UNCERTAINTY AND PROJECT MANAGEMENT IN CONSTRUCTION PROJECTS: APPROACHES USED BY PUBLIC CLIENTS

Master Thesis

Mamoun Meggouh

25th August 2022

Master Thesis

UNCERTAINTY AND PROJECT MANAGEMENT IN CONSTRUCTION PROJECTS: APPROACHES USED BY PUBLIC CLIENTS

By

Mamoun Meggouh

Master of Science: Construction, Management and Engineering

Institution: Delft University of Technology,

Faculty of Civil Engineering and Geosciences,

The Netherlands

Date: 25th August 2022

Information

Author:

Name: Mamoun Meggouh

Student number: 4677331

Birth (date and place): 18th February 1999 (Rabat, Morocco)

Bachelor degree: BSc Civil Engineering (Delft University of Technology)

Graduation Committee:

Chair: Prof.dr.ir. M.H. Hermans

Main supervisor: Dr.ir. M.G.C. Bosch-Rekveldt

Secondary supervisor: Dr.ir. B.M. Steenhuisen

Company supervisor: ing. W. Kraamer (Rijksvastgoedbedrijf)

Preface

In pursuit of a master degree in construction management and engineering, I am delighted to present my research on one of the most challenging topics in the field of construction project management: Uncertainty. Executing this research has been a rich process with many fun experiences, challenges and lessons learned. Through this process, I was supported by a great amount of academic and practical expertise from my supervisors. I want to thank them all for their guidance, support and constructive criticality. I also want to thank the Rijksvastgoedbedrijf and Rijkswaterstaat for facilitating this research and involving the right people to interview, as well as the interviewees themselves, who were very enthusiastic about the topic. This end product is for all who are interested in the role of uncertainty in construction projects. I hope that this report improves the understanding of this complex topic and makes readers more aware of uncertainty and how to deal with it in construction projects.

Mamoun Meggouh

Amsterdam

25th August 2022

Summary

We live in increasingly uncertain times. Also in the construction sector, uncertainty will continue to play a role. Construction projects become more complex, which means that it becomes more difficult to manage the different interrelated and interacting attributes involved, such as organisations, technical systems, environments and contracts. Public clients have to manage these complex construction projects, and are therefore confronted with preparing for uncertainty in those projects. The aim of this research is to understand how public clients can manage uncertainty better in construction projects. The main research question is as follows:

How can the management of complex construction projects by public clients be improved in preparation for uncertainty?

To answer this research question, concepts from the literature are compared with empirical data. Literature concepts are used to describe what can be uncertain in projects and how to manage this uncertainty before it impacts projects. Empirical data is used to describe how public clients manage projects to prepare for uncertainty. Eventually, these two are compared to see if practical improvements can be suggested. A case study is conducted on four complex construction projects, managed by two large public clients in the Netherlands. At total of 17 Interviews were conducted across the cases, with members of the project management teams. Participants were asked about uncertainties in their projects and the management of those uncertainties before they impact(ed) the project.

The literature points out that uncertainty can be present in eight aspects of projects: Objectives, methods, market, resources, stakeholders, contracts, technology and environment. And managing uncertainty can be done by three types of approaches: Learning, selectionism and representing complexity. The latter contains various approaches, which are the involvement of decision making, integrated projects teams, planning stage strategies and governability.

The results show that uncertainty is present in all eight aspects throughout the cases. The most occurring uncertainties were found in the stakeholders, objectives and environment. Uncertainty in objectives was mainly in the form of scope uncertainty and not really related to the main objective of the project. When looking at the management of those uncertainties, public clients mainly use the approach of representing complexity and learning in all cases. Representing complexity is seen especially in the use of planning stage strategies through organizational structures that focus on collaboration and integration is found in all cases. In addition, three of the four cases showed signs of involving decision making to prepare for uncertainty and governability, which is mainly seen by creating cohesion between project parties and holding a financial reserve to account for unexpected impacts. Learning is also a prominent approach which was used in three cases, all being renovation projects. This is seen in the form of (off site) experiments, mockups and a pilot. Selectionism was not found to be used in any case. Neither was integrated project teams.

This brings the following improvements: Selectionism and integrated project teams may be used by public clients in the management of uncertainty in construction projects. However, selectionism would require an intense use of resources, both physical and organizational. It is therefore still a question if this approach is feasible in construction projects. In addition, governability can be further developed by focusing more on flexibility and generativity in projects.

Table of contents

List of figures

List of tables

1.Introduction

1.1 General introduction

Construction projects are vital for the social and economic development of a country. Especially in the Netherlands, where the population density is growing, where climate developments have a large impact on the liveability and where tax money is allocated and spent with care. Evidently, there is a need to manage and complete these projects successfully. However, the uncertainties involved in construction projects can hamper successful performance. Large and complex projects like the Noord Zuidlijn and HSL-Zuid were subject to uncertainties which caused delays, cost overruns and conflicts. Large-scale construction projects have experienced serious drawbacks as a result of events that were not considered beforehand or events that were even unimaginable.

One of the projects which demonstrates the challenges in construction projects is the Randstadrail project. The Randstadrail project is an infrastructure project that was characterised by high complexity and uncertainty (Koppenjan et al., 2011). The project involved a reconstruction of train, tram and metro rail infrastructure across Rotterdam and the Hague. Two regional public authorities and a cooperation body of municipalities were involved as clients. The project costs were slightly over a billion euros (which was within budget) and it was delivered a year over schedule. In the initial stages of operation, several issues occurred with the technological system (such as derailments). There was limited knowledge about the new application of several technical systems, which turned out to have unexpected implications on the project (Koppenjan et al., 2011). Complexity was also present in the different organisations involved in design, construction and operation. As a result, this project faced uncertainty in how the complexity of the organisations and the novelty of the technology would engage in delivering a light rail infrastructure line successfully.

Construction projects are becoming increasingly complex (Baccarini, 1996; Cooke-Davies et al., 2007; Williams, 1999). This makes projects unpredictable and difficult to manage (Kiridena & Sense, 2016). It is widely acknowledged that complexity in projects causes uncertainty (Baccarini, 1996; Bosch-Rekveldt et al., 2011; Cooke-Davies et al., 2007; Kiridena & Sense, 2016; Vidal & Marle, 2008; Xia & Chan, 2012). Complex projects face significant uncertainty, especially at the start (Jaafari, 2001). In practice, construction projects regularly suffer from negative consequences of events as a result of complexity and uncertainty (Zhu & Mostafavi, 2017). Positive effects and opportunities related to uncertainty are often overlooked or neglected (Perminova et al., 2008; Ward & Chapman, 2003). Hence, construction projects are challenged to cope with complexity and uncertainty in order to deliver their objectives.

Several efforts are made to improve the management of construction projects to deal with uncertainty. Over the last two decades, project management has mainly focused on risk management and uncertainty management as methods to deal with uncertainty (Long & Cheok, 2019). More recently, studies have also looked at managing complexity as a means to deal with uncertainty to achieve successful project performance (Brady & Davies, 2014; Giezen, 2012; Kardes et al., 2013; Pich et al., 2002). However, more knowledge is needed about the kinds of uncertainty that play a role in construction projects specifically and how to deal with uncertainty in the management of complex projects.

Public clients are the organisations that commission, fund and manage construction projects on behalf of the government. In the Netherlands, there are several public clients involved in complex construction projects. Rijkswaterstaat (the national infrastructure agency), Rijksvastgoedbedrijf (the national real estate agency), ProRail (the national rail-infrastructure agency), provinces and municipalities are all examples of Dutch public clients. Public clients need to deal with uncertainty

effectively, as they have a prominent role in the initial stages of complex construction projects. In these stages, uncertainty plays a significant role (Kolltveit et al., 2005; Migilinskas & Ustinovichius, 2006). Therefore, it is interesting to examine this role in managing uncertainty in construction projects. From the perspective of Dutch public clients, there is no satisfying answer yet on what different types of uncertainty play a role in construction projects and how uncertainty is or should be managed. These organisations are exploring ways to deal with uncertainty in their project management strategies.

1.2 Setting the scene

The purpose of this report is to present a master thesis on the uncertainty that plays a role in construction projects and how public clients manage this uncertainty. In pursue of better managing uncertainty, this research also aims at improving the management of construction projects by public clients with regards to uncertainty. This is done by exploring the different uncertainty that is present in construction projects and the current way of dealing with uncertainty by public clients in the Netherlands. Thereby, an image is created of the uncertainty in Dutch construction projects and the current approaches used by public clients to deal with it. Using this image, points of improvement are identified based on a comparison between the current approaches used, the kinds of uncertainty present in the context of projects and managing strategies that deal with uncertainty in the literature. Hence, the focus of this research is on three aspects:

1. Uncertainty in projects
2. Management of uncertainty
3. Improvement in the management of uncertainty

So what do these aspects really mean? In the remainder of this section, these aspects are defined and clarified in the context of this research.

1.2.1 Uncertainty in projects

Speaking bluntly, anything can be uncertain. Nothing is completely certain at all times. So when is something considered an uncertainty in the context of project management? To answer such a question, we return to the classical distinction between uncertainty and risk in social science, denoted by Frank Knight (1921) and Keynes (1937). In case of uncertainty, one cannot assign a probability to any outcome. In other words, there is no scientific basis to determine what is likely to occur. When speaking of risks, the general principle is that probabilities can be assigned to certain outcomes. Next to this distinction, Perminova et al. (2008) defined uncertainty as a context that allows risks (with negative impacts on project performance) and opportunities (with a positive impact on project performance). In general, uncertainty applies when you do not know what will happen, what can happen and what is likely to happen to the project. This research is specifically looking for things that are uncertain in construction projects.

According to the definition of Perminova et al. (2008), uncertainty should have a possible impact on the project. Since this impact is not specified in the paper, it is assumed that it can be anything: Events, changes, emerging circumstances, issues, etc. Obviously, this impact is unexpected and unforeseeable. However, not all impacts are completely unexpected. For some uncertainties, possible impacts can be expected or anticipated, which makes people aware of this uncertainty. This is illustrated by Floricel & Miller (2001) in Figure 1. The left circle represents all anticipated possibilities in the future world and the right circle represents all realities of the future world.

Eventually, the reality matches some of the expectations in the anticipated world. The events that are both anticipated and realised are called realised risks. Events that occurred in reality but were not anticipated are called surprises. The focus of this research is on realised risks and surprises.

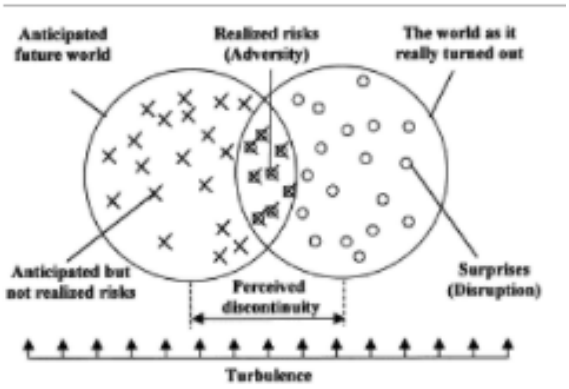

Figure 1: Uncertainty illustrated (Floricel & Miller, 2001).

1.2.2 Management of uncertainty

Adding to the focus on uncertainty, this research also looks at the management of uncertainty in construction projects. Uncertainty can be managed from two perspectives: preparation and reaction. First, in preparation for uncertainties, they can be managed before unexpected impacts occur in the project. Second, in reaction to uncertainties, management focuses on dealing with the effects of uncertainty after the occurrence of unexpected developments. The nature of these two management processes is different, and therefore they are distinguished. This research focuses only on the management processes in preparation for uncertainty. The main reason for this choice is that public clients play an important role in the initial phases of the project. They are therefore important contributors to the management of uncertainties before they impact the project.

In this research, managing in preparation for uncertainty means to direct certain actions, decisions, processes and interactions towards (the possible effects of) uncertainties before they impact the project within the scope of project management. Koppenjan et al. (2011) defined project management as: ‘’*The complete set of decisions regarding the setup, organisation and management of a project, taken during the various phases of the project, aimed at coordinating the efforts of the various actors involved in order to successfully realise the project.*’’. Within this definition, this research seeks to understand what is done in the project management of public clients to deal with uncertainty in construction projects.

Regarding the role of public clients, it is important to distinguish between public clients and government clients. The latter refers to the Dutch state departments (ministries), who often act as clients of public clients. Government clients determine specific needs for the development of construction facilities based on policy and decision-making processes. The focus of this research is on the public client, who is often part of a ministry (Rijksvastgoedbedrijf and Rijkswaterstaat are such public clients) and enacts assignments for government clients. They are responsible for organising and delivering construction projects for those ministries. This is done through project management using a team of project managers, also called the IPM team (*RVB Kader IPM* , 2021): The public client initiates a scope of construction work and requirements and contracts a private party to carry out

this work within specified resources and time-frames. The research focuses on the project management enacted by the project teams of public clients. This is illustrated in Figure 2.

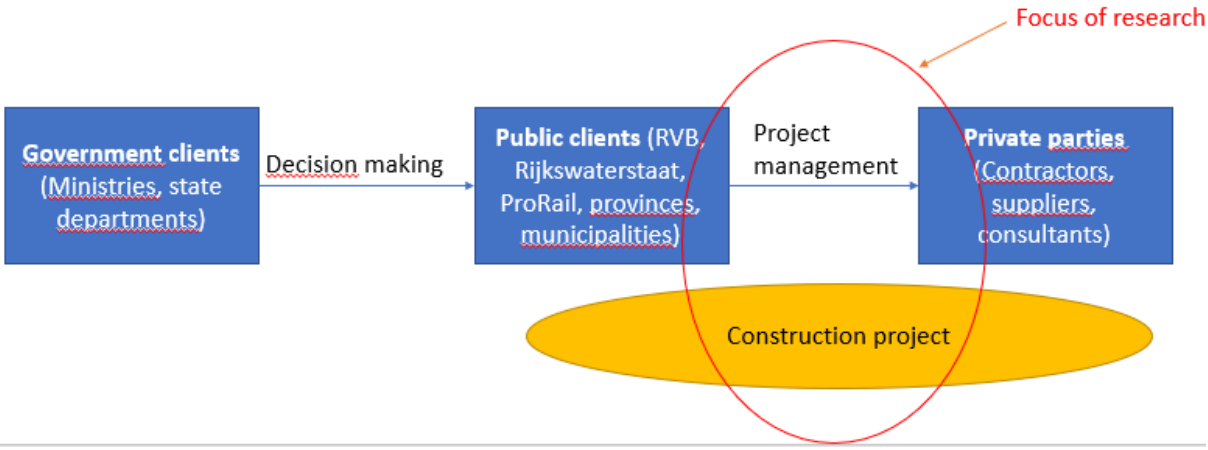

Figure 2: Construction projects in relation to public clients and government clients.

The management of construction projects by Dutch public clients is practiced using Integral Project Management (IPM) . A detailed description of IPM is given in APPENDIX 2: The IPM model. The aim of IPM is to offer a management approach that incorporates many different perspectives, interests, disciplines and components in projects that are becoming larger and more complex (*RVB Kader IPM* , 2021). The philosophy behind it pleads for the recognition and inclusion of these different aspects. Arguments from different disciplines are integrated into the decision-making by equal contributions from all members the project management team (*RVB Kader IPM* , 2021). The IPM project team consists of five management roles that represent different fields of discipline in the management of projects. In some cases, one person can fulfil multiple roles (*RVB Kader IPM* , 2021), depending on the size of the project and the available competences within the team. The five IPM roles are (*RVB Kader IPM* , 2021):

1. Project management
2. Project control management
3. Environment management
4. Contract management
5. Technical management

1.2.3 Improving the management of uncertainty in projects

After defining uncertainty and the management in preparation for uncertainty in projects, this research also aims to provide suggestions on how this management of uncertainty can be improved. However, the difficulty of improving the management of projects in preparation for uncertainty lies in the uncertainty itself. How do you better prepare for something that you cannot predict or foresee? Answering such a question would require extensive and accurate data on different ways of preparing for uncertainty and their effects on the project. This research does not pursue that path.

Hoewever, some researchers have aimed to tackle such a question. As a result, different ‘’proposed solutions’’ to prepare for uncertainty are found in the project management literature. They are mainly based on case studies on complex projects with high levels of dynamics and unknowns. Next to the traditional predict and control approach of project management (Koppenjan et al., 2011),

flexible approaches of learning and selectionism (Pich et al., 2002) and complexity facing approaches (Brady & Davies, 2014; Floricel et al., 2016) are presented as suitable approaches to deal with unforeseeable uncertainty, changes and dynamics. Therefore, a comparison between these approaches and the approaches used in practice can be a good basis to suggest improvements.

1.3 Structure of the report

The structure of the report is as follows: It starts with the research design in chapter 2, which explains the main objectives, research questions and methods of this research. Thereafter, the literature review (Chapter 3) of this research introduces the main concepts in the literature on uncertainty and complexity. In this chapter, the kinds of uncertainty in projects are explored and the ways to manage in preparation for uncertainty. The following chapter (4) describes the main managing approach of public clients in complex projects based on a review of the documents related to project management. More specifically, it describes how public clients aim to prepare for uncertainty in projects. Chapter 5 presents the results of the research. Chapter 6 provides an analysis of these results to point out the main implications. In Chapter 7, these implications are discussed in relation to the literature, practice and the possibilities for future research. To end the report, chapter 8 provides the conclusion by answering the main research questions and recommending further actions for public clients and future research.

2. Research design

The introduction described different aspects related to uncertainty in complex construction projects. These aspects form the focus of this research. This chapter explains the objectives of this research, including the research questions, scientific relevance and research methods and is structured as follows: In 2.1, the objectives of the research are described. In section 2.2, the research questions are formulated. After that, the scientific relevance is explained (2.3). Lastly, the research methods are introduced and explained in section 2.4.

2.1 Research objectives

The main objective of this research is to find possible improvements in the management in preparation for uncertainty in construction projects. In pursue of this objective, the aim is to better understand what is uncertain in construction projects and how public clients practice project management to prepare for this uncertainty. This understanding is needed to compare the approach of public clients with approaches in the literature. With this comparison, gaps can be identified between what is done by public clients and what is considered best practice by the literature. Additionally, it helps to understand the types of uncertainty that are present in construction projects in the Netherlands. Three main objectives can be identified:

1) **Exploring uncertainty in construction projects**

The goal is to explore what is uncertain in construction projects. This results in a better understanding of how uncertainty in Dutch construction projects can be classified and what the nature/source of these uncertainties are. This determines the main challenges that public clients are dealing with in the first place.

2) **Defining the management of projects in preparation for uncertainty**

This research reveals what can be done to manage in preparation for uncertainty and what is done by public clients to manage in preparation for uncertainty. An overview is given of approaches in the literature and approaches used by public clients. It is about what is done exactly to manage uncertainty and how does this aim to deal with uncertainty before it impacts construction projects.

