic terminal building projects

Step 2.2: Include project specific risks to the general RBS to build a customized RBS for a particular project
Next, the traditional risk registers of the design and construction phase of the FA Terminal project are evaluated. This is done to detect the foreseen and unforeseen risks. In addition, the foreseen and unforeseen risks are included to the general RBS of Figure 7.3. The purpose of this is to customize the general RBS specific for the FA Terminal 3 project. The customized RBS, as visualised in Figure 7.6, is constituted into five hierarchical level.

For the pilot study, the decomposition of the customized RBS provides the opportunity to approach the traditional risk registers on different levels. The reason for this is that the combination of the risk register with the RBS enables to better rely on the relationship between complexities and risks. To show the relationship between the complexities of step 1.1. and the risks of the customized RBS, the useful information is found in the highest level of the customized RBS. These levels are expected to be the vulnerable points of the foreseen and unforeseen risks of the FA Terminal project.

Step 3.1: Provide cause-effect search to predict the likely behaviour of that particular project and understand how the causalities between the complexity elements and risk-factors are likely to interact
In addition, the CBRAT is tested by building three risk-influence diagrams in Figure 7.7, Figure 7.8 and Figure 7.9. In doing so, the complexity elements are linked to the risk-factors (foreseen and unforseen risks) that appeared as negative counterparts in terms of schedule objectives. This is done by the use of various cause-effect chains. The various cause-effect chains are represented through different ´complexity-risk-project objective' paths. The logic behind the 'complexity-risk-project objective' paths is visualised in Figure 7.4. The purpose of this is to elaborate on how these risk-influence diagrams have been formed.

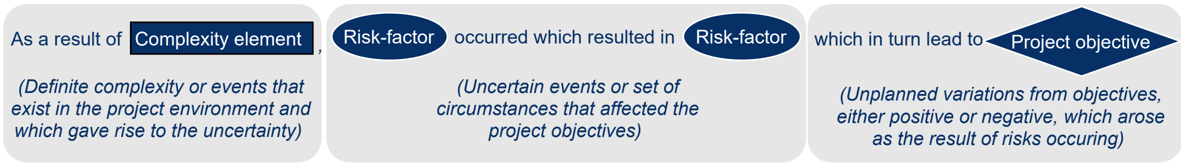


Figure 7.4: The logic behind the 'complexity-risk-project objective' paths within the risk-influence diagrams

To reach the various cause-effect chains, Cause-and-Effect (CE) search is carried out. This is done by first constituting arrows from the ten complexity elements of step 1.1 to the risk-factors (foreseen and unforseen risks) from the customized RBS of step 2.1 . The causal chains between the complexities and risk-factors are illustrated through the use of arrows from *Complexity A causes, exacerbates or promotes risk-factor B*. These are the risks directly induced by complexities. Next, the risk-factors (foreseen and unforeseen risks) from the customized RBS are linked by *what would make this happen* and *so what if this happens*. These are the risks indirectly induced by complexities due to the fact that they evolved from the risks directly induced by complexities. After that, arrows are constituted between the foreseen and unforeseen risks to the project objective. In case of the pilot study of this research, this is the project schedule.

Moreover, it is crucial to understand how to read the 'complexity-risk-project objective' paths. Therefore, Figure 7.5 illustrates an example of a 'complexity-risk-project objective' path that can be found on the left side of the risk-influence diagram of Figure 7.7. The example is further defined as: *As a result of* strict quality requirements, special infrastructure requests by airlines such as closed gates and additional technology to handle the process *occured which resulted in* changes in the airline mix (larger aircraft) due to the ICAO guidelines requested by the airlines *which in turn lead to* significant deviation from the approved planning status due to internal requirements.

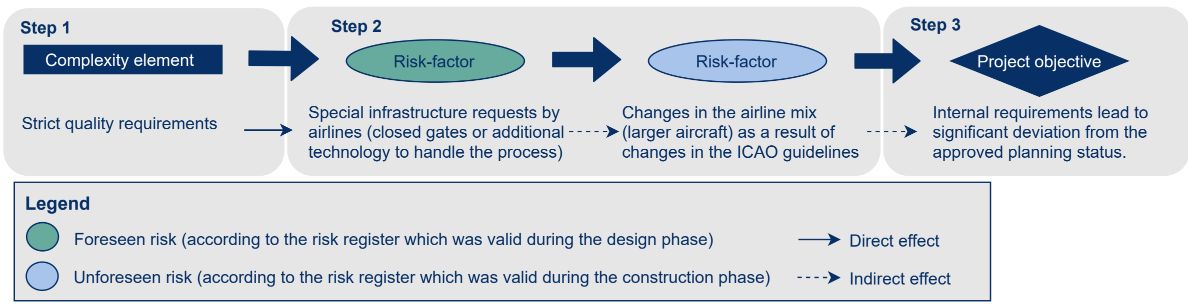


Figure 7.5: An example of a 'complexity-risk-project objective' path within the risk-influence diagram 1 of Figure 7.7

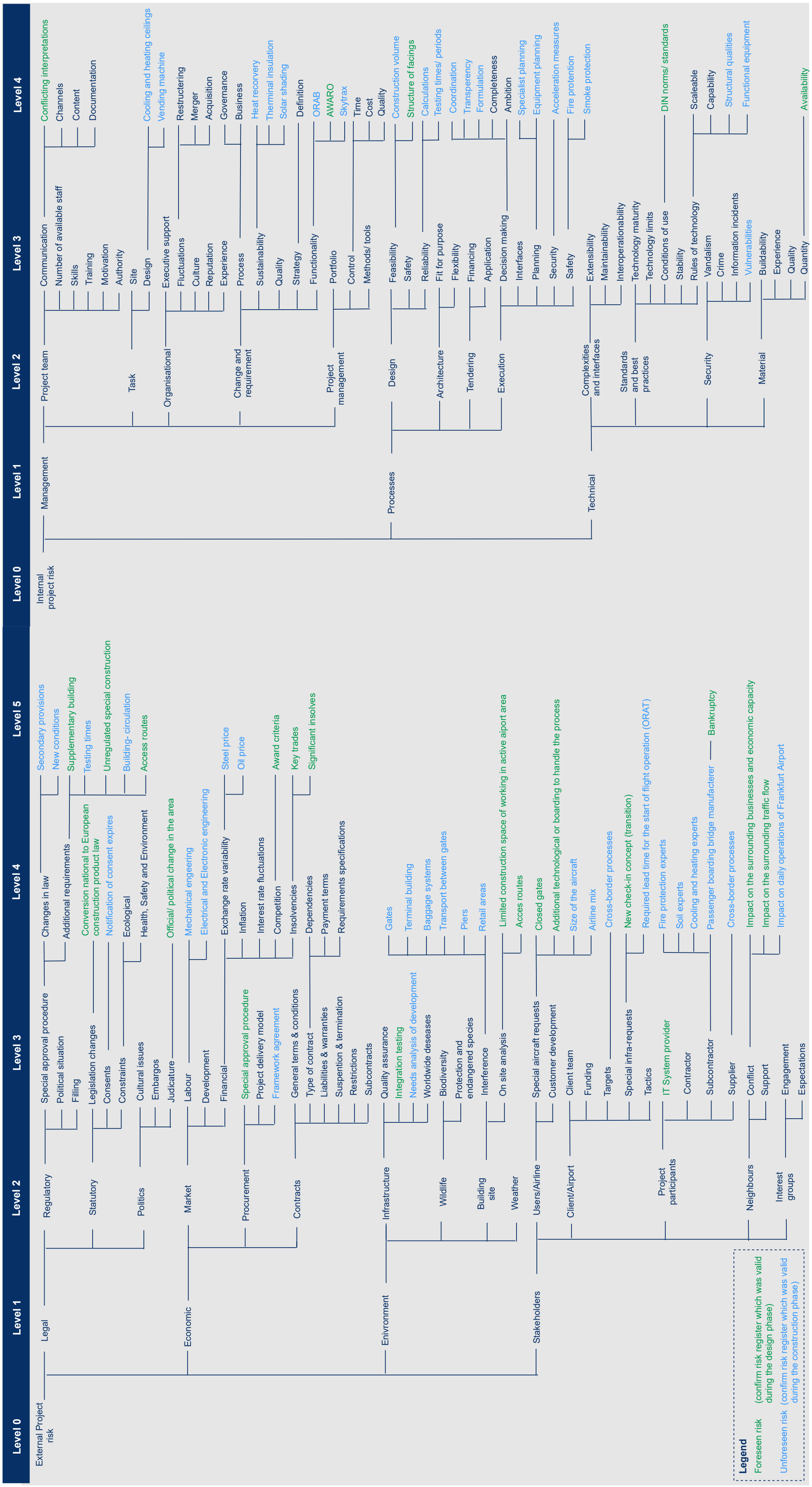


Figure 7.6: RBS specific for the external and internal risks of the Frankfurt Airport (FA) Terminal 3 project

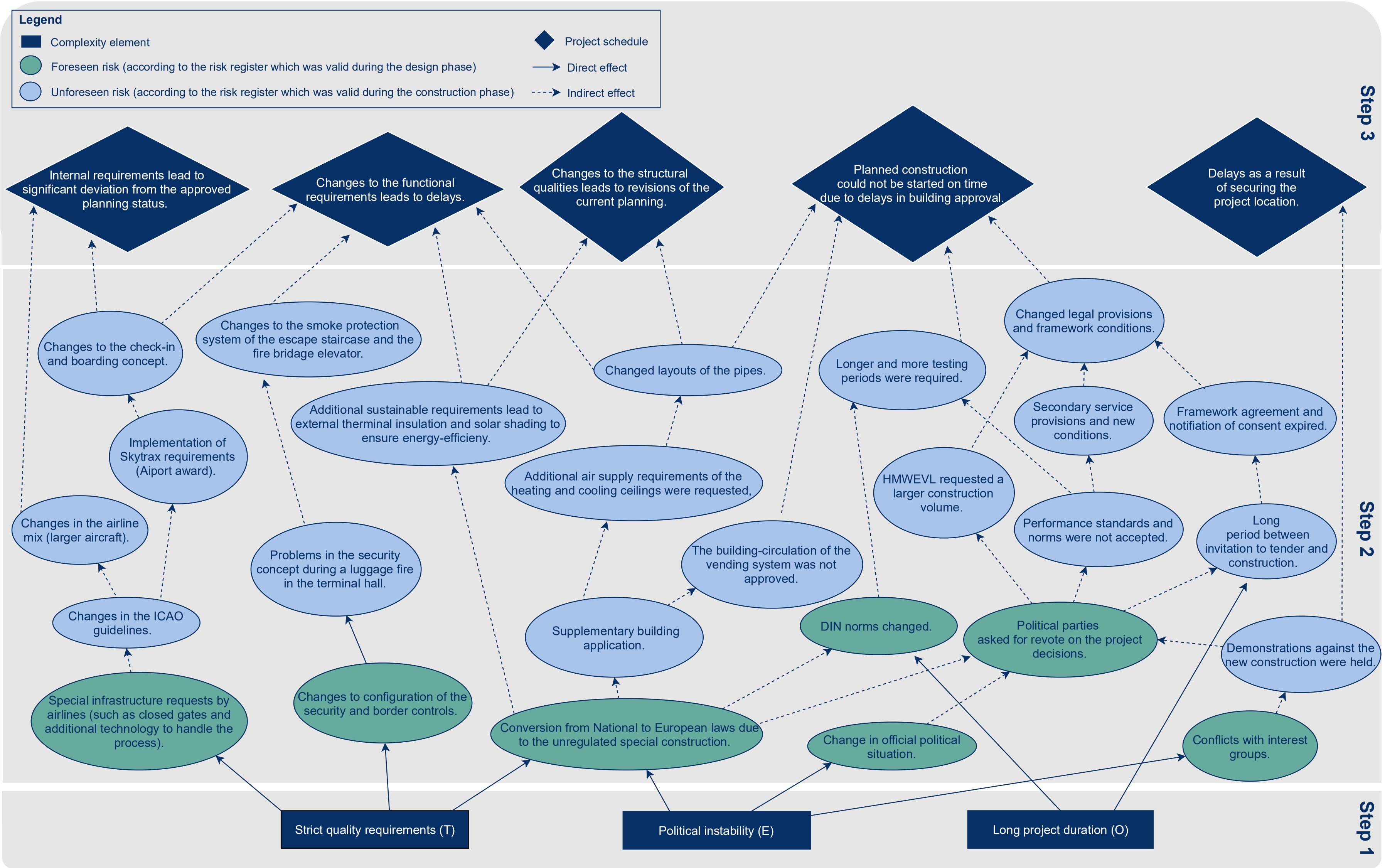


Figure 7.7: Risk-influence diagram customized to the Frankfurt Airport (FA) Terminal 3 project focusing on; strict quality requirements, political instability and long project duration

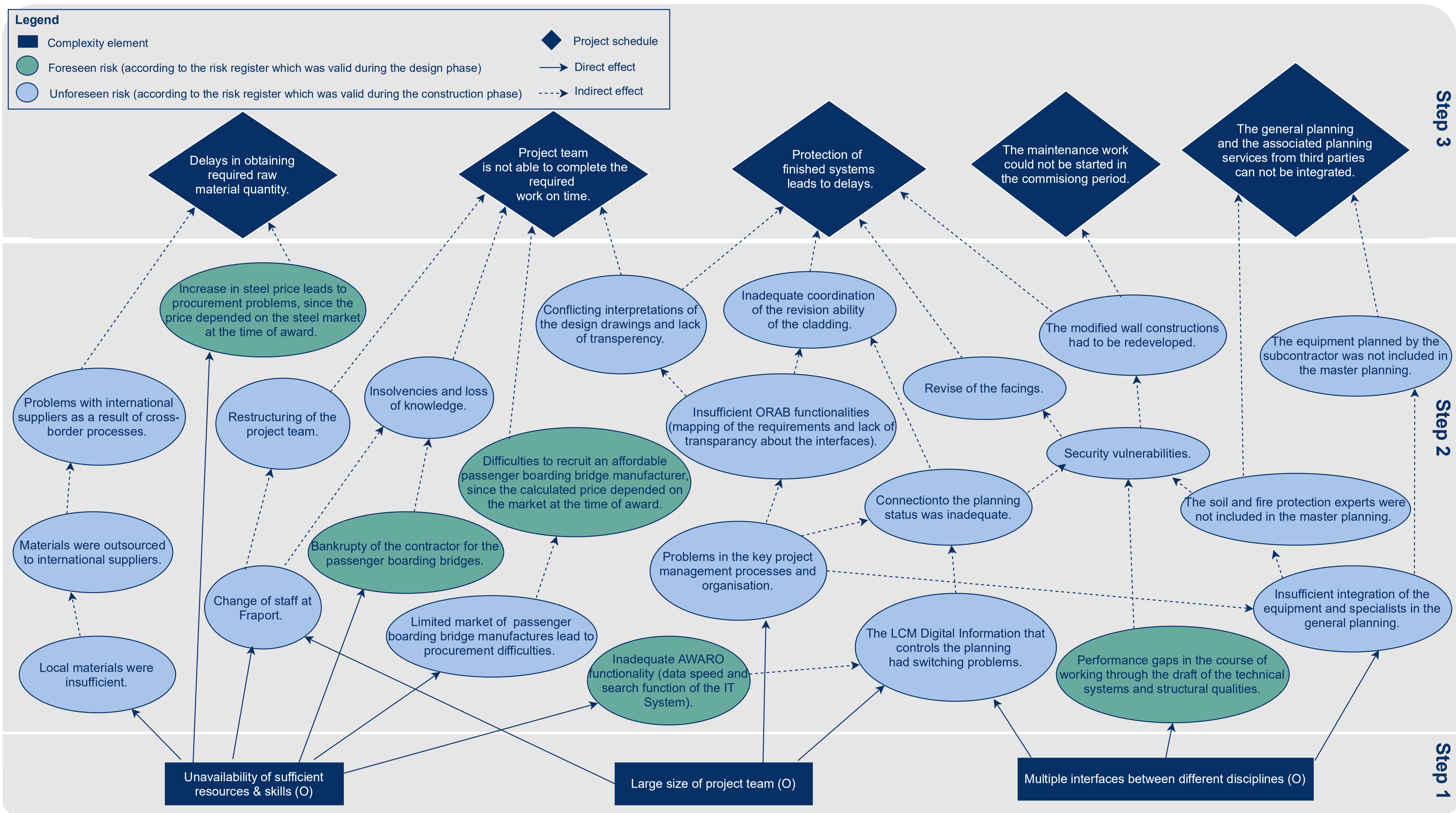


Figure 7.8: Risk-influence diagram customized to the Frankfurt Airport (FA) Terminal 3 project focusing on; unavailability of sufficient resource & skills, large size of project team and multiple interfaces between disciplines