3) **The improvement of management in preparation for uncertainty**

The final objective of this research is to figure out if and how the current practice by public clients can be improved. This is done by looking at how the literature of project management addresses the challenge of preparing for uncertainty and how this can be considered better practice in managing uncertainty. The final result is a review and comparison of the findings of this research with the findings in the literature to identify improvements.

2.2 Research questions

In line with the objectives of the research, the main research question of this research is:

How can the management of complex construction projects by public clients be improved in preparation for uncertainty?

Four sub-questions are put in place to support the answer of the main research questions:

1. What uncertainties are involved in construction projects?
2. What project management approaches can be used to prepare for uncertainty?
3. How do public clients manage construction projects in preparation for uncertainty?
4. How can the project management approaches in the literature improve the management of projects by public clients?

2.3 Scientific relevance

The research contributes to the literature on project management and construction management in two ways:

1. The types of uncertainty that are specifically encountered in construction projects are explored. Previous studies have looked at uncertainties in construction projects, but these did not look at the specific effects of complexity and dynamics (Bryde & Volm, 2009; Chapman & Ward, 2000; Kolltveit et al., 2005; Kreye et al., 2019). Many authors have explained which uncertainties play a role in projects (Atkinson et al., 2006; Chapman & Ward, 2011; Jaafari, 2001, 2003; Perminova et al., 2008; Ward & Chapman, 2003, 2008). However, these uncertainties apply to all projects, and not specifically to construction projects. In addition, there is a body of literature that explains what makes projects complex, and hence uncertain (Bosch-Rekveldt et al., 2011; J. Geraldi et al., 2011; J. G. Geraldi & Adlbrecht, 2007; Kiridena & Sense, 2016; Luo et al., 2017; Maylor et al., 2008; Vidal & Marle, 2008). Only Luo et al. (2017) discussed the implications of complexity on construction projects in particular. This research can explore the uncertainties that are specifically present in complex construction projects. Furthermore, this research offers a contemporary view of uncertainties, taking into account uncertainties related to dynamics, unknowns and information. This is useful because projects are becoming more complex in the coming years.

2. The application of various approaches of managing uncertainty in the literature is explored in construction projects. It is not clear how the approaches in the literature apply to construction projects. Learning and selectionism have been discussed as approaches that are specifically useful in highly uncertain projects with many unknowns, involving innovative technology and intense development efforts (Pich et al., 2002). Construction projects are not so uncertain in technology that they have such high levels of unknowns both at the start and during execution (Collyer & Warren, 2009). It is also difficult to translate the management of complexity in the literature to the context of construction projects (Luo et al., 2017). On top of that, most of these studies mainly addressed infrastructure projects ((Brady et al., 2012; Floricel et al., 2016; Floricel & Miller, 2001; Giezen et al., 2015; Salet et al., 2013). This research looks into the way public clients manage in preparation of uncertainty in construction projects, also regarding the construction of buildings and facilities. This way, it can be identified whether some of the recommended approaches in the literature are applied or not. And if they are applied, it is explained how and why these approaches are applied in construction projects.

2.4 Research methods

This research is composed of a literature review, document analysis and a qualitative case study using interviews. Research questions 1 and 2 are answered using the literature study, where the answers to these questions can be enriched using results from the interviews. Research question 3 is partly answered by a brief outline of the approach of public clients using document analysis. Using interviews from the case study, the answer to this question is further elaborated. The answer to

research question 4 is formulated after empirical data is collected, and will be part of the conclusion of the research.

2.4.1 Literature review

The literature review aims to study the concepts of risk, uncertainty and complexity in the scientific literature. Uncertainty is perceived in different ways throughout these concepts. In the end, the literature review gives an overview of aspects that are uncertain in projects and the project management approaches to prepare for uncertainty. This provides the theoretical background required to collect relevant data in the interviews. Interviews require prior knowledge on the subject to determine the subject areas of importance (Kallio et al., 2016). The researcher needs to have a comprehensive understanding on the subject to determine what knowledge can be added to the existing knowledge (Kallio et al., 2016).

The literature review was initiated with a web search (on title, abstract and keywords) on Scopus, using the terms ''Uncertainty'' and ''Project management''. This revealed an initial selection of papers that discuss uncertainty in the context of project management. Subsequently, ''risk'' and ''complexity'' were separately searched in combination with ''project management'' and ''uncertainty''. The topics of engineering and management were specified, including the following journals: International Journal of Project Management, Journal of Construction Engineering and Management, Journal of Management in Engineering, IEEE Transactions on Engineering Management, European Journal Of Operational Research and Construction Management and Economics.

The search of ''Uncertainty'' and ''Project management'' yielded 359 results, of which 26 papers were selected. Adding the term ''complexity'' yielded 103 results, of which 12 papers were selected. The combination of ''risk'', ''project management'' and ''uncertainty'' yielded 245 results, of which 16 papers were selected. Papers were selected based on their title and abstract, which addressed uncertainty as the main topic. The selected papers either explained or discussed what uncertainty is, how projects are perceived uncertain or how uncertainty can be managed in projects. All selected papers were read and reviewed, including cited articles that were found relevant.

2.4.2 Document analysis

In addition, the approach of public clients with regards to uncertainty is explained and elaborated using documents from the Rijksvastgoedbedrijf. These documents explain their main methods of project management in IPM teams. The general way of perceiving and preparing for unforeseen uncertainty in construction projects is described, so that more relevant questions can be identified for interviews.

2.4.3 Case study

This research makes use of case studies to collect empirical data. Case studies are conducted to reveal how things work in specific contexts (Yin, 2003). This method is effective in studying complex subjects, especially how and why phenomena occur. The cases in this research are construction projects, and more specifically, project management teams of public clients. Yin (2003) calls this an embedded multiple case study. It focuses on a specific unit of analysis within projects (the project team). A case study on multiple projects at different public client organisations is performed to

collect data. This is generally seen as a more robust method compared to single case studies, as it provides more compelling evidence (Yin, 2003). However, multiple case studies can take much time and efforts, which may be beyond the capacity of a single student and beyond the available time frame for this research. Hence, the focus is laid on four different cases. To collect data, a limited amount of interviews were carried out in each case with members of the IPM team, and in two cases, a portfolio manager or project manager from the government client.

Case selection

Four complex construction projects are studied. Two of those are managed by Rijksvastgoedbedrijf, and the other two by Rijkswaterstaat. Cases were selected based on their complexity, contract and project phase. As a result, the cases are complex, meaning they are large in size, take a long time to complete, use new technologies or integrate different technical systems and involve multiple organisations and interests to achieve project objectives (Floricel & Miller, 2001; Hertogh & Westerveld, 2010; Luo et al., 2017). All the cases involve at least Design and Build responsibility in the contract. One case involves design, build and maintenance responsibility. Projects with these contract forms are managed by IPM teams from the public client. All cases have also passed the procurement phase, which means that at least part of the uncertainty has been managed by project teams. It also means that some uncertainties may have impacted these projects. An overview of the selected cases is found in Table 1.

Case 1: European Medicines Agency (EMA)

This project involved the construction of an office building in the densely built area in the southern part of Amsterdam. The EMA had a central office in London, but needed a new office in Europe as Great Britain left the European Union. The new building includes office space and conference rooms for approximately 900 employees from 30 different countries. The project was characterised by limited time to deliver the building, as the EMA needed an office as quick as possible. The procurement procedure was started in October 2017. Several design and construction processes were conducted simultaneously to enable a faster delivery. The project's contract price was 255 million euros. The contract type was a design-build-maintain (DBM) agreement with 20 years of maintenance after completion. The project was completed in November 2019, which is 2 years prior to the time of the research.

Case 2: Breedplaatvloeren Turfmarkt (JuBi)

This project involves the reconstruction of the floors in a large office building in the Hague (Turfmarkt 147). The building is used by the ministries of Internal Affairs and Justice (JuBi). After it was discovered that the technique of the concrete floor structure is unsafe, Rijksvastgoedbedrijf initiated study to assess the constructive safety of the floors. It turned out that all 37 floors of the Turfmarkt 147 had to be restored to fulfil safety requirements. The challenges of this project were to find a suitable method for reconstruction and to carry out the work considering the interfaces with other installations, systems and safety requirements without disrupting the regular use of the building. In addition, the project is characterised by urgency and political influence. A DB contract is used and the project is currently in execution.

Case 3: Julianakanaal Berg-Obbicht (JBO)

The JBO project involves the widening of part of the Julianakanaal, a channel that is connected to the Meuse river in the southern part of the Netherlands. The channel was constructed a century ago. It

needs restoration and the channel is widened. This project faces numerous complex challenges. The shipping process has to be continued during the execution phase, which limits the amount of possibilities to work on site and creates risks for the environment. This counts especially for this part of the trajectory: Berg-Obbicht. The contractor that was initially selected withdrew in 2019, after escalations with Rijkswaterstaat about the construction method. In 2020, a new contractor was selected, using a different method. This method is being tested in a pilot before full application in the execution process. After the pilot, the real execution starts in June 2022 on the last part (3 km) of the channel, with a planned completion in 2027. The project has a DB contract.

Case 4 Renovation Eerste Heinenoordtunnel (REH)

This case involves the maintenance of the Heinenoordtunnel, which is due for large-scale maintenance and updating of the installations to fulfil the modern tunnel safety standards of Rijkswaterstaat. The tunnel, built in 1969, is an important highway link (A29) between Rotterdam and the Southwestern part of the Netherlands. It goes under the Meuse river. The complexity of this project lies in the scale of the maintenance works and the road traffic through the tunnel. The tunnel has to be closed to execute part of the works, restricting over 100,000 vehicles per day who use the tunnel. The project was procured with a DB contract and is currently in the early stages of execution.

Table 1: Overview of cases that are studied.

	Project	**Contract (maintenance)**	**Phase**
Case 1	**EMA**	DBM (20 years)	Completed
Case 2	**Breedplaatvloeren Turfmarkt**	DB	Execution
Case 3	**Julianakanaal Berg-Obbicht**	DB	Execution
Case 4	**1e Heinenoordtunnel**	DB	Execution

Interviews

A semi-structured approach is used to interview participants in the cases. Semi-structured interviews is a type of interviewing in which most parts of the interview questions are prepared beforehand, but depending on the answers of interviewees, the interview questions can be adapted (Kallio et al., 2016). It is a scientific method for collecting empirical data on qualitative aspects. To set up the qualitative semi-structured interviews, the framework by Kallio et al. (2016) is followed.

The reason to use semi-structured interviews is because the method is suitable to study people's perceptions and opinions on complex issues (Kallio et al., 2016). This enhances the collection of data about the complex subject of uncertainty in construction projects. Participants for the interview do not need to have high levels of awareness about the subject for semi-structured interviews to be appropriate (Kallio et al., 2016). Unknown concepts about the subject can be introduced to participants. Through the semi-structured interviews, different issues can be discussed, depending on the specific perceptions of the participant. This allows to be flexible in the topics that are addressed by interviewees and it allows to go deeper into the matter by asking follow-up questions.

Empirical data is collected from practitioners that experienced prominent roles in the IPM teams and in the decision-making of the project. An overview of the interviews that were conducted is given in table 2.

Table 2: Interview schedule.

Role	Date	Duration	Setting
Case 1: EMA			
Project manager	21 April 2022	50 min	Physical
Contract manager (post procurement)	26 April 2022	60 min	Online
Government client	26 April 2022	60 min	Physical
Contract manager (pre procurement)	3 May 2022	50 min	Online
Risk manager	4 May 2022	40 min	Physical
Case 2: Breedplaatvloeren Turfmarkt			
Contract manager (pre procurement)	2 May 2022	50 min	Online
Program manager	2 May 2022	50 min	Online
Project manager	11 May 2022	50 min	Online
Contract manager (post procurement)	23 May 2022	40 min	Online
Case 3: Julianakanaal Berg-Obbicht			
Portfolio manager	25 May 2022	40 min	Online
Project control manager	27 May 2022	60 min	Online
Environment manager	30 May 2022	50 min	Online
Contract manager	30 May 2022	40 min	Online
Project manager	30 May 2022	40 min	Online
Case 4: 1e Heinenoordtunnel			
Contract manager	1 June 2022	60 min	Physical
Project manager	7 June 2022	30 min	Online
Project manager (stand- in)	9 June 2022	40 min	Online

A set of questions is prepared (see APPENDIX 3: Data collection protocol) to address the different types of uncertainty and the ways to prepare for uncertainty. These questions are mainly based on the findings from the literature review. In addition, there are more general questions in place to introduce the topics to the participant. Questions are asked about the complexity and uncertainty of the project to raise awareness about the topic. The main interview is about uncertainty in construction projects and the management of uncertainty in construction projects. In the first part of the interview, different kinds of uncertainties are discussed that play a role in the construction project. It is about where uncertainty is experienced in the project and how these uncertainties emerged and affected the project. The second part of the interview is about the approaches that the project team used to prepare for uncertainties in the project. Questions are asked about how the team dealt with uncertainties in the project. This includes how they prepared (or are preparing) for uncertainty throughout the project and how they dealt with specific uncertainties in the project.

2.4.4 Data analysis

Based on data from the interviews, reports are made of individual cases. This denotes which kinds of uncertainties were present in the project, how they were managed in preparation and how it worked out in the specific context of the project. Consequently, the results from different cases are analysed and reported. This is done regarding the similarities and differences between uncertainties and approaches to manage uncertainty in the projects studied. The similarities and differences with regards to the theory from the literature are also analysed to see how the theory is supported throughout the cases. Replication is important in analysing the data from the case study. If multiple cases support a certain theory, replication can be claimed, making the theory more potent (Yin, 2003).

The data of the cases case is analysed and compared to answer the research questions. By this step, the main research question can be (partly) answered. The final results from the case study describe which kinds of uncertainty are involved in construction projects and how public clients manage uncertainty. In addition, the approach of public clients is evaluated against the findings. This step addresses improvements that can be made to the current way of dealing with uncertainty by public clients.

3. Literature review

This chapter contains a review of concepts in the literature, related to uncertainty in project management and construction management. The review serves as a basis for the understanding of uncertainty in the context of projects and the management of uncertainty in projects. From this understanding, frameworks are set up to allow for a structure for data collection and data analysis. These frameworks also form the basis on which the findings of the case study are compared and analysed. In section 3.1, the concepts of uncertainty, risk and complexity are introduced in the context of project management. Section 3.2 discusses the role of uncertainty in projects and highlights certain aspects of projects that are uncertain. Section 3.3 covers the management of uncertainty in the literature, which is also presented in a framework that includes various approaches. The review of the literature provides useful answers to the first two research sub-questions, which can be used to analyse the data from the case study. These answers are given in section 3.4, which concludes this chapter.

3.1 On uncertainty, risk and complexity

This section provides a literature review on the concepts of uncertainty, risk and complexity in projects. The concepts of uncertainty, risk and complexity are explained, including their underlying principles, definitions and relations to uncertainty and project management. It is shown that the relation between risk and uncertainty is straight-forward (uncertainty causes risk), whereas the relation between complexity, uncertainty and risk is more sophisticated.

3.1.1 Uncertainty

Uncertainty is associated with many terminologies in different fields of science. Ambiguity, ignorance and variability are often used to refer to uncertainty in different fields, depending on the theoretical and practical context (Thunnissen, 2003). The distinction between uncertainty and risk was already explained in the introduction. When something is uncertain, outcomes nor probabilities can be known beforehand (Knight, 1921). In construction projects, uncertainty can also be viewed in relation to parameters with unknown probability distributions (Migilinskas & Ustinovichius, 2006).

Uncertainty is often classified into aleatory and epistemic uncertainty (Aven, 2016; Spiegelhalter & Riesch, 2011; Thunnissen, 2003). Aleatory uncertainty refers to inherent variability of some objects or contexts (such as a dice, coin, or the duration of a car trip between certain locations). Epistemic uncertainty refers to a lack of knowledge and understanding of variables. Variability is not considered as a form of uncertainty in this research, because these uncertainties are often controllable (Meyer et al., 2002) and probabilities can be assigned to variability. Therefore, the focus is on epistemic uncertainties.

3.2.2 Risk

Although there is no generally agreed definition of risk (Love et al., 2021), the definition of risk in the scope of project management is rather clear. Risk can be defined as an uncertain event or condition that has an impact on project objectives (PMI, 2017). Risk is related to the consequences of an activity, on something that is valued by humans (Aven, 2016). The previous section explained that risk refers to situations where probabilities can be assigned to certain events and outcomes. This is the main difference between risk and uncertainty. The relation of risk to uncertainty is clear: Underlying sources of uncertainty cause risk in projects (Aven, 2016; Migilinskas & Ustinovichius, 2006; Perminova et al., 2008).

When dealing with risks, probabilities are assigned to both the occurrence of an event and its consequences. The scientific field of risk analysis uses science to explore the risks of certain activities and develop concepts on how risks should be understood and managed (Aven, 2016). Different processes can be identified in doing so (Aven, 2016; Mak & Picken, 2000; Mulholland & Christian, 1999; Schatteman et al., 2008):

- Risk assessment
    - Risk identification (identifying risk factors)
    - Risk analysis (estimating likelihood and impact of risk)
- Risk evaluation (evaluating the size and importance of risks)
- Risk management (cyclical process of identifying, analysing, evaluating and responding to risks)

In construction projects, uncertainty is mainly addressed from a risk management perspective (Migilinskas & Ustinovichius, 2006; Ward & Chapman, 2003). In general, risk management is about iteratively detecting, analysing, evaluating and responding to risks (Aven, 2016; Schatteman et al., 2008). All risk management processes focus on identifying situations and events, analysing causes and consequences, describing the risks and probabilities, evaluating important risks and planning actions to treat risks (Aven, 2016). However, there are views in the literature indicating that risk management is often applied unsuccessfully (Bryde & Volm, 2009), or even inadequate in dealing with uncertainty in projects (Leijten, 2017; Ward & Chapman, 2003). Obviously, the quality of risk management depends on managers that can foresee potential dangers (Perminova et al., 2008).

Risk management contains certain limitations. Project risk management practice is criticised for perceiving risks negatively in the form of threats, thereby neglecting opportunities (Ward & Chapman, 2003). Another limitation of risk management in practice is that decision making and project management are informed separately through risk analysis and risk management respectively (Jaafari, 2001). And for decision making, the variables of the risk management process may be difficult to compare to other decision methods (i.e cost-benefit analysis, multi-criteria analysis etc.) when reviewing alternatives (Aven, 2016). Improvements in risk management are suggested in the analysis of environmental risk factors, handling unexpected and unpredictable information and formulating a crisis management planning (Long & Cheok, 2019).