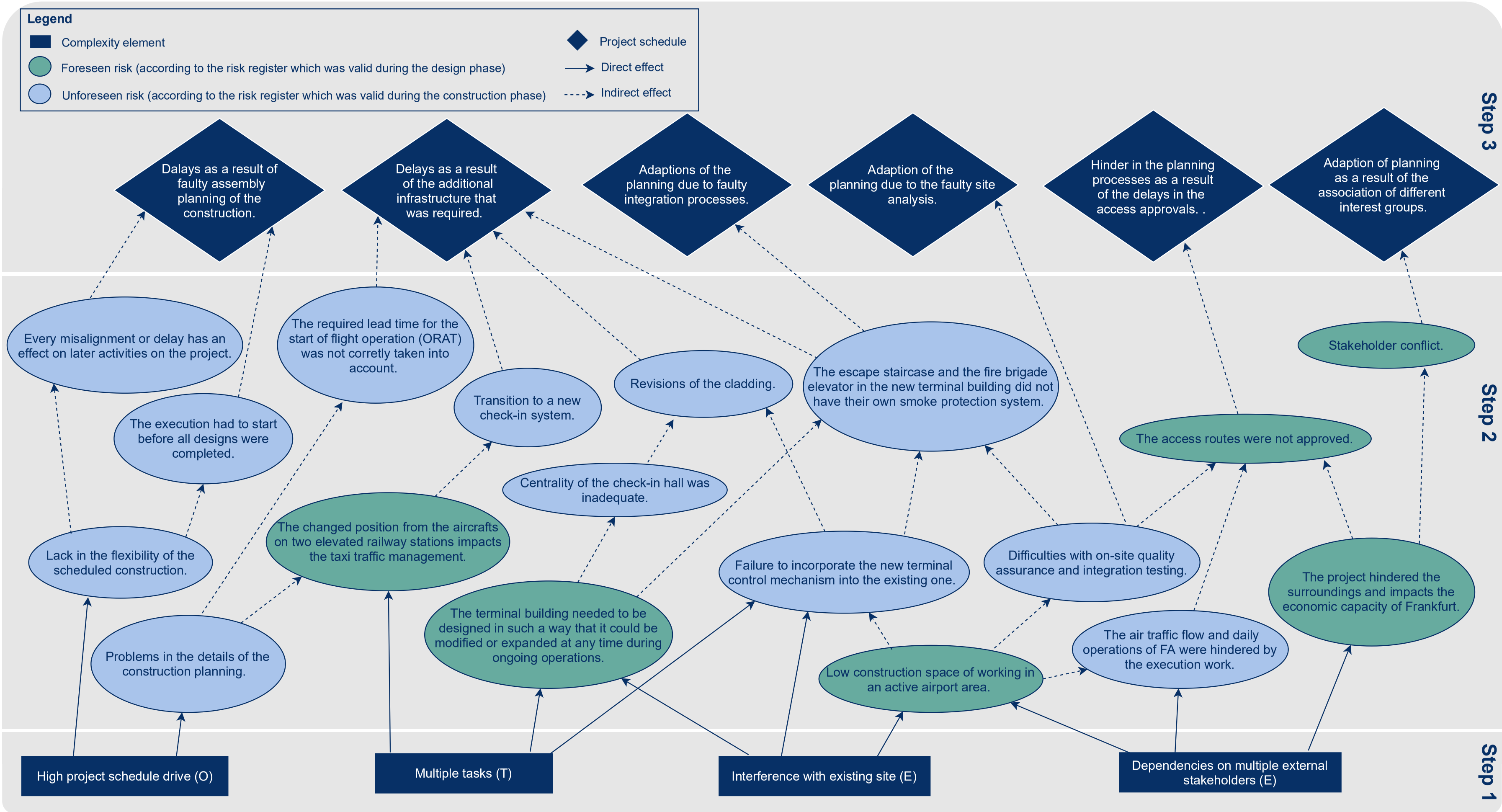


Figure 7.9: Risk-influence diagram customized to the FA Terminal 3 project focusing on; high schedule drive, multiple tasks, interference with existing site and dependencies on external stakeholders in red

Step 3.2: Analyse and understand the direct and indirect inducement of risks from complexity elements
When looking at the risk-influence diagrams of Figure 7.7, Figure 7.8 and Figure 7.9, some results can be drawn up through the two colours of risk-factors. On the one hand, if the density of the green (foreseen risks) colour dominates that means that most of the risks were anticipated before they actually occurred. On the other hand, if the density of the blue (unforeseen risk) colours dominates that means that most of the risks were not anticipated in advance, but included to the risk register, which was valid in the construction phase after they occurred. The purpose of the two colours is to show that it is possible to relate both the foreseen risks and unforseen risks to the complexity elements.

In addition, there seem to exist two kinds of causal relationships between the complexity elements and risk-factors:

1. The first category is the risk-factors that are directly caused by the complexities. This is the case if a risk-factor on the risk-influence diagram is caused directly from the complexity element to the project objective;
2. The second category is the risks that are indirectly caused by the complexities. This is the case if a path from a complexity element to the project objective on the risk-influence diagram consist of more than one risk-factor.

7.4. Research limitations

To check the appropriateness of the CBRAT in the risk management process of Drees & Sommer, the subject of analysis is the almost completed FA Terminal 3 project. In doing so, it was decided to use the risk register which was valid during the construction phase. This is done to explore the risks that were identified in advance and the risks that were completely ignored in the design phase of the project. This is both the strength and weakness of the pilot study. It is a strength because it showed that some causal relations could be set between the risks that were foreseen in advance and the risks that were unforeseen in an ongoing project. However, at the same time, the pilot study has a weakness because every project is unique, and currently the proposed CBRAT is still not applied on a project that has just started. A pilot study on a project in the design phase might add value on the description of the practical implications of the CBRAT.

The application of the CBRAT on the FA Terminal 3 project only focuses on the schedule objective. Despite this, it does not mean that two or more objectives cannot be worked on at the same time. It is expected that some of the risk-factors will exhibit a combined effect at the same time, which makes the CBRAT more complicated. Besides this, there is also a knowledge gap on the exact practical elaboration of all the steps of the CBRAT, since the pilot study only focusses on step 2 and 3. A more elaborate pilot study should analyse all steps and incorporate a distinction in intensity of the steps.

Another note should be made about the subjective and dynamic character of the perceived project complexity. The reason for this is that different parties involved may have a dissimilar view on the complexity of the FA Terminal 3 project. Therefore, the assessment of the TOE scoring process is subjective by nature, in which the complexity of the project is based on the perception and interpretations of three experts involved in the FA Terminal 3 project. To give an example, not all of the risks were caused by only these ten complexity elements. Some other complexities also may have had influenced on the occurrence of some of the risk-factors (foreseen and unforseen risks).

Even though the pilot study aims to examine if the CBRAT could facilitate the cause-effect mechanisms between project complexity and risk-factors, the question remains whether it can be claimed that the CBRAT is found relevant if no significant CE can be explored? For the reason that the risk-influence diagramming technique can only be applied if the complexity-risk pairs appeared to cause the same impact. Despite this, the CBRAT can be applied in and of itself, since it increases the awareness of the causality of the relationships between complexity elements and risk-factors.

Finally, some limitations occured due to the project phase for which the CBRAT has been applied. The CBRAT captures the cause-effect mechanisms between complexities and risk-factors (foreseen and unforseen). The reason for this is that the FA Terminal 3 project is already in the final stage of construction. As a consequence, the pilot study does not really test the applicability of the CBRAT as a risk assessment technique.

7.5. Evaluation of achievements in terms of Risk Management

As mentioned earlier in Section 6.1, the current risk management process of Drees & Sommer still works on the assumption that risks exist independently from one another. Although, some complexity-induced risks are included in the risk register, it does not account for the different types of relationships between complexities and risks. However, these appear to cause an effect on the schedule of the FA Terminal 3 project. In comparison to the traditional process, the CBRAT enables to strengthen the risk assessment capability by including the following:

• *TOE framework increases the awareness of risks that appeared to have high probability value as a source of complexity*; this statement is set up based on the results of step 1.1 . The evidence of the statement can be found in the way that the TOE scoring process explores categories where complexities could be expected to arise, which in turn helps to link the complexities to the risk-factors (foreseen and unforseen risks).

• *The general RBS of Figure 7.3 and the customized RBS of Figure 7.6 enables to decompose and structure the risk-factors into higher levels of detail*; the evidence of this statement can be found in step 2.1 and step 2.2 . From the RBS it becomes clear that when one risk occurred, it appears to reinforce the occurrence of other risk-factors. As a consequence, the higher level risks are used to identify the causal relationship between complexity elements and risk-factors.

• *The risk-influence diagram enables to better understand how the causal effect of complexity elements on risk-factors is likely to interact*; this statement is set up based on the results of step 3.1. The evidence of this statement can be found in the various cause-effect chains represented through 'complexity-risk-objective' paths in the risk-influence diagrams of Figure 7.7, Figure 7.8 and Figure 7.9, which in turn provide crucial information for the risk analysis process.

• *The risk-influence diagram is useful to encourage original and out of the box thinking*; this statement is confirmed based on the outcome of the CBRAT in step 3.1 . From the results of the CE analysis, it becomes clear that the different future paths enhances the creativity. The reason for this is that the 'complexity-risk-objective' paths enable to think further than the risk management process of the FA Terminal 3 project.

• *The outcome of the CBRAT increases the probability-influence scores of some risk-factors*; the evidence of this statement is based on the identified causal relationships between the complexities and risk-factors (foreseen risks and unforeseen risks) in step 3.2 . The reason for this is that the splitted causes can be used to better define and estimate the subjective probabilities and impact scores of the risk analysis process.

7.6. Overall conclusions

The CBRAT as designed in Chapter 6 is applied to the FA Terminal 3 project to test the applicability on a real life complex construction project, and in turn prove the validity of the third sub-question of this research. In doing so, this study tries to demonstrate how practitioners can capture the cause-effect mechanisms within the context of their projects. The reason for this is that each project is unique and, certain events would influence the strength of the relationships between complexity elements and risk-factors differently. Through the pilot study, the condition of feasibility and practicality of the CBRAT are believed to be met if cause-effect mechanisms between the complexity elements and risk-factors can be captured.

In general, the CBRAT is shown to work well on the FA Terminal 3 project. The reason for this is that the CBRAT identified causal relationships between the complexities and risk-factors (foreseen risks and unforeseen risks). The causal effect is expected to exist if complexity-risk pairs cause the same effect on the project objective. Therefore, the foreseen risks and unforeseen risks (that appeared as negative counterparts in terms of schedule objectives) are linked to the complexities (that could have been known at the early phase of the project). As a result, the CBRAT visualises how the causalities are likely to interact and their consequences on the project schedule of the FA Terminal 3 project.

Based on this, the conclusion is drawn that the implementation of CBRAT during risk management might have supported the FA Terminal 3. The reason for this is that there seem to be a causal effect between complexities and risk-factors in complex construction projects so during risk management these two concepts should be handled together. As a consequence, the CBRAT strengthens the risk assessment capability by capturing the cause-effect mechanisms between complexity elements and risk-factors (foreseen risks and unforseen risks). It is expected that once the causal relationship is understood, the impact and probability of the risks can be better analysed. Therefore, the CBRAT can be called a risk assessment technique.

Overall, it is concluded that there might be strong cause-effect mechanisms between complexities and risks in complex construction projects. Therefore, the CBRAT is considered to bring a positive change in assessing and managing risks in complex construction projects. The CBRAT allows project managers to focus on those risks and causalities that create negative consequences on the project objectives, which in turn is beneficial to strengthen control and monitoring areas. After all, combining the complexities and risks provides a means of going beyond the traditional risk assessment techniques to one that identifies the causal relationships between the complexities and risks facing a project. In addition, the CBRAT is positively experienced and therefore recommended for usage in the future for similar projects.

8
Discussion of the results

Throughout the study, several points were raised which need some additional discussion. Firstly, some important aspects of the research topic are discussed in Section 8.1. Next, the capabilities of the CBRAT are discussed in Section 8.2. After that, the validity of the research is presented in Section 8.3 to end with the limitations of the research in Section 8.4.

8.1. Important aspects of the research topic

As observed in the literature study, there are several frameworks developed to examine the complexity of a project. The first step of the CBRAT focuses on the TOE framework to build an initial complexity footprint for a particular project. This decision is made, since the TOE framework enables a more specific source of project complexity, where other complexity frameworks seem to provide a broad overview of the present complexities. Despite this, some similarities are found between the TOE framework and other complexity frameworks. For instance, the studies by De Bruijn et al. (1996) and Hertogh and Jacques (1997) examine the complexity of projects under organisational, social, technical, law and regulation, time and financial complexity. When comparing the frameworks, the *social complexity* characteristics from De Bruijn et al. (1996) and Hertogh and Jacques (1997) is comparable with the *variety of external stakeholders on the project* from the TOE framework. Besides the aforementioned researches, others define the complexities under technical and social complexity. Where technical complexity is related to the size of a project and social complexity includes the interactions among the people involved in the project (Baccarini, 1996; De Bruijn and Leijten, 2008).

The evolvement of complexity throughout the project phases is not included in this research. Despite this, the dynamic nature of complexity is an interesting aspect (Bakker et al., 2018), since different complexity elements are expected to play a role in different phases of the project (Bosch-Rekveldt et al., 2009). Therefore, this study indicates to operate the CBRAT at different phases of a project throughout its life-cycle. Another interesting subject is the perspective that complexity can also be a source of opportunities (Bakker et al., 2010). The opportunity seizing is not dealt with in this study, however it is recognized that complexity of a project is not only a cause of problems, and is therefore, not to be decreased.

Another interesting matter, not thoroughly discussed yet, is the subjective character of project complexity. Kool (2013) suggests the perceived complexity is formed by the choice of particular elements of complexity followed by an individual judgement based on the manager's interests, personal value and role on the project. The sum of these elements then creates the perceived complexity. From this, it is assumed that every manager has its own references of the complexity of a project based on their personal experiences and culture. As a consequence, the awareness of each other's complexity perspectives is a key factor in management (De Bruijn and Leijten, 2008; Bakker et al., 2010; Bakker et al., 2018), since a wrong perception or interpretation negatively influences the project performance (Maylor & Turner, 2017). Based on this, it is noticed that composing a risk management approach based on project complexity can, therefore, be a difficult task if the team member's interpretation of the type of the complexity does not align.

At this point it should be noted that there is, another challenging problem in risk management: possible correlations between risk-factors. Generally, this side of the problem is neglected in the traditional risk management applications. Just at this point, another question arises: if a specific complexity element affects more than one risk-factor simultaneously in the same direction, can it be related to a correlation existing between these risk-factors? This issue can not be neglected while investigating and understanding the direct and indirect inducement of risks from complexities. The study of Ökmen and Öztaş (2008) confirms that the correlations between risk-factors may propagate or amplify the impact of the uncertainty. In addition, complexity is expected to be the most important reason for the correlations between risk-factors, since the impacts of the risks that could be included within the complexity frame create propagative influences on the projects. An example may make things clearer: in case of a causal relationship between on the one hand activities and project objectives and on the other hand project complexity and project objectives, it can be assumed that project objectives are influenced by activities and/or project complexity.

8.2. Capabilities of the CBRAT

As a consequence of the need for a better understanding of the range of risks and their sources, along with attention to their relationships with complexities, the idea of processing complexity more consistently during the implementation of risk management was conceived and developed. Section 8.2.1 gives insights into how the CBRAT can be implicated in practice and Section 8.2.2 defines the contribution of the CBRAT to the theoretical framework of this study.

8.2.1. Implications of the CBRAT in practice

From the results of this study, it comes forward that there exists a strong causal effect between complexities and risks in complex construction projects. Therefore, these two concepts should be handled together during risk management. In addition, the implementations of the CBRAT during the risk management process aims to create awareness to the practitioners of the causal relationships between complexities and risks. The purpose of this is to contribute to the assessment of risks. An overview of the implications is shown in Figure 8.1, and the required steps are elaborated below.

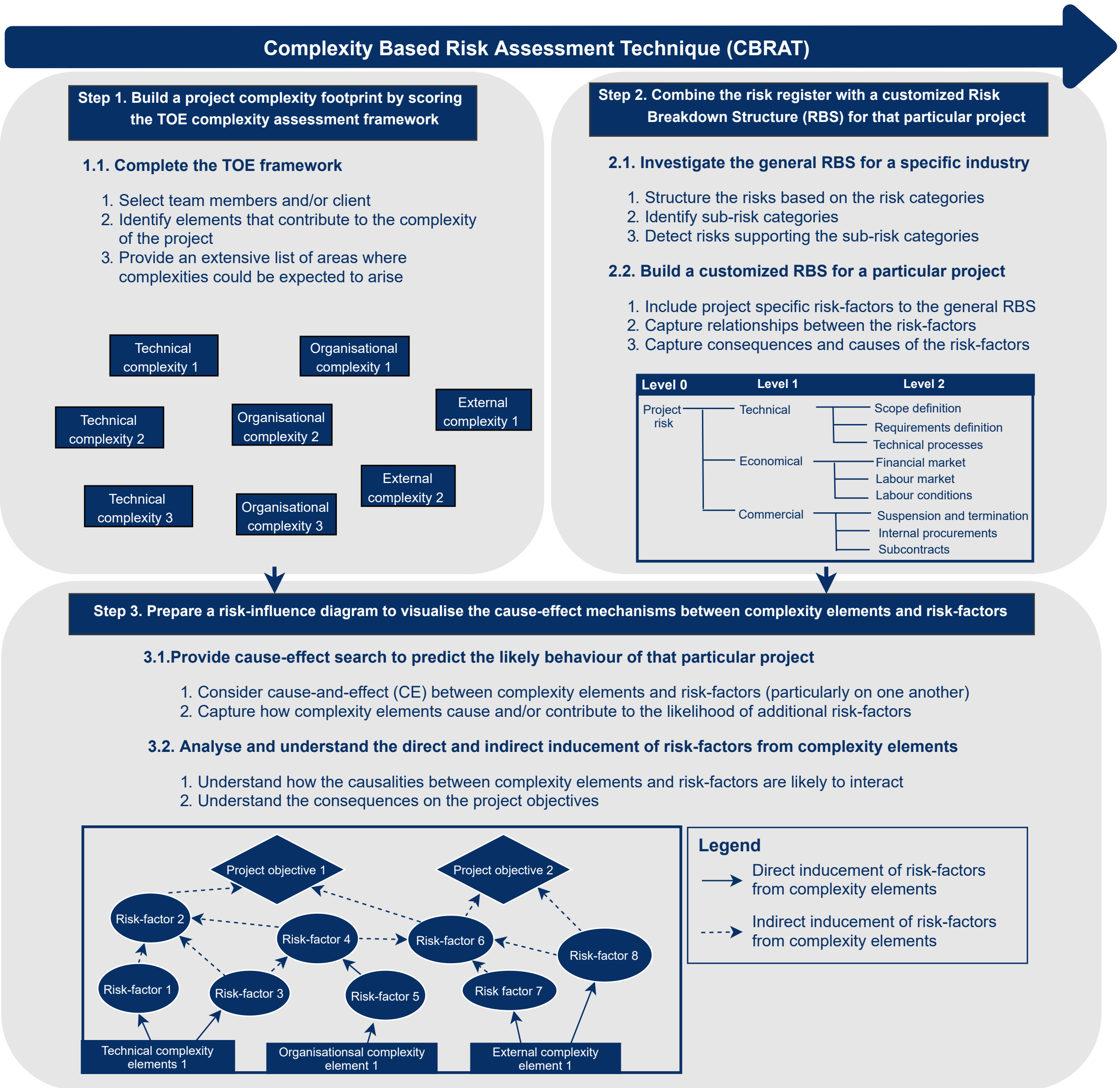


Figure 8.1: Practical implications of the Complexity Based Risk Assessment Technique (CBRAT) in the risk management process

Step 1.1: Once the risk management plan is set up, the CBRAT starts with scoring the TOE framework for a particular project. To ensure broad and depth of knowledge, team members from different disciplines should be selected. It is advised to grasp the complexity by the use of a previously developed TOE complexity scoring sheet in Excel. Depending on where the team members expect complexities to arise in the project, risks-factors can be selected.

Step 2.1: The extensive list of categories where risks could be expected can be used as preparation for an initial risk workshop. It is advised to combine a general RBS specific for the industry of the project with a risk register. The reason for this is that the general RBS enables to record risks which occur frequently for future reference. The lessons learned from previous projects is expected to increase the effectiveness of the interventions of the risk assessment process and therefore may be used to predict the likely behaviour of upcoming terminal building projects.

Step 2.2: To build the customized RBS for the particular project, project-specific risks are to be included in the general RBS. The added value of the RBS consists of providing portfolios of risks, instead of focusing on individual risk items. In doing so, the customized RBS forces conversation across disciplines within the organisation. As a consequence, the risks can be structured into higher levels of detail. The lower level risks from the basis of the risk register need to be further investigated. At the same time, the higher level risks allow to make appropriate interconnections between the risks. This enables to determine the relationships between complexity elements and risk-factors.

Step 3.1: After the relationships between the risks are captured, it is interesting to explore the causal effect between the highest scored complexity elements of step 1.1 and the risks from the customized RBS of step 2.2. In doing so, it is recommended to distinguish the risks that are considered to be directly inferred from the scored complexity elements and the risks that can be indirectly explained by the means of other risks.

Step 3.2: Finally, CE search encourages to focus attention on those causalities and risks that create the most negative consequences on the project objectives. Hence, this information is also valuable to assist the risk analysis process.

When considering the busy time schedules of practitioners, it is crucial to elaborate what the implications of the CBRAT would mean timewise. The supplementary work of a company is to build a database of example projects. This could be wider across construction industries or within the construction industry. The increased knowledge repository is considered as a constant reminder of potential risks and management activities during the project. Besides this, it also enables a reference point by providing information on risks and their previously identified sources that might well be relevant on new projects. Once adequate risk information is available in the knowledge repository, the organization would be able to create best optimal guidance. If such a database can be built, the only additional effort that a practitioner should take is completing a complexity assessment and add project specific characteristics to the general RBS.

To give an example of how this can work in practice; in case of Drees & Sommer, the CBRAT can be easily implemented in their METIS RM software. The METIS RM software is designed with the purpose to better combine RM with project management, tender management and claim management. If the database of this software can be extended, the cause-effect mechanisms between the complexity elements (from the TOE scoring process) and the risks (provided from the risk register + the customized RBS) can be automatically captured through a risk-influence diagram.

8.2.2. Contribution of the CBRAT to the theoretical framework

The CBRAT builds further on the idea to consider complexity as a source of risk in itself (Grey, 2014). In doing so, the CBRAT considers the increasing complexity of projects to result in more interactions and dynamics, which in turn contributes to the management of risks (Bakker & de Kleijn, 2014). This complexity-based perspective of dealing with risk management is also in line with a study of Geraldi et al. (2011). Based on the result of the CBRAT, this study confirms with a statement of Hartono (2018) that once the relationships between complexity elements and risk-factors are better understood, the consequences can also be investigated to improve the project performance.

In general, the CBRAT contributes to the theoretical view by going beyond the traditional risk management techniques to one that creates awareness of the causal relationships between complexities and risks. In doing so, the CBRAT demonstrates that multiple risks can arise from causes and that one risk can have multiple causes through causal risk mapping. Consequently, this is beneficial to deal with the causal effect of complexity elements on risks in practice, while the risks affect the project objectives (Hillson et al., 2006). However, it is critical to notice that only understanding the relationships is not enough to guarantee a successful project. Hence, the structured approach to create appreciation of anticipated complexities of a project helps to strengthen control and monitoring areas. The reason for this is that based on the critical risks, a project manager is able to select optimal risk mitigation strategies.

Overall, the CBRAT aims to serve as a practical tool that encourages experts to go beyond the assumption of complexity elements being independent from risks. Depending on the characteristics unique to a particular project, a practitioner can come up with a risk management approach by focusing attention on those risk-factors and causalities that have the highest potential to create negative consequences on the project objectives.

8.3. Validity

Before continuing, first the internal validity of the results is assessed by looking to the research methodology (Blaikie, 2009; Yin, 2003). This is done because the underlying questions remains whether the results represent the actual situation. The research method consists of a combination of a literature study, exploratory survey and pilot study. Due to the combination of methods, the possibility remains that bias occurs (Miles & Huberman, 1994). For all methods in this study, it is tried to limit the bias. This is done by the use of precautions as indicated in the research design. As a consequence, it can be expected that the theoretical and practical requirements used for designing the CBRAT are valid.

8.4. Limitations of the research

The chosen research methodology has provided the ability to gain a large amount of knowledge on the relationships between complexities and risks. However, the research has some limitations that are highlighted below.

Exploratory survey
The exploratory survey aims to explore the existing practices in the construction industry concerning the causal relationship between complexities and risks. In doing so, this study benefits from the TOE framework by scoring the complexity elements that are thought to have an causal effective on risks. Even though the TOE scoring process has been a quantitative process and the survey procedure is followed, it cannot be guaranteed that no personal interpretation is part of the process.

From the causal effect scoring results it becomes clear that all the complexity elements appeared to cause or contribute to additional risks. However, the aim of conducting empirical research was not to provide a list of complexity elements that have the highest potential to induce additional risks repeatedly. The reason for this is that each project is unique and, certain events would influence the strength of the relationship. Therefore, the use of the TOE framework enables to look to the complexity concept from a broader perspective. A more elaborated survey should be organized to build the causal relationship between complexity elements and risk management by taking the opinions of the experts.

The practitioners' perspectives
All the participants of the exploratory survey are employees of Drees & Sommer, which is a consultancy firm active in the field of project management. Therefore, a similar survey with the employees from a contractor's or client's perspective could result with different answers. The size of the company enables the inclusion of different types of projects, nationalities and types of functions. Consequently, some organisational bias is to be considered, since a similar survey with employees from other companies could show different results. At the same time, the performance of the survey within another company may enhance the variation in the results. Thereby exploring the practice can be enriched by comparing the results of different companies.

Complexity Based Risk Assessment Technique (CBRAT)
The CBRAT has been built on the idea that the risk management procedure can be supported by assessing the perceived complexity. As a result, the aim of the TOE framework in the CBRAT is to provide an extensive list of complexity categories where risks could be expected. As mentioned before, complexity assessment should rather be carried out on a case-based manner due to the uniqueness of each project. Thus, the TOE framework should be completed again for every new project in order to focus on the critical complexity elements of that particular project. However, what if the complexity elements given priority are not the complexity elements that induce to additional risks? Or some other complexity elements with low scores seem to be more effective on the occurrence of the risks? It is noted that a degree of uncertainty must always be taken into account when managing risks. Unfortunately, it goes beyond the scope of this research to investigate how these aforementioned uncertainties can be neglected.

The second critical note indicates the accessibility of the outcome of the CBRAT to the risk analysis process and/or other parts of the organisation. Although, the CBRAT provides guidance, the lack of familiarity with Cause-and-Effect (CE) thinking may result that practitioners feel more comfortable with the use of individual risk items. On top of that, the risk management process can not be supported if the outcome is not clear for all involved people or if people found it overwhelming. Therefore, the CBRAT is designed in such a way that the key risk sub-categories that surface from the RBS enable some level of structure for the reporting process.

9
Conclusions & recommendations

In this concluding chapter, the overall conclusions of the study are presented in Section 9.1. Followed by suggestions for application of the research results in practice and recommendations for further research in Section 9.2.

9.1. Conclusions

Complexity is not necessarily related to only the costs or the size of the project. For a project manager, the increasing number of interfaces and the dynamic character of projects over time make a project complex. Consequently, it is beneficial for a project manager to determine the areas where (potential) complexity could arise in the project more specifically. Therefore, this research aims to support the risk management process by assessing the perceived complexity more consistently. To conclude this report, the sub and main research question are stated again and answered.

RQ1: How is the interdependency between project complexity and risks treated in the literature?

In complex construction projects, complexities and risks are supposed to have relationship in between. Although few studies emphasized different types of relationships between project complexity and risks, most of them considered the complexity as an important contributor to risks. In general, this research recognizes two essential points. Firstly, complexity elements are considered to create an unexpected event or risk-factor (direct inducement of risks from complexity elements). Secondly, unexpected events are believed to influence the project objectives (indirect inducement of risks from complexity elements). Based on this, it can be concluded that complexity elements may trigger a causal effect for risk, while the risks affect the project objectives. Overall, the interdependency between project complexity and risks is observed as: *Complexity-induced events seem to be a major source of risks whose effect for the project are uncertain.*

In conclusion of the first sub-question: on the basis of the reviewed literature, it is concluded that there is some agreement that complexity can be seen as a source of risk in itself. Even though several studies underline the need for integrating complexity elements and risk-factors, the traditional risk management process appeared to be based on the impractical assumption of complexities being independent from risks. There is currently a literary debate on the appropriateness of dealing with project risk management from a complexity-based perspective.

While literature widely researched the practice of risk management within a complex project and dynamic environment, few papers have investigated the actual practitioner's point of view on the causal effect of complexity elements on risk-factors. Therefore, this study analysed the perception of experts who are confronted with project risk management in practice by the following sub-research question:

RQ2: How is the causal relationship between complexity elements and risks perceived and assessed in the risk management process?

Existing empirical researches aim to uncover project complexity and improve risk management (Koppenjan et al., 2011; Saunders et al., 2015; Qazi et al., 2016), however, few studies have investigated the current practice about the causal relationship between complexity elements and risk-factors. Moreover, it is crucial to explore whether the practitioners encourage a potential improvement and/or expansion of the existing risk management process. In order to investigate the practical perception within the construction industry, a survey with 40 experts in project risk management was conducted. Overall, the findings confirmed that the practitioners recognize the causal effect of complexity elements on risk-factors in previous projects. However, the existing risk management procedure does not seem to include the causal effect between complexity elements and risk-factors.

Despite the divergences in literature, most practitioners see the causal relationship between complexity elements and risk-factors as an important contribution to the risk management process. However, they also identify challenges such that practitioners prefer to manage risks in a rather personalised and inefficient way by loosing as little as possible of their work time. This problem can be solved by inspiring the client to spend more resources on risk management, rather than to mitigate the subject. Therefore, the risk management procedure is to be improved by an increased orientation towards the results, by requiring less time, better alignment and encouragement of original thinking and interactions within the team. Besides this, other practitioners link the expansion of the risk management process to including logical steps, suppress unnecessary details and the increased focus on the elements that contribute to the complexity of a specific project. To be aware and accept the existence of the risk-factors and their sources, it is also mentioned to pay more attention to the integration of experiences from previous projects.

During the survey, the perspectives of the risk managers and project managers show small differences. The risk manager seems to perceive the causal effect of complexities on risks generally lower. In doing so, the answers of the risk managers were reflecting the causes rather than the consequences. The reasons for this might be that risk managers focused on cause-event relation and not so much on probability and impact of the risk. When addressing the risks to the response, the risk manager would always try to reduce the probability of risks rather than accepting the probability and just try to mitigate the impact. On the other hand, project managers are more focused on the consequences of the event-consequence relationship. Based on this, it can be concluded that the project manager would try to reflect on the risks and further explain the strategies to reduce the impact.

In conclusion: From the empirical survey, it is confirmed that most practitioners in the construction industry see the introduction of complexity assessment into the risk management process as a must. Although there are many benefits to the use of the existing risk management process, the interdependency between the assessment of complexity and the management of risks is not being captured in the current practice of Drees & Sommer. Consequently, there is a positive attitude towards further professionalization of the implementation of risk management within Drees & Sommer.