3.1.3 Complexity

Complexity is a concept that has been introduced in the project management literature to explain the behaviour of projects. Before describing what complexity is, it should be noted that any definition of complexity limits its true meaning (Shenhar, 2001). Nevertheless, there is agreement on the definition of complexity: Complexity refers to difficulty in understanding, describing or controlling something, both in terms of the object and its behaviour (Kiridena & Sense, 2016). Complexity is mainly related to systems, which can be any physical or social network that generates outputs from inputs (Kiridena & Sense, 2016). Several attributes are involved in complex systems (Baccarini, 1996; Cooke-Davies et al., 2007; Kiridena & Sense, 2016; Pich et al., 2002; Vidal & Marle, 2008; Williams, 1999):

- Size and variety of components/elements (many different parts/objects in a system)
- Interrelations/interdependencies (the behaviour of a component is related to other components)
- Interactions (components interact with each other within or between systems)

- Emerging behaviour (the behaviour and properties of the system cannot be ascribed to the sum of the behaviours of components as non-linear interactions exist)

Projects (and especially construction projects) can be seen as complex systems, containing varied and interdependent activities to achieve an objective (Baccarini, 1996; Cooke-Davies et al., 2007; J.Geraldi et al., 2011; Maylor et al., 2008; Vidal & Marle, 2008; Williams, 1999; Zhu & Mostafavi, 2017). Components of project systems can be people, resources, organisations and structures (Kiridena & Sense, 2016). In the view of project management, project complexity can be defined as the difficulty of reaching a desired outcome in a project (Kiridena & Sense, 2016). Some terms that describe complexity in projects are: difficult, complicated, intricate, involved, tangled and knotty (Whitty & Maylor, 2009).

There are differences in understanding how project complexity arises and how it is driven, but there are many similar factors that contribute to complexity (Geraldi et al., 2011; Kiridena & Sense, 2016). The size or scale of the project; variety of and interdependencies between tasks; lack of clarity of project goals and methods; novelty of technologies used; changing stakeholder expectations; changing composition of the project team (e.g., personnel, expertise, and experience); differences in geographical location, market conditions, legal, political, and macro-economic landscapes; and diversity in cultural and national backgrounds are some of the shared factors of complexity from previous studies (Kiridena & Sense, 2016).

Factors that drive project complexity are classified in different ways. It can be classified based on attributes of the project system. This results in distinctions of Technical-organisational factors (Baccarini, 1996) or technical-organisational-environmental factors (Bosch-Rekveldt et al., 2011; Kiridena & Sense, 2016). Other suggested categories of complexity are pace (speed), novelty (newness) and socio-political complexity (Geraldi & Adlbrecht, 2007; Maylor et al., 2008). Complexity is also classified in goal, cultural and information complexity (He et al., 2015). Cooke-Davies et al. (2007) added complex responsive processes of relating (CRPR) to the project complexity theory, which reflects the complexity of human interactions in social structures (organisations, projects, teams). Complexity is also distinguished in different dimensions. Kiridena & Sense (2016) distinguished between three dimensions of complexity (structural-interactional-dynamic), others distinguish between dimensions of structural-uncertainty (Williams, 1999) and detail-dynamic (Hertogh & Westerveld, 2010; Zhu & Mostafavi, 2017). These aspects are reflected in the concept of faith-fact -interaction complexities (Geraldi & Adlbrecht, 2007). In general, all these dimensions of complexity can be divided in two types of complexity:

1. **Structural complexity:** Structural complexity refers to the static properties of the system: the size and interrelations in the system, the variety of components and the amount of (sub)systems involved. This is the dimension of complexity described by Baccarini (1996). Others call this detail complexity (Hertogh & Westerveld, 2010; Zhu & Mostafavi, 2017).
2. **Dynamic complexity:** Due to time-dependence of relationships and interdependencies, things change in time. dynamic complexity refers to the changes in components, interrelations and interactions in the complex system over time. This change creates a form of unpredictability about future states. This is also called interaction complexity by Kiridena & Sense (2016), or uncertainty by Williams (1999). The essence of interaction and uncertainty dimensions is similar to dynamic complexity.

Uncertainty in relation to complexity

It should be noted that the occurrence of uncertainty in the form of unforeseen events does not necessarily mean that one is dealing with a complex system (Whitty & Maylor, 2009). But still, uncertainty is a key aspect of complexity (Bosch-Rekveldt et al., 2011; J. Geraldi et al., 2011; Maylor et al., 2008; Vidal & Marle, 2008; Williams, 1999). Complexity can be associated with radical unpredictability as a result of dynamic changes and interactions between components over time (Cooke-Davies et al., 2007). Sources of uncertainty in the project complexity literature are related to the differences between perception and reality (Jaafari, 2003; Vidal & Marle, 2008), the inability to identify all interrelated elements and interactions of a complex system (J. Geraldi et al., 2011; Vidal & Marle, 2008), changing information and actions through interdependencies (Vidal & Marle, 2008), uncertainty about the state of the system elements and the impact of interactions on the project (J. G. Geraldi & Adlbrecht, 2007) and uncertainty in goals, methods, and the instability of assumptions related to tasks (Williams, 1999). Therefore, complexity plays an important role in the uncertainty of projects.

But what is the relation between complexity and uncertainty? Concepts of project complexity view uncertainty as something that can both emerge from and give rise to complexity. Vidal & Marle, (2008) explain that uncertainty in a variable can spread through the system via interactions and interdependencies. Following this line of reasoning, they also conclude that complexity can give rise to uncertainty in the form of risks, either directly or indirectly. On the other hand, uncertainty can give rise to complexity by inducing risks, which in turn increase the potential for interactions and dynamics (Bosch-Rekveldt et al., 2011). As a result, there is no general agreement on the relation between complexity and uncertainty . Uncertainty can be seen as a part of complexity, complexity can be seen as a part of uncertainty or they can be seen as separate concepts (Padalkar & Gopinath, 2016). However, there is significant overlap between these concepts in the project management literature (Padalkar & Gopinath, 2016). Surely, complexity and uncertainty are closely related.

3.1.4 Conclusion

The literature agrees that projects are inherently uncertain, and that project complexity plays a role in this uncertainty. The literature also agrees on the definitions of uncertainty, risk and complexity in relation to project management. Causal relations between uncertainty and risk are clear: Uncertainty causes risks. What is not fully agreed in the literature is the relation between complexity and uncertainty. However, complexity and uncertainty are closely related to each other.

3.2 Uncertainty in projects

The literature review provides a basis to define the different aspects of uncertainty in projects. In this section, a deeper look is given on uncertainty in the context of projects. Project aspects that are subject to uncertainty in projects are discussed from the perspective of the literature. Specific uncertainties in construction projects are included here. A framework is set up to allow for a general understanding of the different uncertainties in projects. This framework also facilitates systematic collection of empirical data in the research on construction projects. In the end of the section, the first subquestion is answered: *What uncertainties are involved in construction projects?*

Regarding the literature on uncertainty in projects, several aspects of projects are pointed out that are subject to uncertainty. These aspects can be seen as themes or categories of uncertainty, or even as uncertainties themselves. The idea is that uncertainty is involved in projects through different

aspects. The following aspects can be distinguished in the literature: objectives, methods, market, resources, stakeholders, contract, technology and environment. See Figure 3 for an overview of those categories.

Objectives and methods

The uncertainty in objectives and methods is something which is frequently mentioned (Chapman & Ward, 2011; J. G. Geraldi & Adlbrecht, 2007; Howell et al., 1993; Jaafari, 2003; Perminova et al., 2008; Williams, 1999). Howell et al (1993) mention uncertainty in what to build and how to build it. They state that this uncertainty can last up to the start of the execution phase. Objectives can also become uncertain due to uncertainty in how the project fits strategically in organisations involved in the project (Kreye et al., 2019). Uncertainty can also lie in intangible benefits of the project (Maylor et al., 2008). Furthermore, objectives can be too ambitious, too many or conflicting (Kolltveit et al., 2005).

Market

Markets may be uncertain in the selection of contractors (Mulholland & Christian, 1999) and in the supply chain of Engineer-to-Order products (Gosling et al., 2013). These are products which need to be specified before they can be produced and delivered. Construction projects make use of such supply chains (Gosling et al., 2013).

Resources

Resources are also sometimes characterised by uncertainty. This can be closely related to the market, in terms of finding external parties (contractors, consultants, suppliers) which are competent in delivering the construction project (Kreye et al., 2019). But resources also have to do with the internal organisation of the project and the availability of resources in the client organisation (Kolltveit et al., 2005). This includes finding the capacity and competence for technical aspects, project management aspects and organisational aspects in the project.

Stakeholders

Aside of the client and contractor's organisations, there are other stakeholders involved which can make the delivery of construction projects uncertain. There is uncertainty in which stakeholders are relevant, how they influence the project and what their motives are (Ward & Chapman, 2008). Uncertainty associated with stakeholders can introduce uncertainty in other aspects of the project as well. It can cause uncertainties in objectives, roles, responsibilities, communication in interfaces, capabilities of stakeholders, contractual conditions and arrangements for coordination and control (Ward & Chapman, 2008). Also dynamics play a role, in which new stakeholders emerge, existing stakeholders withdraw or in which stakeholders change in their characteristics (Ward & Chapman, 2008).

Contract

Another aspect that may be subject to uncertainty is the contract. This is closely related to the uncertainty in stakeholders discussed earlier. Especially when multiple contracts are used, the potential for uncertainty is increased (Tran & Molenaar, 2014).Contracts may not be completely clear on how roles and responsibilities are described and allocated (Ward & Chapman, 2003, 2008). Things can become more uncertain if contractual conditions regarding liability and payment mechanisms are not well defined (Gosling et al., 2013; Mulholland & Christian, 1999).

Technology

A considerable amount of uncertainty is related to the technology used in projects. The choice of the technical system can be uncertain, as there are many possible alternatives that could work as solutions (Kolltveit et al., 2005). Dealing with new technologies also brings significant uncertainty with it (J. G. Geraldi & Adlbrecht, 2007; Gil et al., 2006; Gosling et al., 2013; Kreye et al., 2019; Maylor et al., 2008). Technologies are also combined in different systems, having many components (Gil et al., 2006) and multiple interfaces with other technologies which can give rise to uncertainty (Maylor et al., 2008). Designs can change in the course of the project, as requirements can change (Atkinson et al., 2006; Gil et al., 2006; Gosling et al., 2013; Williams, 1999). Uncertainty in technology is influenced by the maturity of scientific knowledge on the technical product, the level of customisation and the access to technical expertise (Kolltveit et al., 2005; Kreye et al., 2019; Maylor et al., 2008). The right equipment, tools and labour resources have to be available (Gosling et al., 2013; Russell et al., 2014). And lastly, space for working on technology and storing components can also be uncertain, as pointed out in relation to Engineer-to-order supply chains by Gosling et al. (2013).

Environment

The environment of the project can be uncertain (J. G. Geraldi & Adlbrecht, 2007). Projects are often carried out in volatile environments (Kreye et al., 2019). Environmental uncertainties can be related to the natural conditions (Russell et al., 2014), operating conditions (Atkinson et al., 2006), local support (Kolltveit et al., 2005) and regulations (Gil et al., 2006; Jaafari, 2001). The project environment can also change and introduce uncontrollable external factors, which drives uncertainty in projects (Atkinson et al., 2006; Jaafari, 2001; Kreye et al., 2019). For example, the political situation in a project can cause uncertain changes to the project (Kolltveit et al., 2005; Xiang et al., 2012). There may also be cultural influences, which is related to the way of working and communicating in local environments (Kolltveit et al., 2005). Uncertainty also lies in how the technology of the project fits into the environment (Kolltveit et al., 2005).

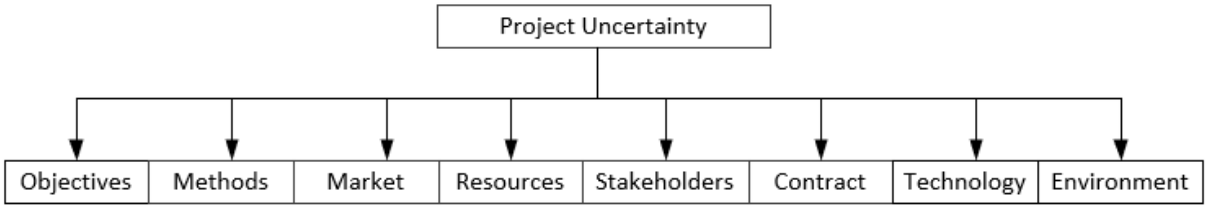

Figure 3: Aspects of uncertainty in projects.

The literature shows many different factors that are related to the eight aspects explained above. An overview of these factors related to each category in the literature is found in APPENDIX 1: Uncertainty factors, which shows the categories addressed by the authors.

Table 3: Aspects of uncertainty in the literature

Source	(Ward & Chapman, 2003) (Ward & Chapman, 2008)	(Mulholland & Christian, 1999)	(Maylor et al., 2008)	(Kolltveit et al., 2005)	(Kreye et al., 2019)	(Atkinson et al., 2006)	(Gosling et al., 2013)	(Russell et al., 2014)	(Perminova, 2008)	(Xiang et al., 2012)	(J. Geraldi et al., 2011) (J. G. Geraldi & Adlbrecht, 2007)	(Tran & Molenaar, 2014)	(Meyer et al., 2002)	(Howell et al., 1993)	(Williams, 1999)	(Xia & Chan, 2012)	(Jaafari, 2001)	(Gil et al., 2006)
Objectives	■		■			■			■			■		■	■	■		
Methods	■		■			■			■			■		■	■	■		
Markets		■			■		■											
Resources			■	■	■		■	■	■		■	■						
Stakeholders	■				■	■				■	■	■						
Contracts	■	■	■	■			■					■						
Technology		■	■	■	■	■							■					■
Environment				■	■	■		■	■		■	■	■			■	■	■

Causes of uncertainty: Differences in perception

When looking at the factors that are related to each aspect, it should be noted that the distinction between causes and consequences of uncertainty is not completely unambiguous. A component that is subject to uncertainty can also cause or give rise to uncertainty in other components, which can again induce uncertainty in other components through interdependencies (Vidal & Marle, 2008). Uncertainty can also sometimes be perceived as something that is simply present in some aspects of the project (in a technical system or relations between stakeholders for example), whereas in reality it is a consequence of another specific uncertain aspect. This is called uncertainty masking (Kreye et al., 2019). As a result of uncertainty masking, the project team identifies certain factors that are ''symptoms'' of uncertainty, instead of factors that are underlying causes of the uncertainty (Kreye et al., 2019). As a consequence, the aspects in the framework allow for different understandings of uncertainty: The aspect may be uncertain itself, or there is uncertainty present in the aspect, or there is uncertainty related to the aspect. Although some of the aspects in the framework may be perceived as causes or drivers of uncertainty, this was not explicitly mentioned in the literature. The purpose of figure 3 is to list aspects that are subject to uncertainty.

Conclusion

This section discussed uncertainty in the context of projects. It explained what (kind of) aspects of projects are uncertain. Thereby, the first subquestion can be answered:

What uncertainties are involved in construction projects?

Eight aspects of uncertainty can be distinguished in construction projects: objectives, methods, market, resources, stakeholders, contract, technology and environment.

3.3 Managing projects in preparation for uncertainty

This section elaborates on the project management approaches to address the management in preparation of uncertainty in the literature. In the conclusion of this chapter, the second sub-question is answered: What project management approaches deal with the preparation for uncertainty?

Management approaches for complexity and uncertainty

The close relation between complexity and uncertainty, which is explained in section 3.1, implies that the management of uncertainty is closely related to the management of complexity. Therefore, the literature is searched for managing complexity and uncertainty.

Several authors have studied specific cases to find effective managing approaches to deal with complexity and uncertainty (see Table 4). Many cases of megaprojects were studied to describe a learning environment in projects (Ahern et al., 2014b, 2014a; Salet et al., 2013), to identify mechanisms of adaptive capacity (Giezen et al., 2015), to adopt a parallel approach in which multiple options are worked out simultaneously (selectionism) (Lenfle, 2011; Lenfle & Loch, 2011; Sommer & Loch, 2004) and to find project management strategies that deal with structural and dynamic complexity (Brady & Davies, 2014; Floricel et al., 2016). These authors have come up with recommendations on how projects can be managed to effectively prepare for situations of uncertainty.

Table 4: Research on the management of complexity and uncertainty.

Source	**Recommended approach**	**Data collection**
(Floricel & Miller, 2001)	Governability to deal with strategic surprises	Survey (60 projects)
(Floricel et al., 2016)	Strategies in the planning stage of projects	Survey (81 projects)
(Salet et al., 2013)	Flexibility in Strategic decision-making	Case study (HSL Zuid)
(Brady & Davies, 2014)	Standardised processes and integrated project teams	Case study (London Heathrow Terminal 5 and 201 London Olympic Park)
(Lenfle, 2011)	Selectionism: Pursuing multiple options simultaneously	Case study (Manhattan Project)
(Loch et al., 2007; Pich et al., 2002; Sommer & Loch, 2004)	Learning and selectionism	Programmatic simulations of projects
(Ahern et al., 2014b)	Learning (complex problem solving and sensemaking)	Empirical study on two Irish state-owned organisations

These managing approaches involve strategies to organise the project in a way that it is capable of being successful in situations of complexity and uncertainty. Most of the approaches are based on the assumption that uncertainty is mainly caused by complexity (mostly dynamic complexity and to some extent structural complexity) (Brady & Davies, 2014; Collyer & Warren, 2009; Floricel et al., 2016). Some approaches are assuming that uncertainty is mainly caused by unknowns and lacking information regarding technical systems and external project environments (Lenfle, 2011; Loch et al., 2007; Pich et al., 2002; Sommer & Loch, 2004). This section further describes these management approaches, and the way they prepare for uncertainty in projects.

First, control and flexibility are explained as two paradigms of preparing for uncertainty in projects. After that, the management approaches that prepare for uncertainty are discussed. And lastly, an overview is given of the different approaches and concluding remarks are made about the use of these approaches in this research.

3.3.1 Control and flexibility

To deal with uncertainty, there is tension between two types of approaches: Control and flexibility (Koppenjan et al., 2011). On one hand, project management can focus on identifying risks and proposing measures to reduce negative impacts. Such an approach is characterised by predicting and controlling the future situation of a project. On the other hand, project management has to be flexible by being able to keep open different courses of action and change plans, as risks will occur anyway (Koppenjan et al., 2011). Brady & Davies (2014) concluded the following from two case studies on complex construction projects: Both projects were successful because they had both types of approaches in place: Koppenjan et al. (2011) make a similar conclusion: Complex projects should be managed by seeking a balance between control approaches and flexibility approaches. This notion is also grounded in the two dimensions of complexity: structural and dynamic complexity:

1. Structural complexity represents the difficulty of managing projects because there are many different interrelated parts involved (Baccarini, 1996). The idea is that the existence of many different parts in a complex system leads to emerging behaviour or emerging properties, which can be uncertain. Emerging behaviour occurs regardless of dynamics. No changes in any element have to occur in order to cause emerging behaviour. It just emerges as the complex system is formed. Control mechanisms deal with this type of complexity.
2. Dynamic complexity, as explained in section 3.2, represents the effects of changes in time. This can make projects unpredictable through radical or sudden changes in parts of the project. Such changes are uncontrollable, and therefore require a more adaptive approach. Flexibility targets this type of complexity.

Control

Control is about reducing the potential for uncertainty as much as possible. Objectives and designs are fixed, changes are rejected and new technologies are avoided (Collyer & Warren, 2009). There is a strong focus on front-end planning and analysis to predict and overcome complexity and uncertainty (Koppenjan et al., 2011). Tasks, requirements and responsibilities are described in as much detail as possible (Koppenjan et al., 2011). And planning of activities and resources is done in detail before project execution (Collyer & Warren, 2009). The aim of the control approach is to predict as much as possible and block changes in scope and schedule. This approach can have benefits, but also has some drawbacks (Collyer & Warren, 2009). The construction industry may be inclined to a control approach, because it has high public safety requirements which makes reliable technology more attractive (Collyer & Warren, 2009).

Control can be beneficial to deal with structural complexity. Organisational structures using contractual agreements with standardised processes help to grasp the structural elements, interdependencies and interactions in a project (Brady & Davies, 2014). This involves separating the tasks, elements and allocating them to different organisations (Floricel et al., 2016). This is effective to grasp structural interactions and control emerging properties in the projects (Floricel et al., 2016).

The downside is that a control approach requires many efforts from the start of the project (Floricel et al., 2016). Control also reduces the potential for flexibility in the project, making it ineffective in

dealing with dynamics (Collyer & Warren, 2009). It takes a substantial amount of efforts to adjust detailed plans when facing unknowns at a fast rate (Collyer & Warren, 2009). Construction projects with well-known goals and methods can have more detailed plans up front (Collyer & Warren, 2009). Such projects often plan phases of the project separately with high levels of process control (Collyer & Warren, 2009).

Flexibility

Flexibility is the ability to quickly sense changes in the project environment (Floricel et al., 2016). Pich et al. (2002) define flexibility as the costs to make changes to the project. The lower the costs of making changes, the more flexible the project is. Flexibility can also be seen as the ability to reconfigure resources (Lenfle & Loch, 2011). The core of flexibility lies in the ability of making changes in projects. Changes are mostly made as a reaction to uncertainty in the form of dynamics and unknowns. Projects benefit from flexibility by being able to make changes without disrupting the project too much. This can be done by having multiple ways in place to carry out the project. Giezen et al. (2015) discussed the adaptive capacity of the Randstadrail project to see how it implemented flexibility.

Adaptive capacity is the ability of actors to adapt to actual changes in the (perception of the) context (Giezen et al., 2015). Note that adaptive capacity is in place to react to uncertainty. The notion of adaptive capacity is explained to demonstrate how projects may use flexibility to deal with uncertainty. Giezen et al. (2015) described four types of adaptive capacity (and demonstrated them using a case study):

1. Incremental adaptation: change in small steps, solving issues, adjusting scope etc.
2. Radical adaptation: Adjustment of fundamental objectives and practices.
3. Socio-historical adaptation: Institutional or organisational changes.
4. Inertia: No adaptation

Incremental adaptations are changes that are relatively small compared to the whole project. For example, it involves encountering unexpected objects during the digging of a tunnel, deciding to procure the project in a different way or deciding to combine different technical systems instead of only using one system (Giezen et al., 2015). Radical adaptations involve a large restructuring of the project's concept and methods. They are often triggered by opposition and resistance of project ideas (Giezen et al., 2015). Such situations need creative solutions which almost change the complete scope of the project (Giezen et al., 2015). Socio- historical adaptations are changes in the structure of governing organisations. Giezen et al. (2015) found one situation of socio-historical adaptation in the case of the Randstadrail project. The government structure was changed before the project started, which introduced city regions as the responsible authorities for public transport. In the earlier situation, each municipality had its own agenda with regards to public transport, and each municipality was responsible for the development of its own public transport system. The introduction of city regions made it easier to negotiate and decide on public transportation projects. It changed the organisation of public transportation in cities, regions and provinces. The last type of adaptation is inertia, which means that no adaptations are made at all. This can be the case if stakeholders stick to their wishes and interests and are unwilling to look for solutions that compromise on their interests (Giezen et al., 2015). This can block flexibility in the planning stage of projects (Giezen et al., 2015).

Conclusion

Control and flexibility are two ways to look at the management of uncertainty in projects, which are both considered necessary to deal with complexity and uncertainty. Considering the tension between these two perspectives, collecting data about them can provide more insight in the mentality behind the management of uncertainty by public clients. The next subsections discuss approaches in the literature that can be used to manage projects in preparation for uncertainty. These are learning, selectionism and representing complexity.

3.3.2 Learning

Learning is considered a key feature of project teams to manage in preparation of unforeseen uncertainty (Ahern et al., 2014b; Koppenjan et al., 2011; Pich et al., 2002; Sommer & Loch, 2004). Especially in situations of complexity and uncertainty, a learning environment stimulates acting and experimenting, which is demanded by this situation (Salet et al., 2013). It is important to learn from the environment to cope with uncertainty (Collyer & Warren, 2009). It creates the flexibility needed to respond to new situations. In complex projects, problems arise that are often unstructured, non-linear and little is known about the inputs and outputs (Ahern et al., 2014b, 2014a).

Pich, Loch, De Meyer and Sommer have discussed learning (and selectionism) as an effective approach to deal with unforeseeable uncertainty (Pich et al., 2002; Sommer & Loch, 2004). The main idea of learning is to create new knowledge by capturing signals in the project environment and comparing those signals to the initial assumptions that were made when planning activities. Based on new information, adjustments have to be made to these plans during the project. More recently, Floricel et al. (2016) discusses the importance of developing new knowledge in the project planning stage to deal with complexity. Learning requires paying attention to the emergence of unexpected information (Sommer & Loch, 2004). Learning also requires coordinating mechanisms in the form of common will, mutual interests, leadership or hierarchical structures (Ahern et al., 2014a).

Project managers learn implicitly by solving complex problems during the project (also called complex problem-solving), thereby generating missing knowledge and coordinating/distributing this knowledge (Ahern et al., 2014b). Regarding knowledge, there are two types (Ahern et al., 2014b):

1. Hard knowledge: Explicit factual knowledge on technical designs, properties or systems.
2. Soft knowledge: Experience and know-how knowledge. This knowledge is less factual and more based on experience and skill. Some of this knowledge is impossible to make explicit (tacit knowledge) (Leijten, 2017). The authors (Ahern et al., 2014b) argue that this type of knowledge is more important in dealing with uncertainty.

3.3.3 Selectionism

When confronted with unforeseeable uncertainty, selectionism can offer a way of preparing for the uncertainty by pursuing multiple options or approaches to deliver the project. This approach is also called the ‘’parallel approach’’ (Lenfle & Loch, 2011). The idea of selectionism is to pursue different alternatives as end deliverable in projects. These alternatives are pursued simultaneously to be able to select one best alternative in the end. Selectionism offers the flexibility to cope with uncertainty in projects. The probability that a project does not reach its end outcome decreases as multiple

alternatives exist. If selectionism and learning are combined, it is called exploration (Lenfle & Loch, 2011).

The benefit of selectionism lies in the flexibility that allows to delay decisions until enough information is available (Pich et al., 2002). In addition, valuable knowledge can be created when experimenting with different approaches (Lenfle & Loch, 2011).

There are specific situations where the strategy of selectionism is effective. Selectionism is appropriate in projects with high complexity and where the costs of learning and delay are high compared to developing multiple approaches simultaneously (Pich et al., 2002). It is also considered suitable when there is a lack of knowledge or information, time constraints and novelty or innovation (Lenfle & Loch, 2011). The combination of these characteristics leads to unforeseeable uncertainty in projects.

There are also downsides to this strategy. It often makes intense use of resources (Sommer & Loch, 2004). The intensity of resources depends on when it is decided to develop the most promising approach and to discard the other approaches (Lenfle, 2011). In addition, there is a risk of overloading teams that work on multiple approaches and producing redundant knowledge (more than needed for the project) (Lenfle & Loch, 2011).

Managing the selectionist approach involves awareness about the progress of different approaches, readiness to assess the priority of the approaches (i.e. which approach should receive more attention) and considering dependencies between different approaches (Lenfle & Loch, 2011). Management should also consider flexibility in allocating resources between different approaches, which is an important organisational challenge (Lenfle & Loch, 2011). Lenfle (2011) outline the following points of importance for selectionism:

1. Communication between different teams that work on parallel alternatives.
2. Approaches that are supported with robust results, resulting from different trials under varying conditions. The choice to develop one approach should be made as soon as possible for cost efficiency.
3. The approaches that are not selected for further development should generate knowledge that can be exploited.
4. Eventually, resources commit on the chosen approach only.

Construction projects regularly deal with innovative technologies which increase uncertainty in the project. It proved good practice to treat new technologies with increased control in complex construction projects (Brady & Davies, 2014). The Heathrow Terminal 5 project was in part successful because the project only allowed new technologies in the project that had been tested offsite (Brady & Davies, 2014). This included all kinds of technologies used in products and processes. In addition, the project had a long period of experimenting and testing technology before execution started (Brady & Davies, 2014). Similarly, the London Olympic Park project was careful with new technologies, which were only allowed in the project if approved by a change control board (Brady & Davies, 2014).

The Manhattan case

Lenfle (2011) conducted a case study on the Manhattan Project, where the atomic bomb was developed. The author demonstrates how the project proceeded simultaneously with the design and construction of the production plant, development of the bomb design (two options), development

of supporting science and with the development of the nuclear material (two options). Having faith in the project was essential in the achievement of the objectives. Although this case was relatively unique, with almost infinite resources and high urgency, the authors point out several principles that govern the implementation of selectionism. The case study of the Manhattan Project revealed three stages of the selectionism approach in projects (Lenfle, 2011):

1. **Competition:** The solution that is most promising is backed up by less promising solutions. The promising solutions are tried in trials.
2. **Re-organisation of trial portfolio:** After failure of the trials of the promising solutions, the list of options are reconsidered. A new solution is added, which was initially discarded as less promising. The project team realised that a combination of different solutions was better than treating them as competing alternatives. Resources that research one solution are re-allocated to another less-developed solution which required more research and engineering.
3. **Finalise the product:** After the solution becomes apparent, designs are completed, tests are organised and the final product is delivered.

Lenfle also demonstrates that the selectionist strategy can be more complex than choosing between two distinct approaches. The Manahattan case showed that managers have multiple ways of adopting selectionism in projects:

1. Managers can aim for the completion of different approaches, and re-allocate resources depending on the level of advancement of different approaches. This way, the efforts can be focused on creating knowledge on less-developed approaches.
2. Managers can combine different approaches to complement each other.
3. Managers can consider adding new solutions as unforeseeable uncertainty can make the original options obsolete. The initial plan can be adapted as a result of changes in the state of technology or client needs.

3.3.4 Representing complexity

The idea of representing complexity relies on the assumption that the project organisation can effectively manage uncertainty if it represents the complexity of projects (Floricel et al., 2016). In this way, the project organisation can grasp interactions and dynamics and limit surprises as a result of uncertainty (Floricel et al., 2016). This section introduces the concepts found in the literature that aim to deal with complexity in projects. Some of these concepts are clearly linked to learning and flexibility as discussed earlier. There are planning-stage strategies, strategic decision making strategies, integrated project teams and governability to deal with complexity and dynamics.

Planning-stage strategies

Floricel et al. (2016) put forward two kinds of strategies in the planning stage of projects to represent complexity:

1. Strategies that shape project development processes. These can stimulate teams to produce and use knowledge (learning). They are closely related to the learning efforts discussed earlier to deal with complex circumstances. They are not specifically focused on control or flexibility, or structural or dynamic complexity. They can be seen as an extension to the learning approach. There are two types of project development processes.

a. **Existing knowledge:** There are linear processes that rely on abstract prior knowledge. It relies on past learning represented in databases or existing (contract) models to shape a perception of the project at hand. Prescribed practices for stakeholder analysis are an example of a linear process that uses existing knowledge.
b. **New knowledge:** There are iterative processes that focus on producing new and specific knowledge to the project. It involves experiments, simulations, concurrent engineering and seeking feedback from clients. By obtaining new knowledge, one tries to match the specific complexities of the project.

2. Strategies that shape organisational and contractual structures of the project: They determine the potential for communication, coordination and integration. There are two types of such strategy:
    a. **Collaboration-Integration:** Integration and collaboration aims to increase the strength of communication ties throughout a project organisation. It integrates diverse perspectives and knowledge, making it easier to adapt representations of complexity. It makes the perception of complexity more flexible in the project organisation. Organisational strategies that encourage frequent communication help to adjust to unexpected developments. However, setting the interfaces for communication early on can present a risk of routinising the communication process and settle implicit fixed representations of complexity, which prevents adaptation and new insights from sensemaking. The authors argue that this strategy is effective in dealing with dynamic complexity. The use of integrated project teams with experts from different organisations is an example of such a strategy (Brady & Davies, 2014).
    b. **Separation-Allocation:** This strategy is based on controlling the structural complexity of projects. Tasks and relevant components are decomposed into separate parts. This type includes the use of Public Private Partnerships (PPP) or turnkey contracts. Tasks are allocated between client and contractor organisations. The authors argue that this type of strategy tackles structural complexity in technical and organisational aspects. It reduces undesired interactions and helps to control emerging properties. This is done through efforts in systems engineering and contracting by dividing the objectives, uncertainties, risks and tasks into parts or modules, to uncover interactions between project elements. Communication is well-defined through interfaces (in contracts) between separate parts. Hidden interactions can still be captured if planners maintain oversight on the integration of separate parts. The development effort is considerable in this strategy, because there are high requirements to facilitate interfaces between parties. These requirements aim for understanding, negotiation, specification, legalisation and price calculation.

Involving strategic decision-making

Salet et al. (2013) advocate for more interaction between the project management team and the strategic planners and decision makers to deal with complex projects. The authors explain that project managers do not have time to involve strategic thinking (for example discussing differences in interests of organisations) in the project. As a response, they recommend to install a strategic board that is separated from the daily project management. According to the authors, this would lead to the following distinction:

1. Strategic decision-making processes: Establish strategic objectives and mobilise institutions.

2. Operational decision-making processes: identify and implement flexible options and create a learning context to generate and select these options.

The first kind of decision making is strategic, and it is done by the strategic board. From the perspective of these strategic decision makers, it is hard to reshape the project management trajectory (2) because there are path dependencies in the project organisation. As a reflection, the authors emphasise the importance of identifying robust measures and preserving flexibility. In other words, they have to make decisions that are compatible with different views, interpretations and possibilities considering the interests of different organisations in the project. This would allow the operational project management (2) to make use of this flexibility.

The second kind of decision making is operational, and should be done by the project management team. The project team should take measures that can handle the strategic differences in interpretation of subject matter and conditions (social, political, environmental). They have to develop different options for the project and they should flexible in choosing these options. In other words, they should be prepared for changes in the strategic processes (1). It is not only about integrating differences in interests, but also about translating these differences into practical measures in the project.

Integrated project teams

Brady & Davies (2014) performed a case study on two large construction projects in the UK: London Heathrow Terminal 5 (T5) and the 2012 London Olympic park (LOP). One main way of dealing with the high levels of complexity and uncertainty was through integrated project teams. Both projects involved an integrated team with managers from both client and contractor organisations, which was expected to come up with innovative solutions to emergent problems (Brady & Davies, 2014). They were especially occupied with the challenges of complex and uncertain situations in the project (Brady & Davies, 2014). The use of integrated project teams to deal with complexity may resemble the collaboration-integration strategy by Floricel et al. (2016), because it focuses on ties within the project organisation. However, it is a different approach that involves a management team with managers from different organisations.

Governability

Floricel & Miller (2001) identified a set of characteristics that enable projects to react to unexpected developments that impact the project. They can be seen as a kind of preparation for uncertainty. Floricel & Miller called this set of characteristics governability. According to their paper, four characteristics can create governability in projects:

1. Cohesion: Parties stay in the project and solve problems. This is characterised by bonds between project parties informal links during execution or operation.
2. Resources: Reserves in resources (financial or other). Ownership is important in building reserves. Distributing and sharing resources between project parties can help to deal with unexpected events. Redundancies and slack resources can also be used to deal with uncertainty. Often, reserves are also financial to allow for contingency in budgets.
3. Flexibility: The project can restructure itself after changes are induced by unexpected events. It can be achieved by strategies that do not constrain options in the long-term and strategies that allow for different paths of action. Flexibility reduces the costs of restructuring and

proceeding in different paths. This builds upon the general notion of flexibility that was introduced earlier in this section. Flexibility in the context of governability means to be able to change between different paths of action in projects. Several factors make it difficult to create flexibility. Contractual structures for example reduce flexibility. Some contracts that reduce risks related to supply and market in the long-term may prevent flexibility in responding to new market situations. Finance arrangements to fund the project can also reduce flexibility because of many conditions attached.

4. Generativity: This is about creative responses to perceived difficult situations. Presupposed factors are correct sensing and interpretation, time and attention required to make constructive discussions. Brining in new parties with different competencies may help. The diversity in views and access to different networks also helps to better detect adverse developments earlier. Creative people add perspectives outside the circle of managers. They can sense dangers and propose innovative solutions. However, some parties can block creativity by focusing on contracts instead of problem solving.

According to Floricel & Miller (2001), these characteristics can be installed deliberately, but they often exist unintendedly in practice. The properties of governability may also be contradicting. As an example, the authors mention that strong organisational bonds (cohesion) can limit flexibility, just as contractual structures do. As a consequence, projects should seek a balance between different characteristics that enable flexibility.

3.3.5 Managing in preparation for uncertainty: An overview

Different management approaches have been discussed in the previous sections. Here, an overview is given of the different approaches in the literature to manage in preparation for uncertainty in projects.

What project management approaches deal with the preparation for uncertainty?

The approaches to prepare for uncertainty in projects are threefold. Learning focuses on establishing a learning capacity of project management teams to be able to adapt the project strategy to uncertainties. Selectionism focuses on pursuing different options simultaneously to deliver the project. And the approach of representing complexity focuses on the ability to understand and manage the structural and dynamic properties of the complex project system. Whereas learning and selectionism are straight-forward approaches based on one specific type of thinking, the representation of complexity by project organisations can be achieved by multiple approaches. These were planning stage strategies, involving strategic decision-making, integrated project teams and governability. An overview of the different approaches to manage uncertainty is given in Figure 4. This framework is used to analyse the empirical findings of this research.