In addition, this study attempts to contribute towards complexity-driven risk management by building a conceptual framework that integrates complexity assessment into the risk management process. To investigate the feasibility and appropriateness of the CBRAT for the purpose of this study, the following sub-research question has been set:

> *RQ3: What effective technique can be applied by practitioners to capture the cause-effect mechanisms between complexity elements and risks in the risk management process?*

Although considerable attention has been paid to think about complexity as a source of risks and integrating these together in literature, there is no solid framework originating in both theory and practice that captures the cause-effect mechanisms between complexity elements and risk-factors. The existing risk management process lacks to understand and integrate all the essential factors that produce and influence risks. In reality, practitioners tend to use risk registers which produce an unstructured list of individual risks, in which risks are assumed to exist independently from one another. As a consequence, managers are unable to accumulate the knowledge necessary for understanding the impact on the project as a whole. This, however, is inadequate for complex construction projects, since the effect of two risks might be more than the sum of the two individual risks.

In order to address the aforementioned issues, a conceptual framework of the CBRAT is developed. From both a detailed literature study and a survey with practitioners, it comes forward that complexity elements might have a causal effect on risk-factors. After careful consideration, the CBRAT includes the following three tools; the TOE framework, the RBS and the risk-influence diagram. Rather than simply providing an extensive list of individual risks, the CBRAT enables project managers to cluster the risk-factors and focus on the risk-factors and complexity elements together.

Overall, the conclusion is drawn that the implications of the CBRAT, as visualised in Figure 8.1, appeared to strengthen the risk assessment capability as follows:

- To start with the *TOE complexity framework* as preparation for initial risk workshops or risk registers. This tool was included, since the risks appeared to have high probability and impact values as a source of complexity elements. In other words, complexity elements that are known at the early phase of the project are expected to cause or contribute to the likelihood of additional risk-factors. Therefore, the extensive list of categories where complexities could be expected to arise can be used to explore the causal relationship between complexities and (potential) risk-factors early in the project;

- Next, the CBRAT introduces the *Risk Breakdown Structure (RBS)*. The purpose of the Risk Breakdown Structure (RBS) is to decompose and structure the risk-factors of the risk register into sub-categories. This strengthens the traditional risk management process, since one risk-factor can reinforce the likelihood of other risk-factors occurring, and so on, causing a complex chain. Besides this, the RBS enables to record generic risks that occur frequently, which can be used as knowledge repository with lessons learned for future reference;
- After that, the *risk-influence diagram* aims to trace the direct and indirect inducement of risk-factors from complexity elements. The visualisation of the causal effect enables to understand how the causalities between complexity elements and risks is likely to interact and evaluate the consequences on the project objectives. In doing so, splitting out the causes encourages the project manager to think original and outside the box. Furthermore, it is concluded that the risk-influence diagram filters out particular areas that require further investigation during the risk analysis process. With those insights, the probability of the risk-factors can be better analysed, as well as their impact on one another. For that reason, the CBRAT is called a risk assessment technique.

From the application of the CBRAT on the FA Terminal 3 project, the conclusion is drawn that the CBRAT would have supported the risk management procedure of Drees & Sommer. The reason for this is that the risk-factors (foreseen risks and unforeseen risks), could have been linked to the complexity elements that are known at the early phase of the project. Thus, if Drees & Sommer had used the CBRAT, they could have captured the cause-effect mechanisms between the complexities and risks which affected the schedule. The reason for this is that the CBRAT strengthens the risk assessment capability by identiying the causal relationships between complexities and risks. Therefore, the CBRAT is positively experienced to bring a change in assessing and managing risks in complex construction projects.

In conclusion: Through the pilot study results, the CBRAT, which is proposed to capture the cause-effect mechanisms between the complexity elements and risk-factors, is shown to work well on the FA Terminal 3 project. The conclusion is drawn that there might be strong causal relationships between complexity elements and risk-factors. Additionally, it is expected that once the causal relationship is understood, the impact and probability of the risks can be better analysed.

Finally, with the help of the answers of the sub-questions, the following main research question can be answered:

In what way can practitioners process the complexities in construction projects more consistently during the implementation of risk management?

From the problem statement of this research, it becomes clear that the complexity elements are not completely independent from the risk-factors in complex construction projects. Moreover, they are supposed to have relationships between them. In general, it can be concluded that project complexity can be seen as a source of risks in terms of propagation, since it includes interconnectivities and interdependencies between its complexity elements (e.g. resource, tasks). Therefore, the traditional risk management process should succeed a complexity assessment process in case of a complex project, differently from ordinary projects. Otherwise, risk analysis and management would not include especially complexity-induced risks which in turn lead us to incomplete and misleading conclusions regarding the risk mitigation actions.

In general, it can be concluded that it is of importance to define the complexity of a project early and clearly for successful risk management. The aim is to enable scaling and putting more or less emphasis on certain complexity elements. In doing so, a project manager is able to come up with a risk management approach that is the most suitable for a project, given the specific and unique circumstances of that project (incl. the industry requirements). Hence, the cause-effect mechanisms between complexities and risks is also valuable to deal with critical risks, to select optimal risk mitigation strategies and gain a more realistic view on the impact on the projects.

With those insights, the practitioners can develop a strategy to process the complexities in construction projects more consistently during the implementation of risk management. For this, the CBRAT can be used as a guidance within the traditional risk management process, as shown in Figure 9.1. The risk management process is defined according to the PMBoK Guide (PMBOK Guide, 2017). The closed control loop start at the beginning of the process, in which the risks identified in the risk identification phase and analysed in the risk assessment phase has to be updated continuously. In case new risks are identified or deviations occur, the feedback loop cycle start a new loop. As a consequence, the combination of the risk register with the CBRAT assists the decision-making and the determination of the risk response and risk monitor strategies.

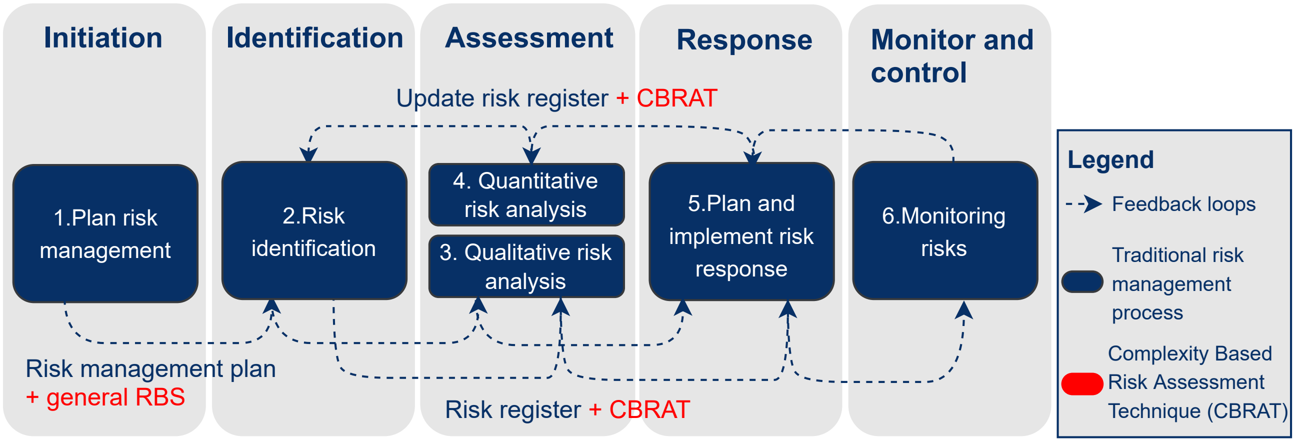


Figure 9.1: The CBRAT (visualised in red) is positioned within the traditional risk management process (visualised in blue)

Depending on the characteristics unique to a particular project, the project manager can come up with a risk management approach by focusing attention on those risk-factors and causalities that create negative consequences on the project objectives. Nonetheless, in the end, being aware of the relationships between complexities and risks in a particular project would be one of the most important success factors of managing risks.

However, one has to question whether it is realistic that practitioners will change their risk management approach, since it is already difficult enough. Because of this, the CBRAT is designed in such a way that it can be easily implicated in the risk management process and therefore, fits well in the busy work schedules of average users of the concept.

Altogether, the contribution of this study consists of four main parts: it explored an important research theme that has potential to support the implementation of risk management, it conduced an empirical study to provide insight on how the causal relationship between complexity elements and risk-factors is perceived and managed within the construction industry; it proposed the CBRAT to capture the cause-effect mechanisms between complexity elements and risk-factors and finally, through a pilot study the CBRAT is shown to work well on a real life construction project.

9.2. Recommendations for future work

On the basis of the conclusions the following recommendations could be made, in which a distinction is made between the recommendations for practice in Section 9.2.1 and the recommendations for further research in Section 9.2.2.

9.2.1. Recommendations for practice

- The main recommendation for practice is the implementation of the CBRAT in the traditional risk management process, as visualised in Figure 9.1. In doing so, CBRAT is recommended to be repeated throughout the project. The reason for this is that complexities and risks are expected to evolve during the project's life cycle. Therefore, project risk management is a continuous process of monitoring, updating and mitigating the state of risks.

- Specifically for Drees & Sommer, it is recommended to improve the risk management process with a more structured and practical guidance on the risks. However, only a checklist is not enough, since this might create a tunnel vision. It is advised to develop a more user-friendly tool to guarantee better alignment between different disciplines and create a higher awareness of the external sources of the risks. During the overall project life cycle, it is also recommended to reflect and maintain the risk tools repeatedly, since this encourages original thinking and interaction within the team.

- Specifically for Drees & Sommer, it is recommended to expand the risk management process by including lessons learned from previous projects and increase the attention at the early stage of the project. In doing so, the entire project team can be included to select the right people to manage the risks. Currently, Drees & Sommer is at the final stage of the development of the METIS RM software, which is designed to combine RM with project management, tender management and claim management. If the METIS RM software seems to work well it is recommended to include the CBRAT into the software to process project complexity more consistently.

9.2.2. Recommendations for further research

- The main recommendation for future work is a more in-depth validation of the CBRAT, because for the full validation it is intended to carry out more pilot studies. Replication of the pilot study ideally tests on a project that is in the early design phase or with more project objectives (costs for instance), because this creates new insights. Ideally, any further improvement is for easier implementation and adaptability to each unique industry. If the pilot studies are evaluated as more than satisfactory by the employees of Drees & Sommer, then the CBRAT can be applied in more projects.

- The causality of the relationship between complexity elements and risk-factors should also be included in the other phases of the risk management process. Therefore, research might be done on how the outcome of the CBRAT can be utilised in the risk analysis and risk response process. This is expected to result in varying conditions and thus requiring a solution best fit to focus on those risk-factors and causality that create negative consequences on the project objectives.

- Associating risk mitigation with the CBRAT is also considered to be an interesting next step. During the exploratory survey within Drees & Sommer, it comes forward that the answers of the risk managers were reflecting the causes of the risks rather than its consequences. The reason for this might be that risk managers focused on cause-event relationships and not so much on probability and impact of the risk. When addressing the risks to the response, the risk manager would always try to reduce the probability of risks rather than accepting the probability and just try to mitigate the impact. Based on this observation, it is recommended to link risk mitigation actions or responses to the CBRAT. These mitigation actions or responses can be taken (whether or not by conscious decisions) by the project team and the expected behaviour of the project participant. In doing so, it is advised to allow the whole project team to express their opinion through risk review sessions, since these critical elements are expected to cause the most damage for a project. Together, an organisation-specific vision can be created to be used for risk management in the future.

- It is argued that one of the distinguishing features of complex construction projects is that there also exist correlations between risk-factors. Despite this, traditional predictive approaches to risk analysis neglects the uncertainty and the correlation effects. In order to investigate the total effect of uncertainty in complex projects, it is recommended to include the effect of correlation between risk-factors in the risk management process. Correlated Schedule Risk Analysis Model (CSRAM) (Ökmen and Öztaş, 2008) might be used for this, provided that it is adapted to capture the indirect correlation between risk-factors and the extent of uncertainty inherent in schedules. Further information about the application of the CSRAM can be found in Appendix E.

- In this research, the purpose of the RBS within the CBRAT is to link multiple risks to causes. However, it is recommended to investigate if a more elaborated RBS could be developed. To give an example, it might be possible to develop a RBS that is also capable to link risks to multiple causes. Instead of only linking the causes to the risks. However, one has to question whether this will make the application and outcome of the RBS too complicated.

- The implementation of the CBRAT can be further enhanced by including a complexity and/or risk-based numbering scheme. This enables to number the complexity elements (from the TOE framework) and the risk-factors (from the RBS). It is expected that this clarifies the visualisation of the risk-influence diagram for a particular project. As a consequence, the accessibility and outcome of the CBRAT to the risk analysis process and/or other parts of the organisation can be improved. On top of that, it enables some level of structure for the reporting process.

- Although certain aspects of risk management are universally useful and transcend different types of projects with diverse forms of complexity within dissimilar industries, there are also still vast differences between projects and industries. However, finding an all-encompassing technique is practical. Therefore, further research could reflect upon the use of the CBRAT in ordinary projects (for example the utility and building sector). It could be a start to identify the different forms of relationship between complexity and risks within different types of industries.

9.3. Reflection

The graduation period that started 8 months ago was an unique opportunity to keep learning and exploring my ambitions while challenging and motivating myself.

Research process and lessons learned
Upfront, I decided to formulate my own research subject to ensure a close relation to my interest by combining the courses I was most fascinated about "Dynamic Control of Projects", "Fit-for-Purpose Management" and "Process Management". From the literature study, I discovered that large infrastructure projects have difficulties in dealing with the project's increasing complexities and the major impact on the way project managers should approach risk management issues. Contrary to my initial expectations, I extended my view and came to the idea to support the risk management process by finding a balance between complexities and risk. After defining what to research, I continued with a wide search to investigate the different types of relationships between complexities and risks. Unfortunately, my research period was in the middle of the COVID-19 that affected large parts of the world. Due to worsening circumstances regarding this crisis worldwide, the biggest part of my graduation work had to be carried out at home.

By introducing my research topic on the first day at Drees & Sommer, many people recognized the importance and emphasized a positive attitude towards further professionalisation of project risk management. Having a civil engineering background, I was familiar with the technical difficulties of projects. However, as I talked with the employees of Drees & Sommer, I obtained insights in the reality in comparison to the theory gathered during my study and literature review. While going deeper into my subject, I had the opportunity to present and discuss my research topic to the Risk Management Competency Group of Drees & Sommer, with nationalities varying from German, English, Norwegian, Swedish and Danish. The Risk Management Competency Group covers the setting up of appropriate structures within the project, and the application and further development of appropriate (IT based) tools. This was also one of the most educational and interesting parts of the graduation process. As a result, I became interested in developing a new approach and/or technique to support the major challenges project risk management is facing with.

In the weeks before my kick-off meeting, the employees of Drees & Sommer and my supervisors pointed me in significantly different directions. Consequently, too many ideas and ambitious plans that I imposed on myself arose that could not all be included in this study. Fortunately, my supervisors advised me to narrow down the scope of my research to the risk assessment phase and skip the pilot study. However, my desire was still to develop a conceptual framework of a new approach and test the applicability on a pilot study. Especially, since this is the unique part of my research and I was really exited to apply my new knowledge on a real life project. After the kick-off meeting, I decided to pursue my desire and stick with the pilot study, despite the additional work it would take me.

Throughout the literature study, I was sometimes overly consumed with technical details as a result of the more technical nature of my prior civil engineering studies. Despite this, I noticed that risk management is typically focused on tactical and strategical decision-making, while identifying appropriate measures to ensure that defined project aims are met. A valuable lesson I also learned is that the traditional risk management procedure does not directly apply to the real world. Based on this, the idea arose to refine the link between the complexity assessment process and the risk assessment techniques in practice. However, before I could build a complexity driving risk assessment technique, I decided to explore some practical requirements through an exploratory survey in addition to the requirements from the theory.

To continue with the exploratory survey, if prior to the survey I had known what the gathering of the results would have looked like and where and when it would take place, I would have taken more time in the preparation of the survey. Unfortunately, the circumstances around the COVID-19 and the holiday season made it difficult for me to take the most out of my survey. Even though I presented the subject of my research to several participants of the survey, I still could have made the survey more clear and better explain the content of the research. To give an example, the survey procedure seemed clear enough for me, however it was not always as straightforward for other people. On top of that, if I could do the exploratory survey again, I would also lay more focus on the complexity elements: technical risks , organizational risks and external risks, since these are considered to be a natural source of complexity and would have achieved the presumed results in a more strategic way.