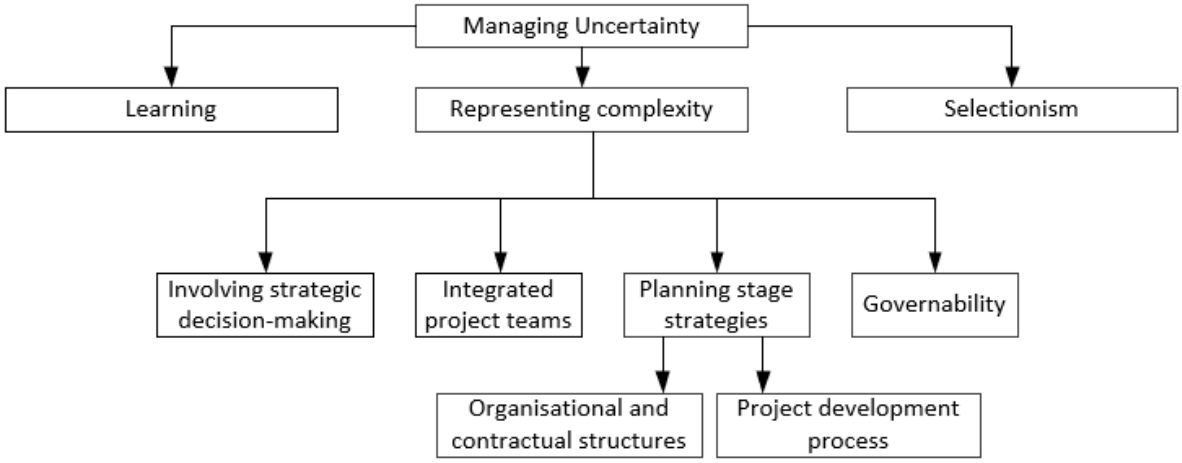

Figure 4: Managing approaches to prepare for uncertainty.

The approaches of representing complexity are not completely independent. There is some degree of similarity between different approaches that aim to represent complexity. The collaboration-integration strategy in the planning stage, the use of integrated project teams and cohesion as a factor that enhances governability in projects are similar in the sense that they aim for a close collaboration between project parties. In addition, the planning stage strategy that focuses on shaping the project development processes and the involvement of strategic decision-making shows similarities with learning. Therefore, the approaches of representing complexity in the literature are slightly overlapping. And there is some overlap between learning and representing complexity.

Considering the two main ways to deal with uncertainty, namely control and flexibility, the majority of the approaches in the literature are focused on flexibility. This is seen in the description of these approaches, which aim to deal with dynamic complexity and inevitable change by adapting the strategy to manage projects in the context of dynamics. However, there is one approach that is specifically aimed at controlling uncertainty: Planning stage strategies that shape organisational and contractual structures that focus on separation and allocation of project complexity and uncertainty aspects. This approach is said to target structural complexity and not dynamic complexity (Floricel et al., 2016).

By collecting empirical data on construction projects, the following insights can be gained:

1. Insights on which approaches are used in construction projects by project teams of public clients.
2. Insights on how certain approaches are used in construction projects, and if there are any differences with the approaches in the literature.
3. Insights on the main aims of these approaches, regarding control and flexibility.
4. Insights on how certain approaches are dealing with (aspects of) uncertainty in construction projects.

3.4 Conclusion

This chapter discussed the concepts of uncertainty, risk and complexity, and how these concepts relate to each other. It is shown that complexity plays an important role in the uncertainty of projects. The literature review has provided answers to the first two sub questions:

1. What uncertainties are involved in construction projects?

2. What project management approaches can be used to prepare for uncertainty?

Regarding the first subquestion, the literature brings forward eight distinct aspects of project that may be subject to uncertainty. Regarding the second subquestion, three main approaches are discussed in the literature, focusing on uncertainty and complexity. These approaches focus mainly on creating flexibility in the face of changes. No relation is found in the literature between certain management approaches and specific aspects of uncertainty in projects. This literature review has provided two frameworks (figure 3 and figure 4) which form the basis of understanding and analysing the empirical data that is collected in the case study. The following chapter adds to the theoretical basis by further describing the context of project management at two Dutch public clients.

4. Document analysis: Project management at public clients

Having shaped a picture of the different uncertainties and managing approaches from the perspective of the literature, a similar picture is needed of what public clients experience and do in construction projects. This research looks at two large public clients in the Netherlands (Rijksvastgoedbedrijf and Rijkswaterstaat), which form the focus of this research. Since this research is carried out in collaboration with the Rijksvastgoedbedrijf, access was offered to guiding documents about project management of construction projects. We want to look through those documents to see if we can find practices or guidelines that aim to deal with uncertainty. In addition, it also helps to further describe the context of this research.

In order to study the approach of public clients in managing construction projects using IPM teams, information is needed on how public clients organise the management of projects in IPM teams. This chapter explains the general process of managing projects by project teams of public clients. The documents may help to formulate a partial answer to the third sub-question: How do public clients manage construction projects in preparation for uncertainty?

Only documents of the RVB are studied, because these were the only documents that were readily accessible within the time frame of this research. A major part of these documents apply to Rijkswaterstaat also, because the IPM model and system based contract management SCB, two main concepts that are found in many of those documents, are used by both public client organisations. The outcome of the document analysis is compared to the approaches in the literature to derive a partial answer to the third subquestion.

The results of this chapter are based on the analysis of documents in the database of the Rijksvastgoedbedrijf. The documents about project management found in the database were about the structure of the IPM model and processes (*RVB Kader IPM* , 2021), collaboration within project teams (*Notitie Stabiele IPM Teams*, 2020), contract management (*Kader Systeemgerichte Contractbeheersing Rijksvastgoedbedrijf*, 2017) and contract planning (*Afweegkader Contractvorm*, 2020). In addition, several documents about procurement strategies were found and scanned, but these did not provide information on the management of projects within project teams.

Relevant information was found about the management of construction projects by IPM teams. This is about the role of the project team in shaping the project strategy. In addition, two concepts were found that refer to the management of uncertainty and complexity, similar to the findings in the literature review. These concepts are: 1) Collaboration within the IPM team and 2) the selection of a contract form. Section 4.1 explains the general role of the project management team in the organisation and management of complex construction projects. 4.2 discusses the two concepts found in the documents that aim for a preparation for uncertainty in projects. Thereafter, concluding remarks are made about the management of projects by public clients, and how this is aimed to deal with uncertainty.

4.1 Integral Project Management (IPM)

The project teams that manage construction projects on behalf of public clients are responsible for the planning and execution of the complete project according to the assigned scope and resources. When the project is complex, meaning it involves an integrated contract with at least a design-build responsibility for the contractor, this project team follows a specific structure of project management: Integral Project Management (IPM). IPM was briefly explained in the introduction of the report. This section further explains the role of IPM teams in construction projects.

The IPM team is formed at the start of the project. This team has to make a plan to deliver the project and make decisions about the general content as the project progresses. The IPM team has several authorities to make decisions to manage projects in preparation for uncertainty. They decide on the contract strategy, collaboration with organisations, technical content, interfaces and they make the overall plan to deliver the project in the complex environment (*RVB Kader IPM* , 2021). This is set down in a project initiation document (PID), which explains in detail how the project is procured and realised in terms of time, money, quality, information and communication. Therefore, the IPM team has an important role in shaping the structure and the strategy of the project.

However, some of the decisions regarding the project are not made by the IPM team. Before the project team starts managing the project, a project brief is set up, in which an asset or portfolio manager specifies the need for a specific scope of work to develop the portfolio of assets. This work can be the construction of a new facility or the renovation of an existing facility. The IPM team is less involved in this phase. Some of the IPM team members are consulted by asset or portfolio managers. These are mainly the project manager, contract manager and technical manager. These managers can advise the portfolio or asset manager about the scope of the project, objectives and contract form. In addition, there is a representative of the customer (often a government client) which can make decisions about the project.

4.2 Managing in preparation for uncertainty

Based on a comparison of the documents with the literature on managing uncertainty, there are two ways in which public clients can prepare for uncertainty, in line with the literature. This can be in the collaboration within the IPM team and in the selection of the contract form of the project. These are the only concepts that were found in the documents that resonate with the approaches in the literature. This offers limited knowledge on how public clients manage uncertainty in projects. First, because the way collaboration in IPM teams is explained in the documents does not provide definitive conclusions on how this deals with uncertainty in projects. Second, the selection of the contract form is only a small portion of the approaches available to prepare for uncertainty in projects. In addition, the contract form is more effective to control the structural complexity of projects and less effective to deal with dynamic complexity (Floricel et al., 2016).

4.2.1 Collaboration within the IPM team

The IPM method relies on effective collaboration within the IPM team (*RVB Kader IPM* , 2021). This has similarities with the concepts of integrated project teams that learn together about the changing environment of the project (Ahern et al., 2014a; Brady & Davies, 2014). Some of the factors addressed in this subsection may also be closely related to the collaboration-integration strategy in projects (Floricel et al., 2016). All the information comes from the RVB Kader IPM (2021).

Trust and collaboration

Trust makes the team members more confident in expressing their weaknesses and mistakes. This has a positive effect on experimenting, because team members are more likely to experiment and make mistakes in a trusty environment. Good collaboration does not only involve trust, but also confidence in confronting each other's ideas. Engaging in conflicts enriches the ideas and helps to find appropriate decisions that consider different interests. It also stimulates the team to do research and explore possibilities. Communication in dialogue helps to be exploring insights instead of discussing the validity of existing insights.

Interaction with project environment

Awareness of the influences of the environment of the project (internal and external) can also be important in dealing with uncertainty. This helps to detect developments in the environment and recognise different interests. This point is elaborated in the document on IPM from the Rijksvastgoedbedrijf.

Being aware of the interests of stakeholders is also an important factor of collaboration in project management. These interests can be hidden, unclear, unknown or conflicting. It is important to explore beforehand how different interests can be fitted properly in the management strategy of the project. This can reduce uncertainty according to the Rijksvastgoedbedrijf.

IPM teams that showed high levels of trust are said to have more open teams. This means that people or organisations outside the team can interfere and influence the work and results of the project. It does not matter who engages in interactions with the project environment. This can contribute to mapping the environment and being flexible in addressing potential changes and developments.

4.2.2 Selection of contract form

Another potential way to prepare for uncertainty is through the selection of the contract form, which has implications on the contractual and organisational structure of the project (Floricel et al., 2016). A specific document about the selection of contract models (*Afweegkader Contractvorm*, 2020) offers a process of selecting the contract model for a project. The contract model includes the scope of work in the contract, the division of risks, the specification of requirements (functional or specific) and the management of the quality.

Level of integration

The most integrated form is DBFMO. The least integrated form is the traditional form (Client hires a consultant separately to specify a design and selects a contractor to build that design). In between are contract forms of DB or DBM. To make a weighted choice on the contract form in a project, several aspects related to uncertainty are considered to decide on the integration level in contract form:

- Information uncertainty: The available information about the object (in case of reconstruction), technology and the environment can be incomplete or inaccurate. This affects the potential of scope changes to achieve the desired result. Someone has to assess the completeness and accuracy of the available information to make a decision on which contract form is more suitable.
- Short-term demand stability: If the scope is not stable, there is more potential for arising requirements and needs. This is the case when the scope is incomplete and it is unknown what needs to be added. Unstable scopes can lead to scope changes during the realisation of the project, where new issues can impact the scope definition and the design process. It is important to make the uncertainties in the scope and the organisations that can change the scope explicit.
- Long-term demand stability: How stable are the long-term demands and objectives of the end-user of the facility? This relates to the uncertainty of contract scope in its ability to deliver the long-term objectives of the end-user (which often is the customer of the Rijksvastgoedbedrijf).
- Technological interwovenness: This relates to how the technical system of the project is affected by systems and objects outside the project. This factor is important in renovation or

reconstruction projects, where the technical system interacts with other external systems to deliver a function. This adds interfaces between the technical system of the project and other external systems. Uncertainty in the impact of external systems on the project scope is driven by the interwovenness of technical systems. Therefore, before determining the contract form, these interfaces and risks involved have to be addressed.

- Contractual interwovenness: This aspect plays an important role in reconstruction projects, similar to technological interwovenness. It is about the uncertain influences of other contracts on the contract of the project. Therefore, it is important to map the relations between the project contract with other contracts and the possible impacts this may have on the contract scope. And how do different contract forms deal with these interrelations between contracts.
- Technical complexity: This can be related to inner city contexts, difficult technical challenges and strong responsibilities between design, construction and maintenance. Technical complexities associated with the project have to be listed explicitly before the choice of a specific contract form can be made. It is also important to consider the knowledge of contractors in dealing with complexity in the design and construction.

4.3 Conclusion

The analysis of documents in the database of the Rijksvastgoedbedrijf has provided two ways in which IPM teams may manage projects in preparation for uncertainty: Collaboration within the IPM team and selection of contract form. These ways fit with the existing descriptions in the literature. Based on these findings, a partial answer to subquestion 3 can be formulated as:

The documents point to two ways in which the RVB and RWS manage uncertainty in line with the literature. Namely by means of shaping an organisational IPM structure that focuses on collaboration and by selecting a contractual structure that incorporates uncertainty and complexity of projects.

This is what the documents say. In the following chapter, the results of the interviews with IPM teams of the RVB and RWS are presented. These results should confirm and/or complete the answer to the subquestion. Empirical data is used to elaborate on how public clients manage uncertainty in their project teams. This is presented per case with regards to the aspects of uncertainty and the management approaches.

5. Case study results

To gather the empirical data, 17 interviews were carried out with IPM team members across 4 cases, two at RVB and two at RWS. Participants were asked about what is uncertain in their project and what is done within the IPM team manage in preparation for these uncertainties. This chapter presents the results of the case studies. Detailed descriptions of the results of each case study are found in Appendix 4: Case results. This appendix describes in detail wat participants described as uncertainties and management approaches that deal with uncertainty. In addition, quotes from the interviewed participants of each case are found in Appendix 5: Interview quotes to support the detailed case descriptions. The results provide the empirical data needed to compare the concepts of the literature study (see chapter 3: figure 4 and figure 5) with the findings from the case study. Hereby, the third subquestion is answered: *How do public clients manage construction projects in preparation for uncertainty?* The content of this chapter serves as a basis for the cross-case analysis in the next chapter, so that patterns in uncertainties and approaches can be found, and eventually, improvements can be suggested.

In this chapter, the results per case are showed using two themes: Uncertainties and managing uncertainty. The first theme introduces uncertainties that played a role in the project and how they impacted the project. This results in a comparison of these uncertainties based on the categories identified in the literature. In the second theme, the approaches used by the project team to prepare for these uncertainties are outlined and explained. These approaches are also compared to the approaches in the literature. Section 5.1 to 5.4 outline the results of case 1, 2, 3 and 4 respectively.

5.1 European Medicines Agency (EMA)

This section presents the results of the EMA case study. Different uncertainties and approaches to manage uncertainty were found that fit into the concepts of the literature.

5.1.1 Uncertainties

Uncertainties were found that fit into six of eight categories from the literature. Many uncertainties were related to the tight planning of the project.

Table 5: Overview of uncertainty aspects found in the EMA case.

Uncertainty	Finding
Objectives and scope	Part of the scope was overlooked.
Methods	None.
Market	Finding a contractor in procurement.
Resources	Delivery of Steel components.
Stakeholders	-The user organisation -The contractor's processes
Contract	-Clarity of requirements and processes -Changes in the contract
Technology	None
Environment	-Local support for permits -Political environment - Storm

Objectives and scope

No uncertainties were encountered about the objectives of the project. In fact, the objectives were clear. A building had to be delivered on 15 November 2019. However, the scope was fairly uncertain. A misunderstanding occurred about the integration of ICT facilities in the project. The government client had expected ICT facilities to be delivered in the project, whereas this was not the case. As a result, this had to be included later on in a separate contract. The installation of ICT equipment had to take place during the regular construction of the building, which is unusual practice. As a result, it was uncertain how this would work and whether this could finish in time.

Market

The procurement was pointed out as an uncertainty. There was uncertainty about finding a suitable contractor for the project on time. This impacted the project when several contractors withdrew from the procurement procedure, and only one contractor remained as a potential candidate. An unexpected event after procurement was that another market party joined the selected contractor to do the job. According to the project manager and contract manager (pre procurement), this was unexpected and had a positive effect on the project finishing on time.

Resources

The delivery of steel material was an uncertainty in this project. This was known during the procurement phase, when the contractor entered into a competitive dialogue procedure with the client. However, it had an unexpected impact on the project when, suddenly, the steel work was delayed by two weeks because of delays in the delivery.

Stakeholders

The EMA organisation, which is the final user of the building, formed a source of uncertainty in the project. The project did not know whether or when EMA would come up with additional requirements, which could delay the project. As a preparation for this uncertainty, The project team had set a deadline, after which the user could not come with new requirements. However, the EMA organisation demanded an important design change after the deadline.

Next to the users, the contractor is a stakeholder which played an uncertain role. It is mainly the uncertainty in the processes of the contractor, and whether they are conducted according to the contractual requirements. The public client does not know whether the contractor conducts the processes exactly as agreed in the contract. This uncertainty plays a role in almost all DB and DBM projects, where detailed process requirements are set down. In the EMA project, several unexpected deviations were found in the building as a result of inadequate verification processes.

Contract

This project also had to deal with uncertainty related to the contract. It is uncertain whether the contract is clear about all requirements and processes, and if the both parties understood the contract in a similar way. As a result of this uncertainty, changes can occur in the contract. The contract manager stated that changes in the contract are always uncertain. They can lead to discussions about the justification and the price of the change, which may have a major impact on the project. Several discussions took place in the project about changes in the contract and who is responsible for the costs. One of the discussions was about the design, which had to be changed as a result of a requirement from the local permitting authority and a flaw that was discovered in the design.

Environment

With regard to the permits, there was uncertainty about complaints (from local actors) against the procedure for receiving permits. There were also uncertainties related to the political environment. According to the project manager, there are always uncertainties with regards to who holds positions in the government client organisation (in this case the Ministry of VWS) and in parliament. And in the EMA case, European politics was also involved. Italy enacted a lawsuit against the European Commission for deciding to move EMA to the Netherlands. Although the political uncertainty is beyond control of the IPM team, the political environment did not cause surprising impacts on the project. A heavy storm did have an impact on the project six weeks before the final delivery. Considerable damage was done to the inside of the building, which was not waterproof at the time of the storm. The reason for that was, because of the speedy construction process, installations were placed in the building while the facades were not finished.

5.1.2 Managing uncertainty

Different types of approaches to prepare for uncertainty were observed in this project. Only the approach of integrated project teams was not used. Table 6 shows how managing approaches were applied in the project.

Table 6: Overview of Managing approaches in the EMA case.

Managing approach	**Finding**
Learning	Project development process based on new knowledge.
Selectionism	None.

Representing complexity:	Signs of all approaches found, except integrated project teams.
Involving strategic decision-making	Close involvement of government client in project matters.
Planning stage strategies	- Organisational structure focused on both collaboration-integration and separation-allocation - contractual structure focused on separation-allocation and risk management processes
Governability	Cohesion and trust between project parties
Integrated project teams	None.

Learning

No signs of learning in the project environment were found. However, the project team arranged the project development process based on the development of new knowledge. A competitive dialogue procedure was included in the procurement phase, which resulted in elaborate discussions with the contractors about the objectives, challenges, risks and possibilities of the project. This way, the project team focused on new knowledge rather than relying on existing knowledge. Project parties, such as the user and the local authority, were consulted early in the process to explore their needs and discuss the plan for the project. Apart from the competitive dialogue, no approach of learning during the project was described by the participants. Therefore, we do not consider learning to be used in this project.