Research results
Looking at the final results of my research, I can say that I am really pleased that I completed my research with all the ambitious plans that I had imposed on myself. Even though some of these plans were sometimes too overwhelming,

all my effort and the extensive communication with my supervisors has allowed me to answer the research questions. Furthermore, I have achieved all my personal goals. First, I have gained scientific insights and knowledge into how theories are transferred to practice and how a qualitative pilot study research are performed. Secondly, I have learned a lot about how project managers perceive complexities and approach project risk management, what the influences of project complexity are on project risk management, and how to set up a conceptual framework of a complexity driving risk assessment approach that can be applied in practice. Finally, I have got a really interesting job opportunity at Drees & Sommer as a Junior Risk Expert and I consider all these aforementioned subjects as very useful knowledge for my future career.

Overall opinion
Graduating as a student at Drees & Sommer has taught me to value open-minded thinking and has shaped my analytical mindset. It has also given me the opportunity to study a real life project in the field of infrastructure that I admire the most; airports. However, during the study I also learned that sometimes I made some decisions too quickly which I regret later on. If I could do it all over again, I would have narrowed down my ambitions plans much earlier in the process, since my ambitions were too broad in some fields, which made some parts of the study too time consuming. Overall, my interest for risk management and all the tactical and strategical decision-making that comes with it has grown and I have learned that I want to continue in this area after my graduation.

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A

Risk management plan of Drees & Sommer

In this appendix, detailed information is given about the risk management plan used within Drees & Sommer. Firstly, the aims and purposes of the risk management plan are elaborated. Thereafter, the organisation of Drees & Sommer's risk management is explained. Next, the definitions and the methods and tools are discussed, followed by the monitoring/controlling of risk reponse measures and documentation rules and principles for reporting.

Aims and purposes of this document

The standard Risk Management Plan of Drees & Sommer describes how risk management will be implemented for the particular project. It helps to set the context and boundaries of the risk management approach within the project and will support to clarify the parameters for risk management including technical, company-specific, political, financial, legal, contractual and market policy objectives. The risk management plan defines the following subjects; organization of risk management, risk definition, risk management process, project-specific methods and tools, monitoring/controlling of risk response measures and documentation rules and principles of reporting.

Organization of Drees & Sommer's risk management

The project organisation of Drees & Sommer is accompanied by a proactive risk and opportunity management approach. As a result, Drees & Sommer is responsible for the implementation and coordination of he risk and opportunity management approach. Since risk management supports mainly the decision-making process of the management board of the project, the appointed risk manager participates on the project steering committee meetings. All project participants actively contribute to the process. Identification and assessment of risks will be done in the form of risk workshops. Depending on the planning phase and on the systems to be analyzed. The risk workshops are attended by representatives of the client, specialist planners, site management and executing contractors.

In the early planning stages, the identification of risks mainly deals with general issues such as building permits, design basis, space allocation program etc. . In later planning stages, the risk workshops are carried out in more depth for various systems (e.g. structural framework, building services systems, site logistics, etc.). In consultation with the client, the risk manager defines the systems (i.e. the disciplines/specialist works sections) to be analyzed.

Definitions of the Drees & Sommer's risk management process

For the purpose of projects of Drees & Sommer's, the term 'Risk' is defined according to the "Guide to the Project Management Body of Knowledge (PMBoK)" by Project Management Institute (2013): 'A project risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives'. Hence a risk can have a positive up-side-effect (i.e. opportunity or chance) or a negative down-side-effect (i.e.threat or hazard) on the project objectives. The project objects of Drees & Sommer are defined as follows:

1. **Cost:** Economic efficiency in terms of building cost and leasable area v.s built area. Best quality for given budget is the aim for this project. It ensures the quality selection of the materials in an early stage of the project.
2. **Time:** Strong time management is applied. Thinking out of the box is required by all project participants.
3. **Quality:** Only first class parties are involved to ensure the quality of the design and execution of the project. International approach ensures this goal.
4. **Flexibility of use:** The design and construction approach is flexible in a sense that it can easily react to that changes requirements from the market, or changed requirements from the investor. Open approach to the contracting is essential to achieve this goal.
5. **Sustainability:** Energy-efficient building to Building Research Establishment Environmental Assessment Method (BREEAM) standards; ecologically sensible solutions are aimed at, Green Building (BREEAM) certification is intended to be achieved. However, also the European Norms (EN) guidelines with respect to sustainability need to be examined. A project of Drees & Sommer consider EN certification, if this system is more practically.

Risk Management (RM) is a process whose implementation requires several successive sub-processes. These sub-processes are risk identification, risk analysis/assessment, risk response and risk monitoring and controlling. The RM process is a closed control loop in which the risks identified in the risk identification phase and assessed in the risk analysis phase are constantly monitored. If deviations occur or new risks are identified, the closed-loop cycle starts a new loop. As risks change constantly and rapidly, it is absolutely necessary that the RM process be implemented continuously throughout all phases of the project. The following paragraphs give a brief introduction into the individual phases of the risk management process.

Risk identification

Within the scope of risk identification, the threats and opportunities are identified and documented using various methods (e.g. brainstorming). Depending on their root causes, the identified threats and opportunities can be allocated to different risk categories that are either rooted within or outside of the project. They are documented in the so-called "Risk Register". This tool, which is implemented during the risk identification phase, serves to continuously document the risks in a structured manner throughout all phases of the RM process, In the risk management of Drees & Sommer, the risk categories are differentiated as visualised in Figure A.1.

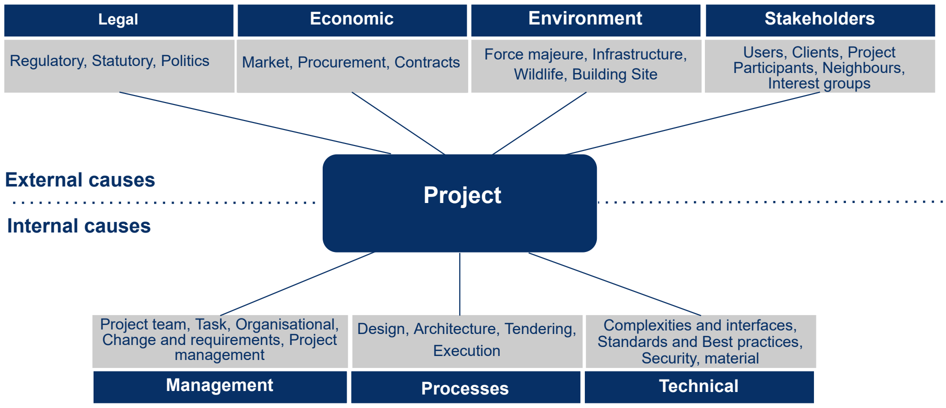


Figure A.1: Drees & Sommer's risk categories

Risk assessment

The risk assessment is either qualitative or quantitative in nature. For a project of Drees & Sommer it is intended to start the process using a qualitative approach. Additionally, some specific risks can be evaluated quantitatively, but this has to be agreed with the client. The results of the risk assessment are likewise documented in the risk register. The identified opportunities and risks are qualified, i.e. their priority is assessed on the basis of their likeliness of occurrence and their potential impact on the project objectives. The qualitative risk assessment is done on the basis of a risk matrix. Further explanation of the methods and tools of the risk management can be found in Appendix A.

Risk response

In the risk response phase, measures are determined that are designed to avoid or mitigate the occurrence of risk, or to shift the impact of risks to third parties or absorb the risk oneself; these measures can be categorized as risk avoidance, risk mitigation, risk transfer and risk acceptance. In the cases of risk avoidance and risk mitigation it is often appropriate to entrust additional experts with the implementation of the risk response measures. Important focal areas for the implementation of response measures are: optimization of planning, optimization of the execution of the construction work and optimization of project organization. Appropriate risk response measures are developed and determined in consultation with the client, and other specialists are involved for implementation of the measures. The involvement of additional experts is subject to prior approval by the client.

Risk monitoring and controlling

Risk monitoring and controlling is not a one-off action. The status of the risks and the status of the countermeasures must be monitored and controlled continuously. This process of following up on the risk response measures is discussed in the previous section.

Risk management methods and tools

Risk workshops

Risk workshops are the most efficient method for the identification of project risks and opportunities. Workshops bring together a defined number of persons and make use of group dynamic aspects in a joint session to identify risks inherent in a specific project and develop a common assessment. The risk manager records the results in the risk register. The meeting is chaired by the risk manager who acts as a moderator and makes sure that certain rules are observed and the meeting progresses smoothly. Figure A.2 provides an example of the basic steps of a brainstorming-based risk identification workshop.

Content	Methods/ means	Duration	Responsible
Step 1: Welcome, introduction		5 min	Risk manager
Step 2: Presentation of the systems to be analyzed	Presentation	15 min	Risk manager
Step 3: Identification of risks (brainstorming)	Brainstorming/ Risk Register	90 min	All participants
Step 4: Assessment of risks (risk matrix)	Risk Matrix/ Risk Register	60 min	All participants
Step 5: Feedback, next steps	Ripchart	10 min	All participants

Figure A.2: Example of the step sequence of a risk identification workshop

Participants are selected on the basis of their experience, their expertise and their function in the project. The group of participants is defined by the risk manager in consultation with the client prior to the workshops. Invitations for the workshops will be sent out by Drees & Sommer. Frequently, for efficiency reasons, several topics are worked on in one and the same workshop. However, it may also be necessary to hold independent workshops for some systems, because different participants are needed to properly deal with the different subjects.

Risk register

All identified risks are compiled in a project-specific risk register. Application of such a project-specific risk register is useful to make available the results of risk management to other project members, in particular to the client, for continuous use during all project phases. By using a risk register it is ensured that no risk is lost out of sight. For the risk identification phase, the Risk Identification (ID) number, Cause/category of risk, short description of the risk (keywords) and detailed explanation/description of the risk are recorded in the risk register:
In addition to the elements of information recorded in the risk identification phase, also the other phases of the RM process will be documented in the risk register. For instance, during the risk assessment phase, the following information will be recorded:

- Impact of the identified risk on the project objectives;
- Probability of occurrence and impact/consequences;
- Risk profile according to risk matrix.

The risk register is compiled in the risk identification process and updated during the qualitative and quantitative risk assessment. In the risk response development process, the appropriate measures are agreed upon with the client and likewise included in the risk register. For reasons of efficiency, measures are not defined for all risks. Only high and moderate risks are covered in detail by measures. Low-priority risks are recorded in a "monitoring list" for periodical monitoring. The information elements that are recorded in the risk register comprise the description of the risk response measure agreed, risk owner and allocated responsibilities, deadlines stipulated for implementation of the defined measures and (qualitative) Risk assessment after implementation of the risk response measures.

Within the scope of risk monitoring, the risk register will likewise be updated and completed. The updated risk register reflects adjustments with regard to Probability, Impact, Priority, Response plans, Responsibility etc. The risk register is thus a tool that is used consistently throughout the entire RM process. From risk identification, through risk assessment and response development and up to the monitoring of the measures, all steps are recorded in the register and they are thus transparently documented at any time for all parties involved in the project. An extract of the standard risk register for risk identification is visualised in Figure A.3.

		Risk description			Pre-response assessment		Risk Response	Post-response assessment			
		Cause (must be a fact)	**Risk event** (something that might happen)	**Consequence** (impact on one or more of the project's objectives)	**Probability**	**Impact**		**Probability**	**Impact**	**Post-risk action**	**Secondary risk**
1	Techncial										
2	Economic										
3	Commercial										
4	Political										
5	Social										

Figure A.3: Example of the risk registers as used for the identification and assessment of risks

Risk matrix

The identified risks are assessed in terms of their probability of occurrence and their impact on the project objectives. The assessment of importance and resulting prioritization of the risks is done on the basis of a risk matrix. The risk matrix consists of a coordinate system in which the X-coordinate reflects “impact” while the Y-coordinate reflects “probability” of occurrence. Such a matrix permits a prioritization of risks in low, moderate or high priority.

In assessing the consequence of a risk, a difference is made between unimportant, important, critical and highly critical. A differentiation is also applied to the likeliness of occurrence: unlikely, likely or very likely. The presentation of the risks in the matrix helps in the steering of the subsequent risk response efforts. For example, RED risks (which, if they occur, have a negative impact on the project objectives) call for aggressive risk response strategies. This facilitates concentration of response efforts on the important issues.

Monitoring/controlling of risk response measures

The implementation of the risk response measures is followed up on within the scope of risk monitoring. For this purpose, controlling deadlines and target/performance comparisons are also recorded in the risk register. This ensures the approved risk response measures are monitored timely and permits a high quality reporting on a regular basis.

Project risks are not static conditions that retain a constant importance throughout the project. It is therefore necessary to continuously monitor the identified project risks. Thereby it is ensured that changes in the project risks are recognized in good time. For instance, it must be recognized if a risk that had originally been assessed and classified as insignificant suddenly turns into a critical risk that jeopardizes the project success . Likewise it is also necessary to review whether risks are no longer applicable from a certain project phase on, and thus can be ruled out. Therefore, the risk register is updated upon completion/at the start of each project phase, e.g. at the beginning and at the end of the final design phase or of the detail design phase. Thereby it is avoided that an excessive number of individual risks is carried along in the risk register which would render the risk management process sluggish and inefficient.

Documentation rules and principles for reporting

An accurate and detailed documentation is of utmost importance for risk monitoring throughout the entire project. The documentation of risks forms part of project documentation and project reporting and is thus an integral element of the quality management activities. The risk documentation is managed by the risk manager and made available to the entire project team by means of the risk register and/or in form of risk reports.

It is the main task of risk manager to support the client’s management board in every respect with regard to the risk situation. The better the information is compiled, the better can be the decisions made by the owner/client. This requires faultless and functioning risk documentation, for only so can it be assured that all parties involved in the project are aware of the prevailing opportunities and risks.

The project risk information must be routed from the planning team to project management. Therefore, risk reporting is integrated into the monthly reports of the project management. The risk report contains the main risk management activities developed in the reporting period. Furthermore, the report provides an insight into the current risk situation of the project. The risk report is the documentation tool on the project management level. Therefore, the risk report shows the aggregate risks for the steering committees.

If corrective actions turn out to be necessary as a result of risk response measures or risk monitoring, which have to be implemented by the project team, such corrective actions are likewise to be set out in the risk report. Thereby, the risk report also provides an outlook on pending or imminent activities.

B
TOE Framework

This appendix describes the TOE Framework complexity assessment model. As mentioned before in Section 3.4.1, when selecting project complexity dimensions, this study refers to the classification by Bosch-Rekveldt et al. (2011). This complexity assessment model is based on primary data from interviews conducted on the nature of the complexity of the organization in engineering projects and secondary data from existing literature. The authors developed a comprehensive framework that suggest three main forms of complexity. These three forms aim to grasp project complexity, where all elements are assigned to either the technical, organisational or external category.

The dimensions according to the TOE framework can be used as a footprint of that project in terms of where the complexity is expected in the project or to achieve a better understanding of project complexity. Once the complexity of a project is better understood, the implementation of the front-end development steps of projects to the specific complexities can also be investigated in order to improve the project performance. The technical elements are further elaborated on in Table B.1, the organisational elements can be found in Table B.2 and the external elements are further explained in Table B.3.

Technical complexity element	Explanation
High number of project goals	There are a lot of 'strategic' project goals
Non-alignment of project goals	There is more than one 'strategic' project goal present
Unclarity of project goals	There is unclarity of project goal(s) amongs team members
Uncertainties in scope	There is unclarity in the agreed scope of work
Strict quality requirements	There are a lot of quality requirements for the project deliverables
Project duration	Long term project duration
Size in CAPEX	High capital expenditure: the total investment for the realization of the project is high
Number of locations	A lot of different sites/locations involved in the project, including contractor's location
Newness of technology	The project makes use of new technology e.g. non-proven technology (which is new in the world for this application)
Lack of experience with technology	The involved parties have no experience with the technology or used it before in the project
High number of tasks	The project have a lot of tasks, count for example work packages or sub-projects
High variety of tasks	The project have lots of different types of tasks.
Dependencies between tasks	There are a lot of dependencies between the different tasks
Uncertainty in methods	There are uncertainties in technological methods
Involvement of different technology disciplines	High level of multi-disciplinary
Conflicting norms of standards	The design standards and country specific norms included in the project are conflicting
Technical risks	The general consideration of the project risk in terms of technical risks is high

Table B.1: The 17 complexity elements assigned to the technical category of the TOE framework (Bosch-Rekveldt et al., 2011)

Organisational complexity element	Explanation
High project schedule drive	There is high pressure on the project schedule.
Lack of resource & skills availability	There are problems with regard to the availability of the resources (materials, personnel) and skills required for the project.
Lack of experience with parties involved	The parties involved in the project have not worked together before, like joing Venture (JV) partner or contractor supplier.
Lack of HSSE awareness	The involved parties are not aware of the importance of Health, Safety, Security and Environment (HSSE) issues.
Interfaces between different disciplines	There are a lot of interfaces between the different disciplines involved (like mechanical, chemical, civil, finance, legal, communicating etc) that could lead to interface problems.
Number of financial sources	There are a lot of different financial sources of the project like own investment, bank investment, subsidies, JV-partners, customer(s).
Number of contracts	There are a lot of different types of contracts involved in the project, think of contracts with the customer, the contracts, suppliers, etc.
Type of contract	There are a lot of different types of contract chosen for the project.
Number of different nationalities	There are a lot of different types of nationalities involved in the project.
Number of different languages	There are a lot of different languages used in the project communication.
Presence of JV partner	There is a JV partner involved in the project.
Involvement of different time zones	There are a lot of different time zones invovled in the project, which for example planning of joint meetings is more difficult
Size of the project team	There are a lot of people involved within the project team.
Incompatibility between different PM methods/tools	There are a lot of compatibility issues regarding project management methodology or project management tools between involved parties.
Lack of trust in project team	There is no trust in the members of the project team.
Lack of trust in contractor	There is no trust in the contractor(s) involved.
Organisational risks	The general consideration of the project risk in terms of organisational risk is high.

Table B.2: The 17 complexity elements assigned to the organisational category of the TOE framework (Bosch-Rekveldt et al., 2011)

External complexity elements	Explanations
Number of external stakeholders	There are a lot of external (e.g. outside project team) stakeholders invovled in the project (like NGO's, governments, different departments, suppliers, local residents, etc); those parties that can influence or are influence by the project team
Variety of external stakeholder's perspectives	There are a lot of variation in perspective of the different stakeholders involved.
Dependencies on external stakeholders	There are a lot of dependencies on the external stakeholders.
Political influence	There is high influence of the political situation on the project.
Lack of company internal support	There is no company internal management support for the project.
Required local content	The participant of local parties in the project is required in order to have permission to execute the project.
Interference with existing site	There are a lot of interdependencies between the current site or the current use of the site and the (foreseen) project location.
Remoteness of location	The level of remoteness of the project location, think of readability, availability of infrastructure and other facilities in high.
Lack of experience in the country	The involved parties have not worked in the country before.
Company internal strategic pressure	There is a lot of internal strategic pressure from within the company \organisation, for example from business / competitive departments.
Instability of project environment	There is no stability of the project environment, think of exchange rates, raw material prices, economic situation.
Level of competition	There is a lot of competition related to current market conditions.
External risks	The general consideration of the project risk in term of external risk is high.

Table B.3: The 13 complexity elements assigned to the external category of the TOE framework (Bosch-Rekveldt et al., 2011)

C
Exploratory survey design

In this appendix, supporting information is given for Chapter 5. In Appendix C, the participants of the exploratory survey are further elaborated on. Thereafter, the procedure of the exploratory survey is given in Appendix C.

Overview of the participants of the exploratory survey

To start with an overview of all the respondents in **??**. Due to privacy of the respondents, the numbers on the list are not in line with the numbers used in Section 5.3. A total of 40 employees of Drees & Sommer participated.

The research was executed in collaboration with Drees & Sommer. Mainly for this reason, the target group of the survey consisted of project professionals from the company Drees & Sommer. As mentioned earlier in the study, this company is an international partner for consulting, planning, construction and operation. Drees & Sommer offers services to clients through a collaborative partnership-based structure. Therefore, the respondents represent the consultant's and client's side of the construction industry. The company already provided a well-developed risk management process. Thereby the size of the company enabled inclusion of very different types of projects.

The criteria of the respondents meet the following criteria:

- The respondent is currently an employees of Drees & Sommer;
- The respondent is or has been directly involved in large scale and complex construction projects;
- The respondent is currently or has been in contact with the client and therefore represent the consultant's and client side of the construction industry;
- The respondent has experience in the construction industry, in particular, the infrastructure sector.

Subsequently, the survey was held with with project professionals with two dissimilar characteristics and experiences. The respondents were divided into two groups: project managers (N=30) and risk managers (N=10). This was done to create some variety in the perspectives and insights of the answers. The responsibilities and expertise for each function within Drees & Sommer are further elaborated as follows.

- **Risk management** covers the systematic application of management principles for dealing with project risks and fulfils the related transparency requirements as a basic prerequisite for project control. These are measures for identifying, analyzing, evaluating, monitoring, controlling and documenting risks. In addition, a risk management also covers the setting up of appropriate structures within the project and systematically detects areas where strategic or operation action is needed and points out the available options, identifying appropriate measures to ensure that defined project aims are met.
- **Project management** covers the management of project that in particular require special skills in leadership and organization in addition to technical know-how. They are responsible for coverage of the entire AHO service spectrum, autonomous technical elaboration of clearly defined work packages in the project (e.g. feasibility studies) an takeover of tasks in project administration.

Besides the difference in function, there was also a variation in the nationalities. All the participants of the study were working as an employees for the Dutch or German part of the company. Thereby the years of experience were also kind of diverse. Varying from (<5 years) to (25-30 years). With an average of (15-20 years). Based on the average years of experience, it can be concluded that the respondents did have considerable experience in the field of complex construction projects, which increases the value of their answers.

Restricted for online version

Exploratory survey procedure

Firstly, the participants were contacted by email. Attached to the email they found the exploratory survey procedure, as visualised in Figure C.1. The exploratory survey was organised through an Excel format and was set up in English and Dutch. In this report, only the English version is published. As can be found in the introduction sheet of Figure C.1, extra information about the TOE framework was included to the exploratory survey procedure, which is similar with the information in Appendix B.

First of all, thank you for participating in this survey that aims to support the implementation of risk management by assessing the perceived complexity of construction projects.

This excel document consist of a TOE scoring model and a questionnaire. In addition, I have also included a short introduction to my research. Please do not hesitate to contact me if you have any questions.

The results of the scoring process are used to explore if complexity elements listed in the TOE Framework have potential to induce additional risks that must be taken into accournt during the risk management process applied in complex construction projects.

The survey will take about 15/30 minutes to complete.

Step 1. Respondents name: ***add name***

Your name is explicitely asked for, but all results will be analysed anonymously and future publications about this research will never make any project, company or person traceable.

Step 2. Introduction to the research

Step 3. Perform a causal effect assessment through the TOE Framework scoring models

For the TOE scoring process, I am asking you to take the last completed complex construction project into mind. Please use this project as a reference in scoring the complexity elements.

Step 4. Answer the questions

In the first part of the survey, you will be asked to reflect on the current risk management process of Drees & Sommer and for you opinion towards processing the complexity of projects more consistently in the context of your project. First some general questions are asked including your background, experience into the field of complex construction projects and the most recent projects involved. After that, you are asked to reflect on the current risk management process of Drees & Sommer and the way it deals with the complexity of projects and if you ever experienced any lacks that could be linked to the incomplete understanding of the risk-factors and their sources.

Step 5. Please submit your completed .xls and the answers to the questions by email: ***lise.andringa@dreso.com.***

Extra. More information about the TOE Framework

Figure C.1: Excel sheet 1 of the exploratory survey procedure

Step 2. Introduction sheet on the research context

Construction projects are dynamic endeavours and require a manager to keep control of the situation. Unfortunately, the increasing complexities have appeared to be the cause of considerable disasters in projects. High failure rates show megaprojects around the world fail by a staggering 65% .The advanced technology, forward-thinking environment, social awareness, shifting market conditions and changing legal and statutory obligations have had unexpected and far-reaching effects on construction projects. Researchers claim that an increased awareness of dimensions and levels of project complexity may help to establish the adequate control, coordination and planning. While the project risk management has resulted in various powerful standardised tools, researchers argue that the complexity of a project is an overlooked aspect of managing risks.

The complexity in projects is most often related to dynamic elements, structural elements and the interaction of these. Complexity in projects appear to have its most significant impact on risk management, since the type of relationship and number of interactions between complexity elements and risk-factors cause the most problems in projects. In addition, the rise of complex projects represents an opportunity as well as a need for new thinking within project risk management. Although several researchers have investigated different techniques, tools and theories for supporting project risks management, there is still a clear gap between practice and theory. However, with projects growing in interconnectedness, researches need to investigate suitable approaches that appeal to practitioners and reflect their practice and experience. In doing so, the causality between complexity elements and risk-factors in complex construction projects is worth considering.

Recently, researches have tried to demonstrate that project complexity is not independent from project risks. The new insights about the complex concept and related risk understanding suggest to link the complexity attributes to different trails of risks. Instead of only covering risks, this enables to include other relevant elements that contribute to the complexity of that particular project. Which in return allows to understand the consequences of project complexity and where risks could be expected. In addition, to define optimal risk mitigation strategies, it is desirable to include the complexity elements that may have potential to cause or contribute to the likelihood of additional risk-factors.

To summarize the problem; in complex construction projects, complexity elements are not independent from the risk-factors. The literature desribe they are supposed to have relationships in between. Despite this, the traditional risk management process have difficulties processing the larger degree of complexity, which in return lead to an incomplete understanding of the number of risk categories and their sources. The objective of this research is to support the risk management process of the project risk management by assessing the perceived complexity of construction projects. The research question to achieve this objective is:

'In what way can practitioners process the complexities in construction projects more consistently during the implementation of risk management?'

Figure C.2: Excel sheet 2 of the exploratory survey procedure

Step 3. In this .xls the action of the TOE framework is used to investigate the causal effect between complexity elements and risk-factors. Scoring sheets will be filled in by all particpants.
After all participants have completed their sheets (TOE scoring model and questions) the average scores will be calculated. For all participants, their score will be compared with the average score of the research (spider diagrams).

The goal of the TOE scoring model is to investige if particular complexity elements have the potential to lead to additional risks and must be taken into account during the risk management process applied in complex construction projects The TOE Framework suggest three forms to grasp project complexity, where all elements are assigned to either the technical, organisational or environmental category. More information about each complexity element and the TOE framework can be found in sheet 'Extra - TOE framework'.
For the TOE scoring process, I am asking you to take the last completed complex construction project into mind. Please use this project as a reference in scoring the elements.

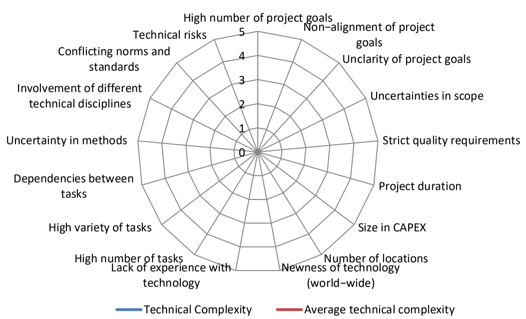
Technical Complexity (17 elements)	Score
High number of project goals	1
Non–alignment of project goals	1
Unclarity of project goals	1
Uncertainties in scope	1
Strict quality requirements	1
Project duration	1
Size in CAPEX	1
Number of locations	1
Newness of technology (world–wide)	1
Lack of experience with technology	1
High number of tasks	1
High variety of tasks	1
Dependencies between tasks	1
Uncertainty in methods	1
Involvement of different technical disciplines	1
Conflicting norms and standards	1
Technical risks	
average T-elements	1

Organizational Complexity (17 elements)	Score
High project schedule drive	1
Lack of Resource & Skills availability	1
Lack of Experience with parties involved	1
Lack of HSSE awareness	1
Interfaces between different disciplines	1
Number of financial sources	1
Number of contracts	1
Type of contract	1
Number of different nationalities	1
Number of different languages	1
Presence of JV partner	1
Involvement of different time zones	1
Size of project team	1
Incompatibility between different pm methods / tools	1
Lack of trust in project team	1
Lack of trust in contractor	1
Organizational risks	
average O-elements	1

External Complexity (13 elements)	Score
Level of competition	1
Instability of project environment	1
Company internal strategic pressure	1
Lack of experience in the country	1
Remoteness of location	1
Interference with existing site	1
Required local content	1
Lack of company internal support	1
Political influence	1
Dependencies on external stakeholders	1
Variety of external stakeholders' perspectives	1
Number of external stakeholders	1
External risks	
average E-elements	1

The explanation of the complexity scores listed in the TOE framework are further elaborated below:

-a score of 1 means that the complexity element has potential to induces "no" additional risks
-a score of 2 means that the complexity element has potential to induce "a few" additional risks
-a score of 3 means that the complexity element has potential to induce "some" additional risks
-a score of 4 means that the complexity element has potential to induce "several" additional risks
-a score of 5 means that the complexity element has potential to induce "very much" additional risks



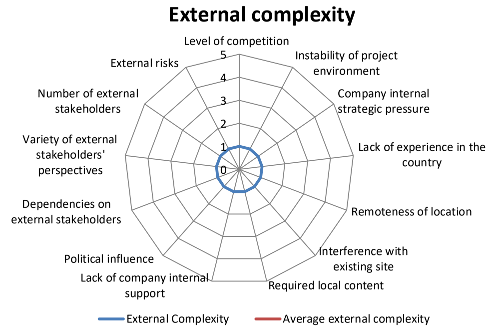


Figure C.3: Excel sheet 3 of the exploratory survey procedure

Step 4. Please answer all questions by focusing on the most recent completed project, typical for the complex construction industry	Answer sheet:
Part 1: General questions	
1. What role do you often fulfill in most of your projects?	1.
2. For how many years have you fulfilled this role?	2.
3. In which project(s) are/were you involved as employee of Drees & Sommer?	3.
Part 2: Improving the current risk management process of Drees & Sommer	
4. Have you experienced any lacks with regard to the current risk management process of Drees & Sommer that could be linked to the incomplete understanding of the risk-factors and their sources? If yes, please give an example.	4.
5. In your experience, what do you think about the idea that some complexity elements of construction projects may cause or contribute to the likelihood of additional risk-factors ?	5.
6. In what way are you prepared to improve the current risk management approach as a consequence of the incomplete awareness of the types of relationships between complexity elements and risk-factors?	6.
Part 3: Expanding the current risk management process of Drees & Sommer	
7. In what way are you prepared to expand the current risk management approach as a consequence of the incomplete awareness of the types of relationships between complexity elements and risk-factors?	7.
8.Do you have any recommendations on how the specific complexities of a particular project (known at the early stage of the project) could be processed more consistently in the risk management process in order to serve as a practical tool for project and/or risk managers?	8.