Selectionism

This project did not use a pure selectionist approach. The project team was not pursuing different solutions at the same time. However, activities that may depend on each other were carried out simultaneously to save time. This procurement procedure was started six months before the final decision was made by the EU to host EMA in the Netherlands. Parallel to this procurement procedure, the project team applied for receiving the funds for the project. Several other activities were carried out in parallel to cope with the time pressure. The design was split in two parts, so that construction was started while the design was still in progress. This strategy aimed to fast-track activites that would not be conducted in parallel otherwise. The project team also established a back-up solution: The contractor had two suppliers in case one would not be able to deliver components on time. This way, the project strategy was to focus on redundancy and fast-track.

Representing complexity

Involving strategic decision-making

The EMA project was managed with close involvement of the decision maker from the government client. The trust between the manager of the government client and the project manager was an important factor that allowed for an even closer involvement. In addition, they met frequently to discuss the progress and make decisions on uncertain matters. The manager of the government client played an important role in managing the interface between the ICT systems and the building structure, which was difficult to integrate because of the time pressure.

Planning stage strategies: Organisational and contractual structures

The organisational and contractual structure of this project includes aspects of both collaboration-integration and separation-allocation.

Collaboration-integration

There was flexibility in the organisational structure, with short-lines of communication within the project team and between the project team and the contractor's team. When something unexpected arose in the project, conversations followed soon after. Members of the project team were also allowed to attend internal meetings of the contractor's design team. The short communication lines were not only present between the public client and contractor, but also between the public client, the government client and the EMA organisation. This strategy by the early involvement of these parties in the project. The Municipality of Amsterdam was informed early in the procurement process about the project and the permits required.

Separation- allocation

Next to the collaboration-integration efforts, the organisational structure was also focused on separation and allocation. The project team had set down a clear description of the roles and responsibilities of the contractor. And although they participated in the meetings of the contractor, they clearly stated that the final responsibilities for the design and the quality of the building lies with the contractor. The contractual structures affirmed this. There were clear requirements with regards to technical specifications and processes for risk management, interface management and systems engineering. Audits were carried out by the public client to verify the use of those processes by the contractor.

Governability

The only characteristic of governability mentioned by participants in this project is cohesion. The bonds between the project parties were strong and characterised by trust. There was a strong desire from the client and the contractor to complete the project successfully. High levels of trust were observed within the project team and outside the project team. The trust between the contractor, the public client and the government client resulted in a strong cohesion between the project parties. According to the project team members, this trust was partly created, but also existed unintentionally as an enabling factor. No concrete approaches that were explicitly based on trust were found to prepare for uncertainty.

5.2 Breedplaatvloeren Turfmarkt (JuBi)

This section presents the results of the case study of the Turfmarkt.

5.2.1 Uncertainties

Uncertainties in the JuBi case were found to fit in four categories of the literature: Objectives, methods, stakeholders and contract. In addition, a new category is formed to include an uncertainty that does not fit in the categories from the literature. This category is called the state of the object. Table 7 shows the uncertainties of the JuBI case for each category of uncertainty.

Table 7: Uncertainty aspects in the JuBi case.

Uncertainty	Finding
Objectives and scope	Amount of floor elements to be restored.
Methods	Which construction method is appropriate and valid.
Market	None.
Resources	None.
Stakeholders	The behaviour of the user organisations.
Contract	Contract price.
Technology	None.
Environment	None.
New category: State of the object	Which installations are located in each floor.

Objectives and scope

The objectives of this project were not uncertain. However, there was some uncertainty in the amount of floor elements that needed to be restored in the building. The public client had conducted a study that determined how many elements needed to be restored. However, in the middle of the procurement phase, it unexpectedly turned out that a new calculation method resulted in more floor elements that needed to be restored.

Methods

One of the biggest uncertainties in this project was the building method to be used. The problem of the strength of the floor structure is relatively new in the field of construction. Therefore, no validated building methods and strength calculation methods exist. This was prepared for by having two methods in place: Boring and liming. The liming method is used as a back-up option. However, this uncertainty impacted the project when the boring method turned out to cause damage at some places. More damage was done to the floors than expected, because the drawings of the floor installations were inaccurate. And the liming option was not ready to be used directly. A validation process had to be conducted to prove that the method leads to the desired floor strength. As a result, the implementation of the liming method was delayed by several months.

Stakeholders

The role of the user organizations was uncertain in the project. The project team members were not certain about how the users would act or react to the hindrance in the building. Nor were they certain about their attitude and requirements during the work. The building had to stay operable

during the works, which requires coordination about measures to reduce hindrance. No surprises occurred from the user's side, except of an investigation that they initiated to review the safety of their building. The user organisations demanded a second opinion for the initial investigation on the safety of the floors, conducted in order of the public client. The conclusion was that the project team had to take extra measures to ensure safety in the building.

Contract

The price of the contract is an uncertainty, as mentioned by the contract manager who was involved in the procurement phase. This has to do with the uncertainty related to the state of the building. There are many different installations in the building present in and underneath the floors that need to be restored. Calculating the costs of all the works would take several months and lead to extra process costs. During the procurement phase, the project team and the contractor developed a variable cost model with a base price for each floor. Any extra costs due to deviations in practice will be compensated according to a maximum percentage of the base cost. The final cost of all works required, and thus the contract price, remains uncertain for the public client.

New category: State of the object

Another uncertainty that played a prominent role in the project was the state of the building floors. This uncertainty is not attributable to any of the eight aspects of uncertainty. It is rather specific to the nature of renovation projects, and all participants mentioned this uncertainty. Due to inaccurate technical drawings, there was uncertainty in what installations are located underneath and within each floor. Despite working with scanners to detect installations in the floor, considerable damage was done to the floors using the boring method. Next to the installations, an issue was discovered with steel beams in the upper floors of the building, which requires extra restoration work. That issue is currently being investigated

5.2.2 Managing uncertainty

A variety of approaches was addressed by the project team members in this project. Only the approaches of integrated project teams and involving strategic decision-making were not observed in this project. An overview of the approaches is found in Table 8.

Table 8: Overview of managing approaches in the JuBi case.

Managing approach	**Finding**
Learning	- Learning from work on less complex floors first. - Experiments and trials with construction methods and hindrance. - Project development process based on new knowledge.
Selectionism	Working with two construction methods, but not simultaneously.
Representing complexity:	Signs of all approaches found, except integrated project teams and involving strategic decision making.
Involving strategic decision-making	None.
Planning stage strategies	- Organisational structure focused on collaboration-integration.

	- Contractual structure focused to a lesser extent on separation-allocation, and risk management processes.
Governability	- Reserve in financial resources. - Generativity from parties with technical expertise.
Integrated project teams	None.

Learning

The project team adopted a learning approach by working on the higher floors first, which are more repetitive in their structure and locations of installations. This allowed the project team to learn about the functioning of the boring method, the locations of installations and investigate the state of the other floors in the meanwhile. The lower floors of the building are more diverse in the types of installations attached to it. The knowledge gained from the higher floors will be taken to the lower floors later on, which are seen as more diverse. Regarding the project development process, a competitive dialogue procedure was included in the procurement process, where this learning strategy was discussed. The competitive dialogue was also used to discuss the uncertainty related to the validation of the construction methods, the contract price and the user organisations.

Several experiments and trials were conducted to test the construction methods at a remote test site. Tests were carried out with representatives of the user organisations at the site to check the levels of hindrance of noise and dust. This also allowed the project team to assess how much space is available to work at the site.

Selectionism

No signs of selectionism were found in this project. The project team demanded from market parties to be able to work with two construction methods. However, these two methods were not designed and executed in parallel. The liming method was kept as a back-up option, in case the boring method would not be sufficient.

Representing complexity

Involving strategic decision-making

No involvement of higher levels of decision-making was observed to prepare for uncertainty in the project.

Planning stage strategies: Organisational and contractual structures

Collaboration-Integration

No contractual structure was found that aimed for collaboration and integration. However, this project uses an organizational structure in which regular meetings take place between the project team and the contractor. The meetings follow a structure of monitoring the progress of risks and control measures, which again follow a structure of risk management. These meetings are used to discuss risks and anticipate on future possibilities. This was seen as a way to prepare for uncertainty, according to the project- and program manager. These meetings are used to come up with a solution to the excessive damage that was done to the installations in the floor. The project team holds a position of collaboration in this meeting, where they aim to help the contractor if needed.

Separation-Allocation

Despite having a contractual structure that focuses on a separation of tasks, processes and responsibilities, this was not mentioned by the participants as a preparation for uncertainty. No references were made of a strong risk management process that was embedded in contractual or organizational structures.

Governability

The primary sign of governability in this project is the use of a financial reserve by the project team of the public client. This reserve is used to absorb risks that may impact the budget more than expected. Another aspect of governability that is addressed by participants is generativity. External parties were involved to offer their expertise in constructive matters and offer a way of escalation of conflicts related to the topic. Although these parties are not necessarily creative in their response to complex situations, they may offer solutions form a technical point of view. Although, this was not observed in the case, it may provide a solution to arising issues in the execution, which is currently taking place.

5.3 Julianakanaal Berg-Obbicht (JBO)

This section presents the results of case 3: JBO.

5.3.1 Uncertainties

Uncertainties from three categories of the literature were observed: Methods, Stakeholders and Environment. In addition, a new category of uncertainty was found, similar to case 2: The state of the object. An overview of the uncertainties in this case is found in Table 9.

Table 9: Aspects of uncertainty in the JBO case.

Uncertainty	Finding
Objectives and scope	None.
Methods	Construction method: Sufficient safety and freedom of the shipping process.
Market	None.
Resources	None.
Stakeholders	The shipping industry.
Contract	None.
Technology	None.
Environment	Emergence of protected species near the construction site.
New: State of the object	- Objects in bottom of the channel. - Leaks in the channel. - Strength of the dikes.

Methods

The construction method is an uncertainty in this project. There is limited space to work on the channel, as the ships should be able to pass by during execution. The contractor that was selected initially used a wet method without construction pits. This caused discussions between the public client and the contractor when considerable damaged occurred to the channel. A new contractor was selected who uses a different method, which is currently being tested in a pilot at the site. Whether this method will work according to all requirements, is still uncertain. For example, the pilot revealed that translation waves cause problems to the safety of the workers and the sailing speed of the shipping traffic.

Stakeholders

The main stakeholder that is involved in the project is the shipping industry. Their main interest is to minimize hinder of the shipping process during construction. There is uncertainty in how this stakeholder will act during the project. The shipping industry initiated a protest against the construction method of the new contractor, which resulted in a pilot where the method is tested on part of the channel to see if it is safe enough and acceptable for the shipping traffic.

Environment

The appearance of protected species in the environment of the construction site is an uncertainty that plays a role in many infrastructure projects. When some species settle in the environment, this can delay the project by months. Up until now, this has not been the case, even though a protected species was spotted in an environment further away from the site.

New: State of the object

The state of the channel is an important uncertainty that was mentioned by all participants. The channel is approximately 100 years old, and it lies higher than ground level. This makes the channel prone to leaks, which can have a devastating effect on the environment and safety. It is also unknown what objects are located in the bottom of the channel. The environmental manager mentioned uncertainty in the strength of the dikes during construction. During the work of the first contractor, a large leak occurred in the channel, which caused the contractor to withdraw from the project. And several smaller leaks occurred, and objects were found or hit during execution, leading to delays and extra costs. In addition, it turned out that the edge of the channel is more difficult to control. Currently, the new contractor is experimenting with another method and monitoring the environment to detect and repair leaks.

5.3.2 Managing uncertainty

The interviews revealed two main managing approaches in this case: Learning and Representing complexity. Within the approach of representing complexity, no integrated project team was used. Table 10 gives an overview of the approaches found in this project.

Table 10: Overview of managing approaches in the JBO case.

Managing approach	**Finding**
Learning	- Pilot for the construction method - Monitoring and scanning of the environment to detect objects and leaks. - Project development process based on new knowledge.
Selectionism	None
Representing complexity:	
Involving strategic decision-making	Close involvement of public client and government client in project matters.
Planning stage strategies	Organisational structure focused on collaboration-integration.
Governability	- Cohesion between project parties to solve problems. - Financial reserve held by the project team.
Integrated project teams	None.

Learning

An important mechanism for learning in this project is the pilot for the construction method. A competitive dialogue was used to discuss the risks with regards to the possible construction methods, thereby exploring the possibilities. This resulted in a pilot, where the method is tested at the site on its safety and hindrance to the shipping traffic. In addition, groundwater levels are monitored in the environment to detect leaks in the channel. And scanners are used in some parts of the channel to detect objects and pipes in the bottom. The pilot should conclude whether the method is safe and acceptable. The results are looking positive, and the contractor is planning to start the real work in June 2022.

Representing complexity

Involving strategic decision-making

The involvement of strategic decision makers was used by the project team to prepare for uncertainty. The project manager communicates closely with higher levels at Rijkswaterstaat and the Ministry of infrastructure about how risks develop, what may emerge and about the views of the decision makers.

Planning stage strategies: Organisational and contractual structure

Collaboration-Integration

The organizational structure is set by the project team to have open meetings with the contractor's team about risks. These meetings take place each two weeks at the site and they are used to update the risk register and foresee upcoming risks.

Separation-Allocation

No strategies of separation-allocation were mentioned in this case.

Governability

There is cohesion between the public client and the contractor. These parties are engaged in this project and seek to solve problems together, as explained by multiple participants. The connection between the public client and the shipping industry is also made at higher levels, making the portfolio manager more involved in the project. Another aspect of governability found in this case is the reserve. A financial reserve is used to account for unforeseen risks in the project. Despite that the expertise of the project team and the contractor was put forward as an important factor of preparing for uncertainty, no signs of generativity were observed.

5.4 Renovation Eerste Heinenoordtunnel (REH)

This section presents the results of the REH case.

5.4.1 Uncertainties

Uncertainties were found from all categories, except in the contract. In addition, two new categories were found: The state of the object (also present in case 2 and 3) and the middle tunnel channel, which is a unique feature of the project. The uncertainties observed in this case are presented in Table 11.

Table 11: Aspects of uncertainty in the REH case.

Uncertainty	Finding
Objectives and scope	Scope of tunnel systems was suddenly added to the project.
Methods	Construction of the middle tunnel channel may impact the construction method.
Market	Material prices
Resources	Organisational resources of the public client.
Stakeholders	The municipality of Barendrecht.
Contract	None
Technology	Development of tunnel systems.
Environment	Excessive hindrance for road users and businesses in the environment.
New: State of the object	- unexpected failure in fire extinguishing system. - Concrete floor higher than expected.

Objectives and scope

The objectives of the project were not uncertain. However, suddenly, the development of tunnel systems was included as an objective of the project. Even when it came out that the development of the tunnel systems would not be ready in time to serve in the REH project, the public client decided at higher levels to include it in the project.

Methods

The method of construction is not a prominent uncertainty in the project. However, it is uncertain how to construct a wall within the tunnel to create a middle tunnel channel. There is not much space and time available. As a result, the contractor is experimenting on a remote site with wall elements. This is not necessarily an uncertainty in the method itself, but it is uncertain how the method is to be used efficiently. The 600m long collision proof wall has to be constructed within the three weeks of tunnel closure. It is uncertain whether this is possible, as it has not been done before. The contractor is experimenting with wall elements outside the tunnel to see how it can be constructed as fast as possible.

Market

The material prices unexpectedly rose as a result of the war in Ukraine. This uncertainty was mentioned by the project manager as an unforeseen uncertainty that surprised everyone in the team. No significant impacts were mentioned by the participants.

Resources

Uncertainty in the organizational resources at the public client were mentioned by the project manager. It is not certain whether the project team will have enough competent people in sub-teams throughout the project. Some sub-teams are confronted with a shortage of people, but this has not been mentioned as something that impacts the project.

Stakeholders

The Municipality of Barendrecht is an important stakeholder who has to grant the permits for the project. Their interests are uncertain because of the political situation, which is subject to change. The relation between the project team and the municipality came under pressure when an issue was discovered in the fire extinguishing system. This may have effects on the permit application process. The contract manager mentioned the risk of not receiving permits on time and the demand for extra measures during the closure of the tunnel. In practice, this has not yet been an issue for the Eerste Heinenoordtunnel. However, the project team overlooked the need for a permit to work on another tunnel near the main tunnel. This permit is needed to make adjustments to the tunnel to facilitate bus traffic during the closure of the main tunnel. The expectation is that the project will be delayed by this process, and more hinder will be experienced in the environment.

Technology

The development of the tunnel systems of the tunnel is uncertain. It is a new package of systems which have not been developed before, and it is supposed to be universally applicable in multiple tunnels. It is uncertain whether the development will finish in time before the renovation starts because of the novelty of the technology. In 2019, the planning revealed that it would not be finished in time for the Eerste Heinenoord tunnel. Nevertheless, Rijkswaterstaat included the development assignment in the project. As a result, the development is being sliced in different parts which are delivered separately. The aim is to finish as much as possible before the start of the renovation in the summer of 2023. Currently, the development is on track, and its progress is being monitored regularly by the project team.

Environment

In close relation to the stakeholders, the environment plays an important role in the uncertainty of the REH project. Although this has not yet impacted the project, the project team is aware of the uncertainties related to the hinder during tunnel closure and how stakeholders in the environment react to it.

New*: State of the object*

The situation in the tunnel is uncertain, according to the project manager and the contract manager. The plans and drawings are not accurate, which increases the risk of discovering unexpected components or deviations in the tunnel. The project team was surprised by finding deficiencies in the fire extinguishing system, which resulted in much more work than expected. And it was discovered that the floor of the tunnel is thicker than expected, which reduces the space available for maintenance in the tunnel. In addition, state of the joints of the tunnel is unknown.

5.4.2 Managing uncertainty

From the interviews, several approaches were found in this case. Learning and representing complexity are the main approaches that are being used prominently in this project. Selectionism is

not used in this project, although several activities are being conducted in parallel. Table 12 gives an overview of how the approaches have been used in the project, according to the interviews.

Table 12: Overview of managing approaches in the REH case.

Managing approach	**Observation**
Learning	- Experimentation at a remote site. - Project development process based on new knowledge.
Selectionism	Conducting activities in parallel to save time
Representing complexity:	
Involving strategic decision-making	Demanding mandate from and escalation to higher levels of the public client.
Planning stage strategies	Organisational structure focused on collaboration-integration for risk management.
Governability	- Reserve in budget. - Flexibility in development of tunnel systems
Integrated project teams	None.

Learning

Experimentation is done through the use of mockups of the tunnel wall elements and reconstruction of the tunnel joint at a remote site to learn about the structure of the tunnel elements and how to work efficiently with them. In addition, the procurement process included a competitive dialogue, in which contractors were invited to discuss their plans to deal with uncertainties related to hindrance in the environment, the middle tunnel channel and the integration of the tunnel systems in the renovation.