Figure C.4: Excel sheet 4 of the exploratory survey procedure

Extra information on the complexity elements within the TOE Framework

T - element	Explanation
High number of project goals	There are a lot of 'strategic' project goals
Non-alignment of project goals	There is more than one 'strategic' project goal present
Unclarity of project goals	There is unclarity of project goal(s) amongs team members
Strict quality requirements	There are a lot of quality reuiqrements for the project deliverables
Project duration	Long term project duration
Size in CAPEX	High capital expenditure: the total investment for the realization of the project is high
Number of locations	A lot of different sites/locations involved in the project, including contractor's location
Newness of technology (world-wide)	The project makes use of new technology e.g. non-proven technology (which is new in the world for this application)
Lack of experience with technology	The involved parties have no experience with the technology or used it before in the project
High number of tasks	The project have a lot of tasks, count for example work packages or sub-projects
High variety of tasks	The project have lots of different types of tasks.
Dependencies between tasks	There are a lot of dependencies between the different tasks
Uncertainty in methods	There are uncertainties in technological methods
Involvement of different technology disciplines	High level of multi-disciplinary
Conflicting norms of standards	The design standards and country specific norms included in the project are conflicting
Technical risks	The general consideration of the project risk in terms of technical risks is high
Unclarity of scope	There is unclarity in the agreed scope of work

E - element	Explanation
Number of external stakeholders	There are a lot of external (e.g. outside project team) stakeholders involved in the project (like NGO's , governments, different departments, suppliers, local residents, etc); those parties that can influence or are influenced by the project team
Variety of external stakeholder's perspectives	There are a lot of variation in perspective of the different stakeholders involved
Dependencies on external stakeholders	There are a lot of dependencies on the external stakeholders
Political influence	There is high influence of the political situation on the project
Lack of company internal support	There is no company internal management support for the project
Required local content	The participant of local parties in the project is required in order to have permission to execute the project
Interference with existing site	There are a lot of interdependencies between the current site or the current use of the site and the (foreseen) project location
Remoteness of location	The level of remoteness of the project location, think of readability, availability of infrastructure and other facilities in high
Lack of experience in the country	The involved parties have not worked in the country before
Company internal strategic pressure	There is a lot of internal strategic pressure from within the company \organisation, for example from business / competitive departments
Instability of project environment	There is no stability of the project environment, think of exchange rates, raw material prices, economic situation
Level of competition	There is a lot of competition related to current market conditions
External risks	The general consideration of the project risk in term of external risk is high

O - element	Explanation
High project schedule drive	There is high pressure on the project schedule
Lack of resource & skills availability	There are problems with regard to the availability of the resources (materials, personnel) and skills required for the project
Lack of experience with parties involved	The parties invovled in the project have not worked together before, like JV partner or contractor supplier
Lack of HSSE awareness	The involved parties are not aware of the importance of Health, Safety, Security and Environment (HSSE) issues
Interfaces between different disciplines	There are a lot of interfaces betweeen the different disciplines involved (like mechanical, external, chemical, civil, finance, legal, communicating, accounting etc) that could lead to interface problems.
Number of financial sources	There are a lot of different financial sources of the project like own investment, bank investment, subsidies JV-partners, customer(s)
Number of contracts	There are a lot of different contracts involved in the project, think of contracts with the customer, the contracts, suppliers, etc
Type of contract	There are a lot of different types of contract chosen for the project
Number of different nationalities	There are a lot of different types of contract chosen for the project
Number of different languages	There are a lot of different languages used in the project communication
Presence of JV partner	There is a joing Venture (JV) partner involved in the project
Involvement of different time zones	There are a lot of different time zones involved in the project, which for example planning of joint meetings is more difficult
Size of the project team	There are a lot of people involved within the project team
Incompatibility between different PM methods/tools	There are a lot of compatibility issues regarding project management methodology or project management tools between involved parties
Lack of trust in project team	There is no trust in the members of the project team
Lack of trust in contractor	There is no trust in the contractor(s) involved
Organisational risks	The general consideration of the project risk in tems of organisational risk is high

Figure C.5: Excel sheet 5 of the exploratory survey procedure

D

Frankfurt Airport (FA) Terminal 3 project

This appendix further elaborates on the characteristics of the expansion of Frankfurt Airport (FA).

General descriptions

The idea for the FA stems back to the end-20th century, when it was a major air base for the United States. With construction of the first terminal starting in 1972, while the second was constructed in 1994, the airport is one of the biggest infrastructure works in Germany. Due to the frequent usage of the airport that exceeds the designed capacity, Fraport started talking with the city of Frankfurt about a potential expansion (Frankfurt Airport, 2020) in the end of 1990. The purpose of this was to secure and expand the Frankfurt location as an international hub with a hub function.

The total capacity of the terminal facilities of FA is to be increased with three piers (J, K and G). The new Sky Line train, similar to the existing Sky Line train, between Terminal 1 and 3 takes over eight minutes. Figure D.1 illustrates the concept submitted by the architects Foster and Partners, which formed the basis of the competition for the realization of FA Terminal 3 (Fraport, 2016). The FAS has outsourced the construction management to one company, since this enabled them to coordinate all tasks in regard to the significantly complexity.

Figure D.1: Two simulations of the new Terminal 3 building of Frankfurt Airport (FA) (Fraport, 2016)

Objectives

This particular project has the objective to realize a pleasant place to spend time while in transit. There are several measures needed to create such a smart terminal for less stress. As stated by Jakubeit (2005): "No matter how much the costs, the easy expandability and the modularity have played the first role, an airport represents itself as an entrance and a gateway to the world". Besides this, the sustainability played a crucial role while developing FA Terminal 3. The energy-efficiency is ensured by solar shading, efficient heat recovery, exclusive use of Light Emitting Diode (LED) lamps and highly effective external thermal insulation (Frankfurt Airport, 2020). Whereas, the roofs of the parking structure and terminal will be covered with photovoltaic panels. Solutions are also being designed to reuse water by the use of a comprehensive dual-pipe system. In addition, rainwater from the roof will be deterred by a retention basin with purification system.

With the airport being the most used airport within Germany, cutting off its functions for any time period would result in handicapping the country. As well ass hampering the accessibility of the city of Frankfurt and its surrounding economic capacity. Besides this, with the construction of the Terminal 3 being a project positioned directly within the area of a large airport the construction space is very low. Therefore, multiple interests are involved in the project. The stakeholders include the municipality of Frankfurt, politicians, the people living nearby the airport, the businesses which will be affected by the construction works and the contractors hired for the construction works. With so many participants, an owner who changes his mind and stakeholders a lot of negotiations and tender rounds has been necessary from the start.

Objectives

To ensure the successful expansion, the following requirements were set byJakubeit (2005):

- The current capacity of 14 million passengers a year should be increased to around 78 million passengers a year (when fully expended with four piers, this should be even increased to 88 million people);
- The terminal should be designed in such a way that the entire infrastructure, baggage systems, transport, the piers, retail areas as well as the gates can be modified or expanded at any time during ongoing operations;
- The passenger path lengths should be in compliance with all transfer relationships within 45 minutes, while at the same time minimizing the number of cost-intensive stations of a new elevated railway on rail ;
- The air crafts should be positioned on the building at the terminal and at the same time efficient taxi traffic management to allow to the runways in the north;
- The traffic management should position 50 aircraft, 35 of them the size of a A380 or Boeing 747;
- The centrality of the check-in hall should be kept within reasonable limits;
- the entire building of the new Terminal 3 building should be designed to be very energy-efficient: consuming only half as much energy as Terminals 1 and 2 together;
- Fresh air should be guaranteed by an efficient displacement ventilation system.
- Fulfill the requirements of the Skytrax world airline rank, representing good standards of Staff Service for the home-base Airport environment (Skytrax, 2020).

The FAS has outsourced the construction management to one company, since this enabled them to coordinate all tasks in regard to the significantly complexity. The overall package, includes the control of the execution of the project in terms of qualities, deadlines, cost, however also with regard to optimized teamwork. Despite this, the teamwork was optimized by an comprehensive advisory approach is included, where specialist in the area of execution are included in the optimization, coordination and planning of the building construction processes. On top of that, the use of Lightweight Communications and Marshalling (LCM) Digital enabled information switches in daily progress control on the construction site (Scheinhütte, 2020). The new Sky Line train, similar to the existing Sky Line train, between Terminals 1 and 3 takes over eight minutes, including a quick stop at Terminal 2.

Risk identification techniques

Risk workshops
During the risk identification phase, the risks were identified using brainstorm sessions with the project team. The meeting was chaired by a risk manager of Drees & Sommer. The group of participants was defined by the risk manager in consultation with Fraport prior to the workshops. They were selected on the basis of their experience, their expertise and their function in the FA Terminal 3 project. Invitations for the workshops were sent out by Drees & Sommer.

Risk register
After that, the risk manager recorded the results of the risk workshops sessions in the project risk register. Throughout all phases of the risk management process, the risk register serves to continuously document the risks. The continuous use during all project phases is useful to make the results of risk management available to other project members, in particular to Fraport. Within the risk register, the Identification (ID) number, cause/category of risk, short description of the risk (keywords) and detailed explanation/description of the risk were recorded in the risk register.

From risk identification, through risk assessment and response development and up to the monitoring of the measures, all steps are recorded in the register and they are thus transparently documented at any time for all parties involved in the project. An extract of the risk register which was updated during the construction phase of the FA Terminal 3 project is visualised in Table D.1.

Risk-ID	Category	Title	Threat	Description	Risk Assessment	Probability	Impact
1	Processes	Internal decisions on GTP	Changed dates / execution specifications of committees	Stability overall schedule: Superordinate bodies make decisions that lead to a shift / change in the overall schedule.	Do not allow outside influences; targeted processing via change management	< 20%	medium
2	Legal	Technological progress through to commissioning	Additional changed conditions from approval procedures	The infrastructure and configuration of the security and border controls will be subject to changes due to technological progress until they are expected to be put into operation and will accordingly be adapted to the current state of the art	Timely coordination with the responsible authorities.	< 20%	small
3	Legal	Official / political change in the Schengen area	Changes in the law	Due to special events, the authorities can e.g. determine the suspension of the Schengen Agreement for one country, several countries or groups of countries or set additional control measures. Depending on the official decision, these measures are implemented	Timely coordination with the responsible authorities	< 20%	small
4	Stakeholder	Airline wishes	Airline wishes	If airlines are won over for Terminal 3, they could use special infra-structure requests such as closed gates, individual appearances in the CKI area or additional technological CKI or boarding to handle their processes	Consistent adherence to the change process with regard to user requests	> 20% - 50%	small
5	Economic	Airline Mix (Schengen - Non-Schengen)	Changed customer / market development	Rescheduling as a result of a changed airline mix (Schengen / Non-Schengen Pier).	Permanent communication with FTU to stick to the airline mix Customized marketing by FTU in terms of the underlying airline mix.	< 20%	very high
6	Economic	larger planes	Changed customer / market development	Planning changes as a result of non-ICAO-compliant aircraft boxes (larger aircraft of the airlines).	Monitor changes to the ICAO guidelines and, if necessary, communicate them to the project team.	< 20%	medium
7	Economic	Skytrax-Award	Changed customer / market development (production	Changes to the project requirements due to the implementation of the Skytrax requirements ("Airport Award").	Implementation only via an orderly change process.	> 50% - 80 %	small
8	Technical	Check-in concepts	Technology change	A possible introduction of a new check-in concept (check-in in transition) requires a change in the current planning.	None - external influences; targeted processing via change management	> 80%	medium
9	Legal	Approval process	Additional changed conditions from approval procedures	New conditions / secondary provisions from the supplements to the existing building permit, as well as conditions due to the influence of third parties.	Close coordination with the approval authorities (authority management).	< 20%	small
10	Management	Change of staff at Fraport	Fluctuation	Change of personnel leads to loss of knowledge. (Key player)	In the event of occurrence, orderly handover of tasks / responsibilities. Clear regulation of representation	> 20% - 50%	small
12	Stakeholders	Testing times building authority	Authorities	Due to the special approval procedure (unregulated special construction -> procedure according to §58 HBO) there are longer approval / test periods.	Submission of the change documents with a corresponding buffer time so that there are no delays. Targeted authority management.	< 20%	medium
13	Stakeholder	Bankruptcies - passenger boarding bridges	Especially key trades / significant insolvencies	Bankruptcy of the contractor for the passenger boarding bridges	The upstream market research is intended to validate the decision-making basis for the award.	< 20%	small
15	Technical	DIN-Normen	Rules of technology, standards	Change of recognized rules of technology. Due to the long period between the invitation to tender and the acceptance of the systems, DIN standards or similar could change. to change	Checking the validity of relevant standards, guidelines, etc. at the time of the invitation to tender (is a revision, adaptation or the like to be expected in the execution period?).	> 20% - 50%	small
16	Technical	Rules of technology, standards	Rules of technology, standards	If legal requirements and / or requirements result in the need for subsequent changes to the functional equipment of the passenger boarding bridges, these must be adapted through subsequent rescheduling, possibly also subsequent conversion.	Checking the validity of relevant standards, guidelines, etc. at the time of the invitation to tender (is a revision, adaptation or the like to be expected in the execution period?).	< 20%	small
22	Processes	Kunst	Changed deadline / execution specifications from	So far, no budget has been earmarked for art in architecture. If art is desired in the building, funds must be made available for this.	Clarification of the task. Budget procurement.	> 50% - 80 %	medium
24	Stakeholders	Insolvencies	Especially key trades / significant insolvencies	With a project of this size and the large number of awards (150-180), individual bankruptcies of companies are to be expected during the construction period.	Contractor due diligence during the procurement process (requests to participate). Setting up a procurement strategy (e.g. redundant assignment of key trades	> 20% - 50%	high
25	Stakeholders	Insolvencies	Especially key trades / significant insolvencies	Due to the long planning and construction time, the insolvency of individual planners is possible. The effects include the procurement of replacements for planners, loss of knowledge, deadline delays as well as supplements and additional costs for other planners.	Ongoing documentation of the updated planning; adequate / appropriate remuneration.Contractor due diligence during the procurement process (requests to participate).	< 20%	small
28	Economic	Competitive situation	Competitive situation	The award price risk depends on the capacity utilization of the mechanical engineering market (few passenger boarding bridge manufacturers = limited market) and the steel prices at the time of award.	Through early market research and targeted inquiries - in consultation with ZEB - the project should be advertised on the market in order to improve	> 20% - 50%	small
30	Economic	Competitive situation	Competitive situation	The award prices can fluctuate enormously depending on the market situation, resulting in a risk that fluctuates between + and - 25% depending on the capacity utilization of the mechanical engineering market and the steel prices.	Improving competition in the market by promoting the project on the market. Division into lots for more competition.	> 20% - 50%	medium
31	Economic	Competitive situation	Competitive situation	In 2018, the framework agreement with the company os, which previously provided the active components for the Fraport IUK network, will expire. The assignment to a new company harbors quality and cost risks. -> Board decision, concerns	The necessary funds must be taken into account and made available to the program. The product or project cost centers must be specified.	> 20% - 50%	small
32	Stakeholder	Demonstrationen	Interest groups	Due to the political explosiveness, demonstrations against the new construction of Terminal 3 are to be expected. This can lead to increased costs for securing the construction site.	Clear communication concept for information "to the outside".	> 20% - 50%	small

Table D.1: The risk register which was valid during the construction phase of the Frankfurt Airport (FA) Terminal 3 project, adapted from Drees & Sommer