Selectionism

No signs of selectionism were observed. The development of the tunnel systems is done in parallel with the design process of the renovation to save time. However, this is not pure selectionism, as these options are not replacing each other.

Representing complexity

Involving strategic decision-making

The overall project manager and the project manager of the tunnel systems have addressed the involvement of decision-makers at higher levels in the public client organization to prepare for uncertainty. The project manager of the tunnel systems regularly demands the portfolio manager for more mandate to be able to make decisions about significant issues. This allowed for a faster procurement process for the tunnel systems, after it was added as an assignment to the regular renovation project. The project manager mentioned the escalation of matters to higher levels if the project team is not able to deal with them. The resource capacity was mentioned as an example of a matter that is escalated.

Planning stage strategies: Organisational and contractual structure

Collaboration-Integration

The organizational structure facilitates joint meetings with the contractor where risk management is central. The teams of the public client and the contractor share the risks on their registers, and discuss the development of top risks and the emergence of new risks.

Separation-Allocation

No strategies of separation and allocation were mentioned to prepare for uncertainty.

Governability

A budget reserve is kept by the project team to fund unforeseen risks. Furthermore, the project is able to adapt its strategy in case the development of the universal tunnel systems is not finished in time. In that case, the project will proceed with the finished parts, and the unfinished parts will be designed to fit specifically in the Eerste Heinenoordtunnel. This is possible due to the sliced approach that is used in the development of the systems.

Integrated project teams

No use is made of integrated project teams in the REH case.

5.5 Conclusion

This chapter presented the results of each case study, regarding the aspects of the projects that are subject to uncertainty and the managing approaches used to prepare for uncertainty in the projects. In three cases, a new category of uncertainty was found: the state of the object. The cases show a variety of approaches being implemented that are present in the literature. Many aspects of learning and representation of complexity came forward.

In the EMA case, uncertainty was perceived in the objectives, market, resources, stakeholders, contract and environment. The main managing approach was to represent the complexity of the project by involving strategic decision-making, focusing on collaboration and integration in the organizational structure and creating cohesion through trust as a form of governability.

In the JuBi case, uncertainty was found in objectives, methods, stakeholders, contract and the state of the object. As preparation for uncertainty, the project team members described approaches of learning and representing complexity through an organizational structure based on collaboration-integration and governability through a reserve in the budget and involving experts to increase generativity in solutions.

In the JBO case, the methods, stakeholders, environment and the state of the object are uncertain. In terms of the approaches, a learning approach has been implemented by introducing a pilot in the project. Representation of complexity is used by involving strategic decision-making, an organizational structure focused on collaboration and integration, and governability by having reserves and cohesion between project parties.

In the REH case, uncertainty is experienced in objectives, market, resources, stakeholders, technology, environment, the state of the object and the middle tunnel channel. The project team prepares for uncertainty through learning and representing complexity. Learning is done through experimentation with components off site. Representing complexity is done through involving the strategic decision-makers, organizational structures focused on collaboration and integration and governability in the form of reserve budget and flexibility in technological solutions.

The next chapter compares the empirical findings between cases to answer subquestions 1, 3 and 4:

- What uncertainties are involved in construction projects?
- How do public clients manage construction projects in preparation for uncertainty?
- How can the project management approaches in the literature improve the management of projects by public clients?

6. Analysis of the cases

Building on the results from the case studies in the previous chapter, a comparison is made between these cases to formulate the main findings of this research. The goal of this chapter is to provide insight in the two main topics of this research: 1) what uncertainties play a role in construction projects and 2) what managing approaches are implemented by public clients to prepare for these uncertainties. Section 6.1 looks at the categories of uncertainties found throughout the cases. Section 6.2 looks at the management approaches used. Section 6.3 explains the link between certain approaches and certain aspects of uncertainty. In section 6.4, the relation between control and flexibility in the cases is discussed. And lastly, section 6.5 discusses the implications of the findings.

6.1 Uncertainty in projects

A variety of uncertainties was found throughout the cases. This section compares the aspects of uncertainty found in the cases (Table 13). The findings are combined to find similarities, differences and things that are remarkable in the uncertainties throughout the cases.

Table 13: Aspects of uncertainty throughout the cases.

	Case 1: EMA	**Case 2: JuBi**	**Case 3: JBO**	**Case 4: REH**
Objectives and scope	■	■		■
Methods		■	■	
Market	■			■
Resources	■			■
Stakeholders	■	■	■	■
Contract	■	■		
Technology				■
Environment	■		■	■
New: State of the object		■	■	■

6.1.1 Aspects of uncertainty

For each aspect of uncertainty, the role it played in different cases is explained and compared.

Objectives and scope

Uncertainty related to objectives played a role in case 1, 2 and 4. In all three projects, this was not an uncertainty in the main objective itself, but it was about what may be included in the scope of the project to serve the final objective. In the EMA case, the uncertainty was in part of the scope that was overlooked by the project team. Whereas in case 4, it was uncertain whether part of the scope would be added as an assignment by higher levels of the public client organization. In case 2, the

uncertainty lied in what parts of the building do not comply with the requirements. Hence, it was mainly the scope that was uncertain and not the objectives.

Methods

Case 2 and 3 experienced uncertainty in the construction methods. It was uncertain whether the construction method to be used is the right one for the situation of the renovation project. In both cases, the state of the object was an uncertain, so that it contributed to uncertainty in the construction method. However, it is not only the state of the object that drives such uncertainty. In case 2, the novelty of the scientific field caused uncertainty in the methods of calculation and validation, which introduced uncertainty in whether the construction method can strengthen the floors of the building sufficiently. In case 3, a main stakeholder (the shipping industry) also played an uncertain role in the use of the construction method. In case 4, the construction method itself was not uncertain, but it may become an uncertainty if the construction of the middle tunnel channel turns out to be infeasible. In conclusion, the construction method seems to be an uncertainty that plays an important role in complex renovation projects, and it is driven by uncertainty in the state of the object, stakeholders and new insights from science.

Market

The market uncertainty was involved in case 1 and 4, although in different forms. In case 1, it was the procurement of the work where it was uncertain whether a suitable contractor would be selected in time for the execution of the contract. Whereas in case 4, it was the prices of materials that unexpectedly rose as a result of economic and political developments. From these findings, this uncertainty seems to be mainly driven by external factors. These are dynamics that are often seen as complete surprises by the participants in these projects.

Resources

Similar to the market uncertainty, the resources were uncertain in case 1 and 4. Case 1 had to cope with uncertainty in the delivery time of steel components. Whereas in case 4, the public client experiences uncertainty in the organizational resources of the underlying project managing teams. Since this uncertainty was only encountered in two cases, and in a different way in each case, it is hard to derive how uncertainty in resources plays a role in construction projects in general.

Stakeholders

The stakeholders were a prominent uncertainty. The behaviour and actions of the stakeholders were uncertain with regards to the project requirements, permits and the construction method. In all cases, there was one main stakeholder that played an uncertain role in the project. In case 1 and 2, it was the organisations of the users. In case 3, the shipping industry was mentioned as an important uncertainty. And in case 4, the municipality's role is considered an uncertainty by the project managers. This shows that the stakeholders are a major aspect of construction projects that contain uncertainty, and that this uncertainty comes mostly from one main stakeholder.

Contract

In two cases (1 and 2), the contract was pointed out as something that was uncertain. However, the contract uncertainty differed in each case. In case 1, uncertainty in the contract was mainly about the clarity of the requirements and changes in the contract as a result of unexpected discussions about the design and execution of the work. In case two, the contract price was an uncertainty, due to the

tight time frame to procure the work and the complicated structure of the floors and installations in the building.

Technology

Only in case 4, uncertainty was experienced in technology. This had mainly to do with the innovative and universal character of the ICT systems that are developed in the project. Technology

Environment

In three cases, the environment showed to be uncertain. This was either by means of the weather conditions (case 1), local support for the permits (case 1), the emergence of protected species in the area of the construction site (case 3) or the unexpected hinder in the environment as a result of the project (case 4). In case 1, only the weather conditions had an impact on the project. And in cases 3 and 4, no impact has yet taken place, although the projects are currently in execution.

New: State of the object

In all three renovation projects (cases 2,3,4), the state of the object was uncertain. The main reason for this is the inaccuracy of drawings. In cases 3 and 4, the age of the object was considerable (over 50 years) so that the state of the object is even more uncertain. In all the cases, this uncertainty had a major impact on the project. In renovation projects, all projects shared the same uncertainty: The project team does not know what the true state of the object is, what elements are included and where these elements are located in the object. This means that this uncertainty is important to consider in renovation projects.

Uncertainty throughout the cases

Examples of all categories of uncertainty in the literature are present in one or more cases studied. The stakeholders category was present in all cases, followed by the environment and the objectives that were uncertain in 3 cases. Less prominently present are the categories: Methods, market, resources and contract. These were only mentioned in two cases. Technology was pointed out as an uncertainty in one case only. It seems to be the case that uncertainty in stakeholders, objectives and environment play a more important role in the construction projects studied compared to other uncertainties.

6.1.2 Interrelatedness, complexity and perception

The data points to several aspects that stood out regarding the role of uncertainty. These are the interrelatedness between different aspects of uncertainty, the overlooking of structural complexities, the difference between known and unknown uncertainties and the perception of uncertainty.

Interrelatedness between aspects of uncertainty

What has been addressed in the literature review, and is also seen in the results of the case study, is the interrelatedness between different aspects of uncertainty in a project. In three cases, it is a combination of uncertainty in different aspects that creates more uncertainty in the project.

In case 2, it was a combination of uncertainty in the state of the object and in the construction method that played a role in the contract (price) uncertainty and uncertainty in the objectives. In case 3, uncertainties in the state of the object and the stakeholders have a significant impact on uncertainty in the construction method. In case 4, uncertainty in the environment is closely linked to uncertainty in the stakeholders. And uncertainty in the technology is closely related to uncertainty in the objectives of the project.

Only in case 1, the interrelation between uncertainties is not so apparent. Many aspects were uncertain by themselves, such as the objectives, the contract and the environment. Little interrelation exist between them, based on the explanation of these uncertainties by the participants of the case. Regarding the relation between uncertainty in the contract and uncertainty in the stakeholder, they are closely linked. The processes of the contractor were uncertain, which may have driven uncertainty in the contract requirements, processes and changes in the contract.

Overlooking structural complexity of the project

In two cases, uncertainty played a role through the emergence of a structural complexity of the project which was initially overlooked by the project team. This happened in case 1 when the team realized after procurement that the ICT systems had to be included in the scope of the project. This introduced uncertainty in the integration of the ICT systems, which had to be done during the execution phase. That is unusual practice and complex due to the limited time and space available at the construction site. In case 4, the project required an additional permit which was not initially expected to be needed by the project team. Shortly after the start of the execution phase, it turned out to be required in order to execute measures against hinder in the environment.

Uncertainty: Known and unknown

Participants were asked to mention uncertainties that the project team was aware of before the start of the execution phase. These were considered known uncertainties. In addition, they were asked to mention unknown uncertainties. Unknown uncertainties are uncertainties that did play a role in the project, but the project team was not aware of these uncertainties prior to the start of the execution phase.

The most important uncertainties that had a significant impact on the projects were known by the project teams by the time of procurement. In cases 2, and 3, the main known uncertainties that played a role were the construction method and the state of the object. And these uncertainties turned out to cause the most surprises in the project. In case 4, the uncertainty in technology and the state of the object had significant impact on the project, as opposed to the unknown uncertainty of the permit that was suddenly required to execute additional works. Also in case 1, most uncertainties were known to play a role in the project before the end of the procurement phase. Some of those uncertainties had a surprising impact on the project, such as the resources, stakeholders and the contract.

When looking at the role of unknown uncertainties, only case 1 reported a significant impact. This was related to the scope. The integration of ICT components was unexpectedly added to the scope, which had a serious impact on the project in the execution phase. In other cases, unknown uncertainties did not have a serious impact. In case 2, the unknown uncertainties were related to finding unexpected objects in the building and having to restore more floor elements than expected. In case 3, the only unknown uncertainty mentioned was the discovery of a phenomenon in the translation waves near the construction site. Although these uncertainties came as a surprise, they

were not reported to have a significant impact on the project compared to the uncertainty in the method and the state of the object.

Hence, the findings suggest that most uncertainties that impact the project considerably are known rather than unknown. This implies that public clients should focus more on known uncertainties if impacts are to be mitigated. Possibly, more efforts can be done to anticipate on these uncertainties.

Uncertainty: perception

What exactly is regarded as an uncertainty depends on the perception of the project team. The way most participants explained uncertainties in the project in similar distinct themes, such as: permits, user, environment, method and state of the object. These themes are regarded as uncertainties. Then, they proceed to explaining why each theme is uncertain and what factors play a role in the uncertainty in the theme. They do this by either describing facts, underlying uncertainties, or both. However, in most cases, they are regarded as separate uncertainties. Interestingly, in case 4, the distinction was made between internal and external uncertainties by two participants. In the other cases, no distinction were made between different types of uncertainties.

When mentioning themes, references are often made to where the uncertainty comes from, or who gives rise to the uncertainty, instead of what the uncertain factor is for the project. This is seen in the mentioning of stakeholder organisations by name, who are often mentioned as uncertainties themselves. However, when looking at the possible impact of a stakeholder on the project, the stakeholder itself may not be the main uncertainty, but it is the actions or requirements of the stakeholders that are uncertain. And regarding uncertainty in the construction method, it is not the method itself that is uncertain, but its effects on achieving the desired state of the object. In case 1, the planning was mentioned as an uncertainty. This was explained by the tightness of the deadline and the changes that may occur in the planning. Although the planning is indeed an uncertainty according to this explanation, this is not an uncertainty in the project. From the perspective of the project, the main uncertainty would be the achievement of the planning before the deadline. Table 14 shows examples of explaining uncertainty in main themes. Note that the explanation, the main uncertainty and the risk involved can all be interpreted as uncertainties.

This interpretation differs from the terminology of risk management. A risk is a possible event that, if it occurs, has a direct impact on the project objectives (Aven, 2016). This event has a specific cause and effect. It is seen that participants often refer to themes that are uncertain, rather than risks. The causes for uncertainty put forward by participants are often uncertain themselves, whereas in terms of risk management, causes are often established facts. Surprisingly, when participants speak about the management of uncertainty, they often do address it from a risk management perspective, as explained in the remainder of the chapter. Participants do not specifically give risk related descriptions, but at the same time they use risk management to address uncertainty. This means that they either are not familiar with the risk management terminology, or they see uncertainty as something different from risk. Hence, public clients should enhance the use of a consistent way of describing uncertainty that is maintained in the management of uncertainty.

Table 14: Examples of interpretations of uncertainty in the cases.

	Source/cause/ Explanation (Not perceived as uncertainty)	**Main uncertainty (Perceived by most participants)**	**Effect: Risk involved (Not perceived as uncertainty)**

Case 1	Tight deadline Constant changes in planning	Planning	The project may not meet the planning
	Little involvement of user in the planning stage	User	The user may require changes to the design during execution
Case 2/3	New field of science in construction (case 2) Availability of shipping traffic (case 3)	Method	The construction method may not lead to the desired strength
	Inaccurate information Age of the object (case 3)	State of object	The state and location of components may be different than on the drawings
Case 4	Having enough information on time	Permits	The permit may not be granted in time

6.2 Managing uncertainty

Throughout all the cases, more or less the same type of approaches were found (see Table 15). All the cases used multiple approaches that are aimed at representing complexity. Three cases showed approaches of learning , some more than others. This section dives into the approaches found in multiple cases to discuss the similarities and differences in the approaches. In figure 8, a visual representation is found of the use of different approaches in the cases.

Table 15: Overview of managing approaches used in each case.

	Case 1: EMA	**Case 2: JuBi**	**Case 3: JBO**	**Case 4: REH**
Learning				
Selectionism				
Representing complexity:				
Involving strategic decision-making				
Planning stage strategies				
Governability				
Integrated project teams				

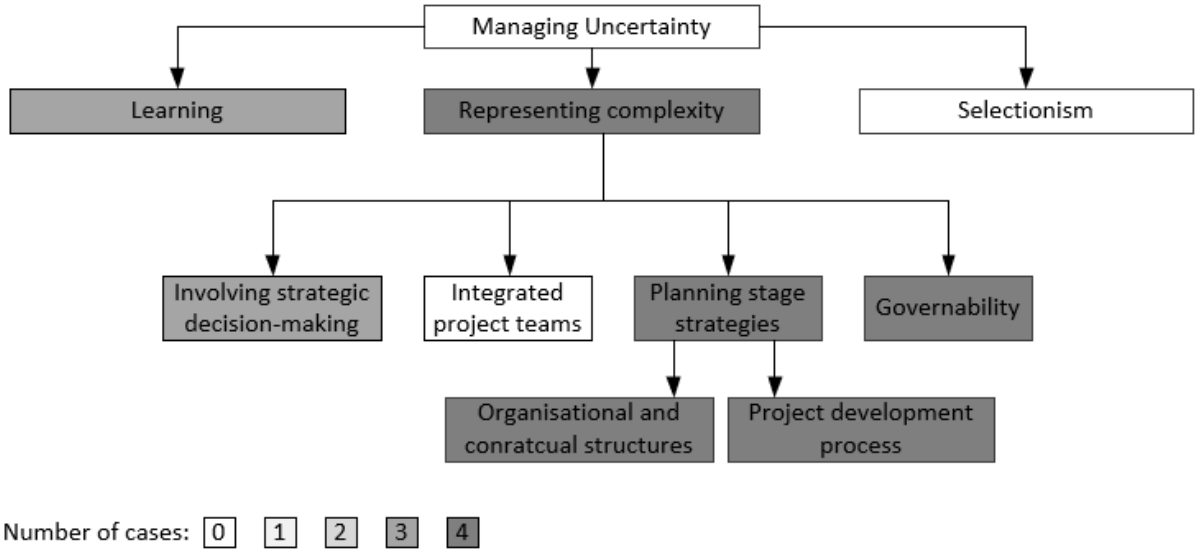

Figure 5: Occurrence of managing approaches in the cases.

Representing complexity is seen in all cases, especially through the use of planning stage strategies and installing some type of governability. Learning is also used prominently throughout the cases, but not in all cases. No cases applied the selectionism or integrated project teams to prepare for uncertainty.

6.2.1 Managing approaches

In this subsection, each managing approach is described in more detail using the different contexts of each case.

Learning

All cases used a project development process that focused on developing new knowledge in the planning stage of the project. A competitive dialogue procedure was used to learn about the challenges in the project and explore solutions. This procedure was mainly focused on risk management, where a variety risks were interchanged and strategies to deal with risks were discussed. In cases 2 and 3, the risks that were discussed were mainly technical.