34	Technical	IT-System	Technology change	Technology changes in IT systems can lead to planning changes in the course of the corresponding commissioning of FAS GmbH by FRAPORT AG.	Strict adherence to the change management process. with evaluation of the cost and schedule effects of a possible IT system change, as a decision-making basis for FRAPORT AG.	> 20% - 50%	small
35	Stakeholder	Lawsuit in the district	Publicity	Action against building permit has no suspensive effect	Consideration of the essential concerns of the parties involved in advance or support of the authorities with the defense.	< 20%	small
38	Legal	Legal dispute with planners and executing companies.	Rechtsstreit	Legal disputes with planners and executing companies.	Ensure high contract quality by engaging specialist lawyers for the preparation of the LV and for contract review. Direct reporting in the event of contractual discrepancies / disputes and treatment of the topics in the	> 20% - 50%	medium
52	Management	AWARO	Organisation	AWARO functionality not sufficient (poor data speed, limited search function)	Proficiency test and system improvement Sufficient IT support must be ensured	< 20%	medium
76	Management	Specification of requirements	Significant deviations from the approved planning status	Changed requirements from the room book -> possibly incorporation / revision required	Import room book, assessment FLP, decision AG Compliance with change management process	> 80%	small
128	Management	Specification of requirements	Significant deviations from the approved planning status due to internal requirements	The check-in area has so far been planned with conventional counters. These are currently on a pedestal that houses the hall's source air supply. Vending machine systems that may be desired in the future must be directly on the	Implementation only via an orderly change process (change management).	> 80%	high
129	Legal	Conversion of national to European laws /	Legislative changes	Conversion from national to European construction product law, usability certificates and test standards.	Definition einer vertraglichen Regelung für die Planerverträge ab PS 5.	> 80%	high
137	Economic	Passenger boarding bridges - additional QA incidental costs	Significant changes in the procurement markets	The award price risk depends on the required quality. This may not be available in Europe. On-site QA is only possible with increased effort.	The award price risk depends on the required quality. This may not be available in Europe. On-site QA is only possible with increased effort.	> 20% - 50%	small
163	Technical	PTS - Systementscheid	Technology change	The system decision will not be made until November 2017. Until then, the length of the wagon is open. A system provider offers a different wagon length compared to the other providers. Should the tender be in favor of the system provider	The planners were asked to estimate a possible rescheduling effort in terms of time, quality and quantity. In addition, the planners were asked to show how planning could be made more flexible.	> 20% - 50%	medium
173	Management	Simulation Entrauchung Innius	Accompanying optimization technology	Innius only carried out 5 simulations for the supplementary building application. According to the coordination of FAS / Innius, the other areas of the end of 2017 will be simulated. Until the simulation is complete, there is a risk that planning changes will be necessary	Implementation of the simulation results.	< 20%	small
166	Management	Additional requirements of the HMWEVL	Additionally changed editions	There is a cost and deadline risk due to the additional requirements of the HMWEVL (Hessian Ministry for Economic Affairs, Energy, Transport and State Development). These require that compared to the feasibility study, a larger construction volume in the same		> 50% - 80 %	medium
167	Management	Building permit Pier G	Additionally changed editions	No deadline security for the timely building permit before the execution of the general contractor service and the associated advance measures, especially the media channel. In addition, the procedure for applying for the		> 50% - 80 %	medium
168	Economic	Market risks for finding a general contractor	Competitive situation	Market risks for finding a general contractor, taking into account the deadline and cost targets of the project.		< 20%	small
53	Management	ORAB	Project organization and processes	ORAB functionality is insufficient (mapping of the requirement, connection to the current planning status, lack of transparency with regard to interfaces)	Clear definition of requirements with regard to the room book and ordering of all necessary functions.	> 20% - 50%	small
57	Management	Equipment planning - Terminal	Planning	Insufficient integration of the specialist planning - The equipment and master planning has an impact on the shell and specialist planning	Clear definition of requirements with regard to the room book and ordering of all necessary functions....	< 20%	small
61	Management	Heating cooling load	Planning	The new heating and cooling load calculation leads to changed layouts of pipe dimensions and the like. a.	Examination of the effects through architecture and specialist planning	< 20%	small
62	Management	Detailplanung CHM - Terminal	Planning	Contradiction details CHM / W + W planning. Detailed CHM planning cannot be implemented / buildable.	Calculation-relevant deviations for the KoBe W + W are to be pointed out by W + W before the KoBe are drawn up and clarification must be brought about with CHM. To bring about final clarification with CHM by PL.	< 20%	small
68	Management	Planning	Project organization and processes	Risk that the existing W + W planning, especially in the public areas of CHM, will not be confirmed and there is a need for clarification regarding the CHM LPH4 planning	Early integration and confirmation of the PS-K planning by CHM	> 50% - 80 %	small
73	Processes	Fire protection during the construction phase	Planning	The fire protection measures during the construction phase are not included in the cost calculation.	The costs are to be determined and taken into account in the project budget.	< 20%	small
74	Processes	Support from CHM	Planning	Design master planning cannot be implemented, revision required. Timely input by CHM required.	Revision of CHM	> 50% - 80 %	small
78	Processes	Cooling ceilings (piers)	Planning	The system does not fully meet the various functional requirements of the cooling ceilings.		> 80%	small
80	Processes	Smoke extraction	Planning	Smoke extraction in public areas, risk if the results of the simulations deviate from the planning.	Follow up the final smoke extraction simulation of changed areas	> 50% - 80	medium
84	Processes	Roof structures- Terminal	Planning	Follow up the final smoke extraction simulation of changed areas (prioritized in terms of time).	Creation of an enclosure concept as a decision template for the client. Provision in cost forecast of € 2.5 million	> 50% - 80 %	small
85	Processes	Roof structures - piers	Planning	Specification of planning (planning depth) - housing of the building services on the following roofs: - TGA roof pier H - TGA roof pier J - Design changes to be expected	The technical solution has been developed and is implemented in the planning. The assessment of the cost risk is pending.	> 80%	small

87	Processes	The facings can be revised	Planning	As a result of the coordination of the revisionability of the cladding, it may be the case that the existing planning cannot be implemented and a modified wall construction / design must be developed.	In-depth consideration of the revision areas as clarification of whether the planning can be continued with the existing design.	> 50% - 80 %	medium
90	Processes	Soil survey - piers	Planning	Soil expert opinion was not included in the planning. Optimization of the existing planning. On the basis of the plans submitted, in-depth coordination is still required afterwards. Possibly. Changes to the floor construction and / or	Revision as part of the K phase removal of defects Coordination of the optimization in the planning team including structural engineer. Based on the results of the PS-K, FM will continue planning, including the height access concept, until the start of PS5	> 20% - 50%	small
98	Processes	Bouwphysic - Terminal	Planning	Building physics - proof of sound insulation - issues relating to building construction to be clarified	Coordination discussions and reverberation measurements are to be carried out. Results are to be incorporated into LpH5.	< 20%	small
99	Processes	Bouwphysic- Piers	Planning	Building physics - proof of sound insulation - issues relating to building construction to be clarified	Familiarization with the PS5.	> 80%	small
101	Processes	Security concept	Planning	The detailing and concretisation of the security concept for Terminal 3, as is typical of the plan young, as an internal planning service and basis for other specialist planning, could lead to the need for adjustments in specialist planning.	Optimal timing of the safety planning in the planning, early comparison of the intermediate planning status of the safety planning with the ongoing specialist planning. Monitoring compliance with deadlines.	> 50% - 80 %	small
113	Processes	HK-Last	Planning	It is necessary to update the heating and cooling load calculation (due to the new VDI, lighting planning).	Revision can be done in performance phase 5, before AP2	< 20%	klein
114	Processes	Approval process	Planning	The notification of consent expires and must be renewed at the TAB. The approval notification is a prerequisite for approval from the building supervision (BAF). The applications for a notification of consent according to §60 BOStrab for the changed station	Coordination with PTS Projekt, Wolfgang Holzhausen - Determination of the time of submission of the notification of approval for submission in relation to the PTS station T3 building application	< 20%	small
132	Processes	ORAT	Project organization and processes	The required lead time for the start of flight operations (ORAT) is not / not correctly taken into account in the detailed construction schedule.		< 20%	small
134	Stakeholders	Defects in passenger boarding bridges	Execution defects	As a result of poor performance, acceleration measures are to be provided	continuous project monitoring	< 20%	small
135	Processses	Disruptions in the construction process	Disruptions in the construction process	Due to a delay in the construction of the Terminal 3 sub-project, protective measures are required for the passenger boarding bridges.	Make provision	> 20% - 50%	small
138	Processes	Wartungskosten	Planning	Maintenance costs in the commissioning period, after acceptance, before handover to operation. E.g. Filter change	Check cost calculation for items. Take up performance positions in the course	< 20%	small
140	Economic	A10-Liste	Quantities and prices	Equipment elements on the A-10 list are rated too low; Equipment planned by CHM that is not included in lists and was not recognized in the WuW plan.	Verify costs.	> 50% - 80 %	medium
142	Economic	Protective measures for finished services	Quantities and prices	Protection of finished systems during the construction phase, possibly additional costs from the construction process	The construction process must be adjusted if necessary. Course positions are to be included in the advertisements. A provision in the project reserve must be made.	> 20% - 50%	small
143	Environment	Required thickness natural stone slabs	Bouwmaterialen	Natural stone facades inside (thickness 40mm instead of 30mm, allowance for plate size)	Check quality and buildability. Provision in project reserve	> 20% - 50%	small
148	Processes	Kitchen planning Pier J	Planning	Planning change required if the Darmstadt RP does not issue a permit based on the risk assessment.	Coordination with RP Darmstadt and implementation of the risk assessment.	< 20%	medium
150	Processes	System control	Planning	The escape staircase and the fire brigade elevator of the apron tower (VFT) each have their own smoke protection pressure system (RDA), which are connected to one another via a common antechamber when the lock doors are open. According to the requirements of TüV and Vorbe	In order to exclude the acceptance-relevant risk of interaction, the following solutions were agreed in coordination with preventive fire protection and fire protection planners. Relocation of the protection goal to the access door of the technical rooms in the respective	> 80%	small
154	Processes	Fortification concept for the routes	Planning	Fastening concept: ensuring that the TGA routes can be assembled, especially in densely populated areas, as well as increasing the flexibility of the fixings in flat ceilings by installing anchor rails (V5) in accordance with the requirements of the specialist planning HK	Implementation of the increase in the flexibility of the fastenings in flat ceilings through the installation of anchor rails.	> 80%	medium
174	Project participants	Luggage fire in the luggage tunnel	Planning gaps	A burning baggage is transported through the baggage tunnel into the terminal building.	Ensure that burning baggage from the GFA tunnel is detected in good time and is not transported into the terminal.	< 20%	small
175	Project participants	Design requirements	Planning gaps	Due to design requirements, the standard slats for the cooling ceilings are not used. This creates a potential cost risk.	Use of standard slats that do not meet the design requirements. Alternatively, ensuring that the special product can be purchased at the prices of the standard product due to the large quantities.	< 20%	medium
169	Project participants	Planning	Delay in performance	There is a deadline risk due to the extremely tight planning time of the general planner and the associated necessary planning services from third parties (e.g. fire protection experts)		> 50% - 80 %	medium
170	Project participants	Delayed tendering cost groups 300 and 400	Delay in performance	The tender for cost groups 300 (building construction) and 400 (TGA) is on the critical path. The main reason for this is the insufficient tender planning (key details) at the time of the report and the late finalization of the Ra	Talks are held with the general planner's management.	> 50% - 80 %	medium
171	Proceses	Planning	Specification of planning (planning depth)	The calculated costs of Pier G are based in part on assumptions at the time of the report. Both technical systems and structural qualities are not conclusively defined. Performance gaps that arise in the course of working through the draft	The cost estimates are currently being examined by APS-T3.	> 50% - 80 %	medium
172	Environment	Planning interface for outdoor facilities	Different execution	Unclear planning interfaces to the outdoor facilities, as these are currently not part of the measure.	Coordination discussions to clarify the interfaces between the sub-project outdoor facilities and the projects Terminal and Pier G	> 80%	small

E
Correlated Schedule Risk Analysis Model (CSRAM)

In contrast to other approaches to risk analysis, the Correlated Schedule Risk Analysis Model (CSRAM) incorporates the correlation effect between activities and between risk-factors when performing uncertainty evaluation on construction network. The model is designed in such a way that the necessary input data is flexible to adapt to specific conditions (Ökmen & Öztaş, 2008). Therefore, the risk data is mainly depends on past experience (subjective). On top of that, the model can be mechanised easily by applying table processor software and surrounded macros.

The input data of CSRAM can be determined at the risk assessment stage of the risk management process. In doing so, the risk-factors are represented by risk-factors' situation probability boundaries, represented in three random events: better-than-expected, expected and worse-than-expected. Correlation coefficient values are not necessary, because the risk-factors are not represented with probability distributions (Ökmen & Öztaş, 2010), rather the correlations are captured qualitatively.

The input data is processed by the CSRAM through Monte Carlo Simulation (MCS) (Ökmen & Öztaş, 2015). This purpose of this is to integrate the correlation between the risk-factors indirectly in both positive and negative directions. As a result, the correlations between the risk-factors can be contained through two steps. Firstly, the investigated risk factor situation probability boundaries of the risk factors are linked. Secondly, the same random numbers for the correlated risk factors are determined. To capture the correlations between the schedule and risk-factors are captured qualitatively and indirectly, random number are utilized. Especially, since the probability of acquiring a value between 0 and 1 during a random number generation is equal when uniform probability distribution is used.

In addition, the simulation-based uncertainty evaluation algorithm stimulates a schedule several times and helps the engineer. This enables a project manager to observe how the real system might behave in reality. Based on this, the uncertainty effect on the project schedule can be analyzed, which refines the risk-factor effect on the project schedule at the end of the CSRAM's execution. The information provided by CSRAM is valuable for a decision maker or construction manager to acquire risk response strategies, know in advance the understanding of the schedule variables to various risk-factors and take safety measures for the success of the project.

The simulation-based CSRAM captures the correlation between risk-factors and between activity duration's concerning the level of uncertainty essential in the schedule (Ökmen & Öztaş, 2008). The flowchart of CSRAM is visualised in Figure E.1. A brief description with regard to the input and output risk data needed for the implementation of CSRAM are lised below:

Input CSRAM :

- Activity network information (optimistic, most likely and pessimistic activity durations, predecessor activities, network relationships in the form of FS, SS, FF or SF, and lag & lead times between the activities;)
- Activity Risk-factor influence degrees (Risk-factors and their expected effects on each activity in the form of very effective, effective or ineffective qualitative terms;)
- Risk-factor situation probability boundaries (Quantitative subjective data showing the probability of a risk-factor's occurrence in the form of better-than-expected, expected and worse-than-expected;)
- Correlated risk-factors and simulation properties.

Output CSRAM :

- Uncertainty evaluation on activity durations, activity float times, activity criticalities, and sensitivity of activities to risk-factors (uncertainty evaluation on activity-level);
- Uncertainty evaluation on activity paths, path float times, path criticalities, and sensitivity of paths to risk-factors (uncertainty evaluation on path-level);
- Uncertainty evaluation on project duration and sensitivity of the project schedule to risk-factors (uncertainty evaluation on project-level).

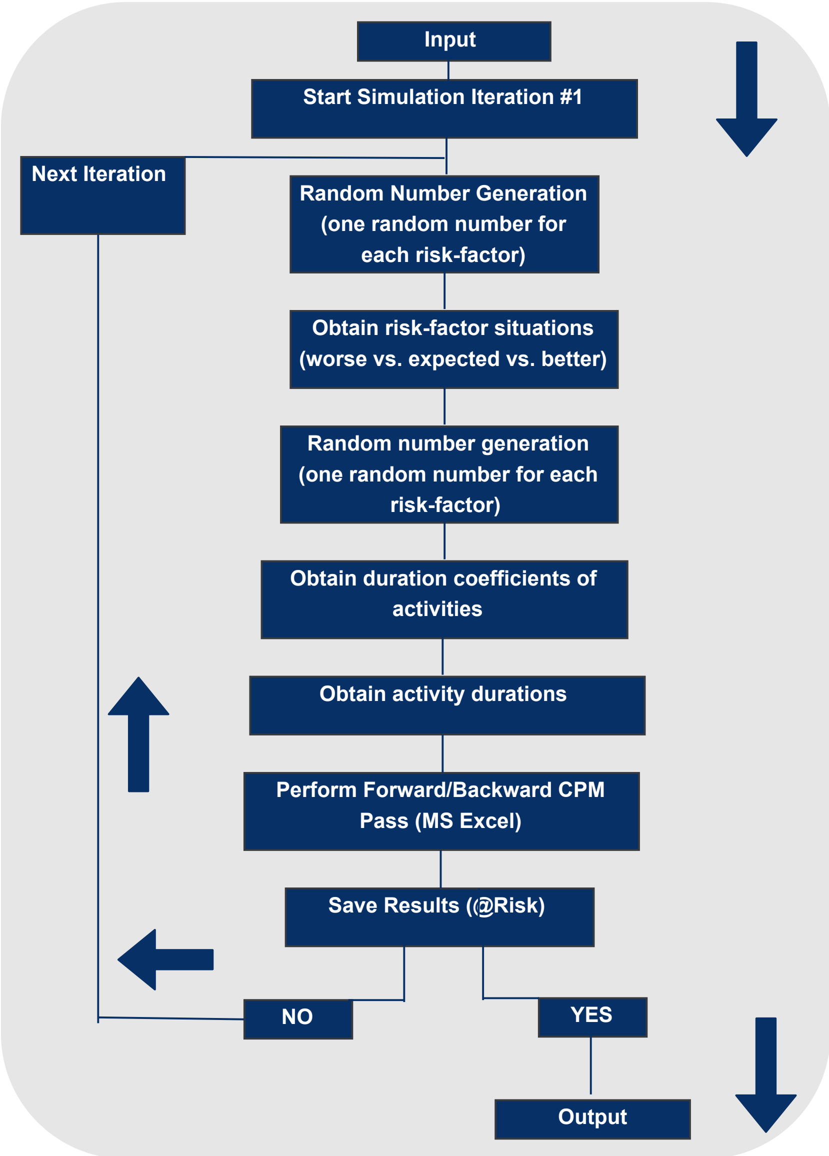


Figure E.1: Flowchart of CSRAM (Ökmen & Öztaş, 2008)