In addition, active experimentation and evaluation was observed in cases 2, 3 and 4. This was done through a pilot (case 3), simulations off site (case 4), work on the site (case 2) and evaluations (case 2 and 3). Only in case 1, no signs of learning through simulations and experimentation were observed. The cases that used learning as an approach did this as a control measure to the risks that were anticipated in the competitive dialogue. Especially the most important risks were mitigated by the learning approach. In case 2, the experimentation was about learning how the construction method works. Similarly, in case 3, the pilot is used to learn about the construction method. In case 4, off site simulation are used to reduce the risk of not being able o construct the middle tunnel channel.

Selectionism

None of the cases used selectionism, where different solutions to the same problem were worked on simultaneously. However, multiple cases conducted different interdependent activities simultaneously. This is seen in case 1 and case 4. Case 1 and 2 created redundancy in the form of

back-up options in case the other solution does not work out as expected. These strategies differ from the selectionist approach by not working on the back-up option and the main option at the same time.

Representing complexity

All cases showed a representation of complexity as an approach to prepare for uncertainty. Signs were found of involving strategic decision-making, planning stage strategies and governability. No integrated project teams were used in any of the cases.

Involving decision making

Nearly all cases made use of the decision making authority at higher levels in the public client or government client organisation to prepare for uncertainty. In case 1, the involvement of decision making was done through the government client, who was closely involved with the project manager in managing project matters. This allowed for extra mandate to be present in the project. A specific feature of this approach in this case is the frequent communication between the project manager and the manager of the government client. Case 3 showed a close line of communication with higher levels of both the public client and the government client to incorporate different interests when making decisions. In case 4, specific mandate was demanded by the project managers to be able to make more authoritative decisions faster and manage the project more freely. This resulted in more flexibility in the procurement phase of the tunnel systems, which was suddenly added to the scope.

Planning stage strategies

The prominent approach present in all cases is the use of planning stage strategies. The project development process is a type of planning stage strategy that was present in all projects. That is discussed in the learning approach. The use of organizational and contractual structures is another approach that is discussed here.

All cases have shown an organizational structure that focuses on collaboration and integration when it comes to managing in preparation for uncertainty. Regular meetings with the contractor facilitated a joint discussion about risks, risk management and future anticipation of risks. In all cases, this strategy was mentioned by all participants. According to the participants, this strategy helps to verify the risk management process, update the risks and look for uncertainties that are recently appearing. Risks are continuously on the agenda of the meetings, especially highlighted in case 4. In cases 1 and 2, close collaboration was observed between the public client and the users, where weekly meetings were/are held to discuss the progress of the project.

In addition, some of the organizational structures are also focused on separation and allocation. This is seen in case 1, where the project team of the public client meets regularly to discuss the progress of the project and the risks involved internally. Part of the risks are assigned to the project team of the public client, which is then responsible for taking control measures and monitoring the risk. In case 1, this separation is more emphasized through the controlling role of the public client and the implementing role of the contractor.

It may be a surprising finding that none of cases referred to the focus of contractual structures on separation and allocation as a means to prepare for uncertainty. It does not seem to be used in preparation for uncertainty in the project. The literature pointed towards the use of contractual structures to prepare for structural complexity (Floricel et al., 2016).

And the documents of the public client organization that managed cases 1 and 2 showed that the contractual structure can be used to prepare for uncertainty in the project. However, none of these approaches were found in the cases. This may indicate that the structural complexity of projects, which is mainly manageable by separation and allocation, is not seen as a form of uncertainty.

Governability

Different aspects of governability were found in each case, where a reserve in the budget for unforeseen events was used in three of the four cases (cases 2-4). Case 1 and 3 showed signs of cohesion between the project team, the contractor and stakeholder to stay in the project. Case 1 showed strong signs of trust that contributed to this cohesion. The flexibility and generativity aspects were only observed in one case. Only case 2 involved external experts to increase generativity in the solutions proposed, but this has not been used actively to deal with uncertainty. And only case 4 created flexibility (in the development of the tunnel systems) to be able to adjust the plan in the project. The focus on resources and cohesion is found to be stronger across the cases compared to flexibility and generativity. An overview of the observations of governability aspects is given in table 16. It can be seen that cohesion and resources are used more often in the cases compared to flexibility and generativity.

Table 16: Overview of governability aspects found in each case.

	Cohesion	**Resources**	**Flexibility**	**Generativity**
Case 1	- Trust - Short lines of communication			
Case 2		reserve budget		-Involving external experts
Case 3	Collaboration with contractor	reserve budget		
Case 4		reserve budget	Slicing the integration of tunnel systems in case of delays	

Integrated project teams

None of the cases was managed by an integrated project team with members from different organisations. The projects were managed by separate management teams from the contractor and the public client. Regularly, these teams meet to discuss the progress and development of risks.

6.2.2 Managing uncertainty in each case: success factors

Next to the general framework of approaches, the data also points towards the importance of certain factors and narratives when it comes to managing in preparation for uncertainty. This subsection highlights aspects that are case-specific and discusses some common factors that were mentioned in the interviews about the management in preparation for uncertainty.

Unique aspects of each case

Although similar approaches are observed in multiple cases, each case has its own emphasis on certain approaches over others.

Case 1 (EMA) put a great emphasis on trust within the project team of the public client, trust between the client and the contractor, and short lines of communication. After that, the extensive risk management process was continuously controlled and updated in the project. The main idea put forward by the project team members is that through this structure, everyone knows what to do or who to consult when things go differently than expected.

In Case 2 (JuBi), the main approach is to have meetings on a regular basis where the project team discussed the status of the risk register with the contractor. This helps them to come up with measures to control risks and anticipate on emerging risks. The main risks had to do with the construction method and the possibility of damage to the floor installations. These risks were explored in the competitive dialogue during the procurement phase. Several external experts and the user organisations are involved to explore the effects of the method on the constructive strength and hindrance. In addition, a budget reserve is held by the project manager to account for surprises in the effects of risks.

Case 3 (JBO) makes particular use of a joint risk management process and involvement of higher levels of the public client and government client organisations in the project's decision-making. The risk management process is based on exploring and quantifying risks, having regular meetings with the contractor to update the status of risks and having control measures in place to mitigate risks. Control measures are mainly aimed at preliminary monitoring studies (through a pilot) on the site, regarding objects in the bottom of the channel, protected species in the environment and the effects of the construction method on the safety of the environment. The involvement of higher decision making levels in the client organisations is done from time to time to raise awareness at those levels and to keep track of developments in the project environment.

Case 4 (REH) is mainly invested in risk management and the mitigation of risks through regular meetings with the contractor. The contractor was asked to deliver a plan to control and mitigate the risks, which was discussed in the competitive dialogue. In addition, decision makers in the public client organisations are involved to increase flexibility in the management of the uncertain development of tunnel systems and uncertainty in the resources available. And if unforeseen risks emerge, there is an extra budget to compensate for it.

We see a main difference between the approach in case 1 versus the rest of the cases. Case 1 is more invested in guarding a close relationship within the project team and between the public client, the contractor and the user. Whereas the other cases stand out in the regular discussion and evaluation of risks with the contractor. The other cases also stand out by having more control measures in place to learn from the project environment and the construction method (only in cases 2 and 3), whereas case 1 focused more on controlling the technical requirements and processes in the contract.

Regarding this difference in the implementation of certain approaches over others, the question remains: Why do projects lay an emphasis on different approaches? Unfortunately, this research does not provide an answer to this question. However, certain success factors were put forward by participants from multiple cases to explain how they aim for a successful management of uncertainty.

Factors of success for managing uncertainty

During the interviews, several factors were addressed as important when it comes to preparing for uncertainty in a project. The main factors were trust, escalation and expertise. These factors were addressed by participants in multiple cases to explain under which conditions the approaches they are using are effective. The idea is that the presence of these factors allow for more success in the management of uncertainty.

1. *Trust*

Trust was a factor that was discussed elaborately by the participants of case 1. This was especially considered a crucial factor for the management of uncertainty in general. The trust between the project team members and between the project team and the contractor's team was on a high level, according to the participants. This explains the emphasis on cohesion in this case. Because due to this level of trust, parties stay engaged in the project to deal with unexpected developments.

2. *Escalation*

The project manager of case 1, the environment manager of case 3 and the contract manager of case 4 addressed the importance of a structure in which things can be escalated when unexpected events take place. It was considered important to know beforehand what to do, who to inform when and how to inform them after such an event. In case 1 and 3, structures and protocols of escalation were mentioned as ways to reinforce the preparation for uncertainty. In case 4, the IPM model was mentioned as a structure in which people (shall) know what to do when something happens. This factor was not specifically linked to a certain approach, except in case 4, where it was mentioned in the context of involving decision making. Hence, such structures of escalation may also apply in general when managing uncertainty.

3. *Expertise*

Some members of the project teams of case 1, 3 and 4 mentioned the importance of expertise of the project team members in managing uncertainty. This is the expertise of the project team members and the expertise of the contractor. Experience was a main factor that was used to represent expertise in these cases. Evidently, expertise is a factor which is not specifically attached to a certain approach. It is seen by the participants as something that should be present in general.

To conclude this subsection, it is seen that each case emphasized on certain approaches and measures when managing uncertainty. And although we do not know exactly why certain approaches are emphasized over others, the cases have shown that three factors are important determinants of success in the management in preparation for uncertainty: Trust, escalation and expertise. There is an important role for public clients and their project teams to make sure that these factors are present in the project, regardless of which approaches are used to manage uncertainty.

6.3 Link between uncertainties and managing approaches

Next to the observation of different approaches used in the cases, it is also interesting to compare the use of these approaches with the aspects of uncertainty that played a role in each case. Based on the data from the interviews, some approaches show a link with specific aspects of uncertainty. A distinction can be made between approaches that were not linked to specific aspects of uncertainty and approaches that were linked to specific aspects of uncertainty.

Approaches that are not linked to specific aspects of uncertainty

First of all, various approaches are used in the cases to prepare for uncertainty in general. These are not specifically tied to certain uncertainties. Such approaches are:

- Project development process based on new knowledge
- Organisational structure based on collaboration and integration
- Governability: Cohesion and resources

The first two approaches revolve around a risk management process where all kinds of risks are identified, explored and mitigated by control measures. The project development process is used to discuss these risks with the contractor early in the procurement process. After the procurement stage, the organizational structure is used to keep track of the development of risks and control measures. These control measures are used to mitigate all kinds of risks related to different aspects which are uncertain. The measures are also specific for each project and for each uncertainty. The data is not clear on all risks and control measures that were included in each case, which is makes it difficult to determine how these approaches interact with all specific uncertainties. In addition, governability in the form of cohesion and resources is not explained as a way to prepare for specific aspects of uncertainty. Table 17 gives an overview of some control measures that were mentioned in the interviews as preparations for certain aspects of uncertainty. Note that this table is by no means complete or exhaustive: There is no data about all risks and control measures used for each uncertainty.

Table 17: Examples of control measures mentioned in the interviews.

	Uncertainties identified in the procurement phase	**Control measures mentioned**
Case 1	- Not finishing on time - Stakeholders - Resources	- Design and construction simultaneously - Setting a deadline for the user to demand changes - Making agreements with two suppliers
Case 2	- Construction method - State of the object	- Preparing two construction methods - Use of scanners to detect objects in the floor
Case 3	- Construction method	- Pilot with construction method
Case 4	- Construction method	- Experimentation with mockups off site

Approaches that are linked to specific aspects of uncertainty

The approaches of learning, involving strategic decision making, organizational and contractual structures based on separation and allocation, and governability in the form of flexibility and generativity showed links with certain aspects of uncertainty. Table 18 shows which approaches were mentioned to deal with specific uncertainties.

Learning

The cases show that learning is used specifically to target uncertainties in the state of the object, the construction method and the stakeholder uncertainty. This is seen in case 2 and case 3 (see chapter 6: 6.2 and 6.3). In case 4, learning was mainly done to prepare for uncertainty in the middle tunnel channel and in the state of the object, and less aimed at uncertainty related to stakeholders.

Representing complexity

Involving strategic decision making

The involvement of strategic decision makers was linked to specific uncertainties by some participants. Only in case 1, the involvement of decision making is not pointing to any preparation for a specific uncertainty. In case 3, it was mentioned that the involvement of the portfolio manager was directed at the relation with stakeholders, which indicates an interaction with stakeholder uncertainty. In case 4, we see that the involvement of decision makers is mentioned to deal with uncertainty in resources, objectives and technology.

Organisational and contractual structures: Separation-Allocation

This approach was only found in case 1. Here, the separation of tasks and responsibilities in the contract was mentioned as a way to control uncertainty related to the contract and the stakeholders. The approach was aimed at the processes in the contract so that changes in the contract or deviations from the specifications would be mitigated. In addition, the contractor's behavior as an important stakeholder was controlled by the project team.

Governability

There is limited data to conclude that governability is aimed to deal with specific uncertainties. Cohesion and resources are mainly used to deal with uncertainty in general. However, flexibility and generativity were used in two cases to deal with specific uncertainties. In case 2, generativity was created by involving other experts in the field to prepare for uncertainty in the construction method. In case 4, flexibility was created in the development of the tunnel systems, which is a technological uncertainty.

Table 18: Overview of approaches used for specific aspects of uncertainty in the cases.

	Learning	**Representing complexity**		
		Governability	**Involving strategic decision-making**	**Organisational and contractual structures: Separation-Allocation**
Case 1	*Approach not used*	*Uncertainty in general*	*Uncertainty in general*	- Contract - Stakeholders
Case 2	- Method - State of the object - Stakeholders	Construction method (generativity)	*Approach not used*	*Approach not used*
Case 3	- Method - State of the object - Stakeholders	*Uncertainty in general*	Stakeholders	*Approach not used*
Case 4	- Method - State of the object	Technology (flexibility)	- Objectives and scope	*Approach not used*

			- Resources - Technology	

The cross case data does not provide sufficient basis for a link between certain approaches of managing in preparation for uncertainty and specific aspects of uncertainty. Although some approaches do have a link with specific aspects of uncertainty, these approaches are linked to different uncertainties in each case. These approaches are governability, involving strategic decision making and the shaping of organizational and contractual structures based on separation and allocation. It is therefore impossible to suggest that these approaches are aimed towards the same uncertainties. Only the learning approach has provided similar findings throughout the cases. This approach was mainly used to deal with uncertainty in the methods, state of the object and stakeholders. Hence, there might be an indication that learning is used to prepare for uncertainties related to the state of the object, the construction method and the stakeholders.

6.4 Control and flexibility

Looking at the general philosophy behind the approaches to prepare for uncertainty, we see that control is the main mantra, which is more strongly reflected by the participants, especially in cases 3 and 4. Also in cases 1 and 2, control was addressed as the main goal of dealing with uncertainty. Flexibility does not appear as a major purpose behind the approaches, but it is not regarded as unimportant. This section elaborates on the role of control and flexibility in the cases.

6.4.1 Control

The management of uncertainty is mainly aimed at control. The risk management process is the main tool used to monitor the development and mitigate the negative effects of risks. In all cases, the stance towards uncertainty is to identify its possible effects on the project, establish measures to reduce or avoid negative impacts and keeping track of how the situation evolves regarding each risk.

In case 1 control was enacted by having a clear contract and a clear organisational structure in which the roles and responsibilities were clear. This is seen in the way the public client and the contractor collaborated using regular communication and clear processes. Each two weeks, the project team of the public client met together to discuss the progress of the project, including risks. This involved both technical requirements and process requirements. Audits were also done to verify that the contractor is following the processes and design requirements in the contract. The public client looked at processes that they thought were most risky. They looked at the importance and size of the risks in a certain process and the level of trust in the ability of the contractor to control the process.

In case 2, control project initiation document was mentioned by the program manager as a frame of control the project. In addition, the project manager mentioned the risk management process as a measure to enact control. A team of experts identified the risks and challenges in the building prior to the procurement phase. Meetings are held regularly to discuss the progress of risks and control measures. The contract contained clear and detailed requirements on the processes needed to deal with the risks of hindering the user, damaging installations and validating the building method.

In case 3, risk management is also practiced extensively, including quantification, risk ownership, mitigating measures and monitoring of the environment. The aim is to gain knowledge about the

risks involved. Such as the groundwater level, the space available for shipping and the safety of the workers.

In case 4, control is being enacted by having clear requirements and responsibilities. Plans were demanded from contractors that engaged in the procurement phase. Detailed risk management processes are prescribed in the contract and verification processes are used to verify that the contractor conducts them properly. The project team also conducts risk management on a wide scale, such that each they are discussed in each meeting.

6.4.2 Flexibility

Flexibility is observed to a lesser extent in the cases.

In case 1, flexibility was mainly enacted by the contractor. They were mainly involved in adjusting the planning and being flexible with the SCRUM sessions. That way, the contractor was able to adapt to unexpected circumstances. Nevertheless, the management team of public client also aimed to be flexible. One factor that was mentioned was the openness for newly proposed ideas from the contractor, such as the ideas proposed in the procurement dialogue. However, newly proposed ideas were assessed and controlled critically by the project team. For such ideas, the risks were identified and control measures were put in place. Another aspect of flexibility was the flexibility of the project team members themselves. The people that were managing the project were flexible. They were accessible almost all the time and they were not stuck in a specific way of working. They were able to switch fast. When something happened, it was solved quickly. The flexibility from the client's perspective is not enacted deliberately. This comes with intuition, personality and experience. It is done implicitly.

In case 2, a slightly different approach is seen. Multiple tools were explained by the participants as enablers of flexibility. The project was mainly steered in a flexible manner according to the program manager, who is also responsible for the project. According to him, the approach was to pick up new insights during the project and continuously adjusting the approach to reach the final result. This is seen in the strategy to work with the more standardised floors first was a way to learn and adapt during the project. Another way to be flexible was by having a financial reserve for unforeseen impacts, which was addressed by the project manager. The dialogue procedure also contributed to flexibility in the procurement phase according to the contract manager in the procurement phase. It allowed the team to discover uncertainties and discuss ideas openly.

In cases 3 and 4, flexibility is not actively aimed for. The project team of case 3 views flexibility in the form of adjusting the risk register based on findings of the pilot and considering alternative strategies to continue the project if the pilot shows that the current method is not safe enough to complete the works. In that case, the canal would have to be drained, which is unfortunate for the shipping industry. However, this scenario is not actively being prepared for. And in case 4, the only sign of flexibility was the team members' role and experience according to the contract manager. The idea is that each member of knows what to do when unexpected things happen, because they are more likely to have experienced similar things in the past and they know what their role is in relation with the rest of the team.

6.4.3 Mix of control and flexibility

The main aim of the approaches used to prepare for uncertainty is to control the possible set of outcomes in the project. Control is mainly pursued through risk management, which sets out the main measures of control, such as monitoring of the environment and controlling risk management

processes of the public client and the contractor. Whereas flexibility is more present in people in the form of openness from the project team, flexibility in attitudes and ways of working and people's experience. Most of the participants are aware of the importance of both control and flexibility as a means to deal with uncertainty, but see control as more important. No deliberate or intentional trade-offs were made by the project teams between control and flexibility. Flexibility aspects are mainly present implicitly and unintentionally. Table 19 sets out the main tools that were mentioned as ways to focus on control and flexibility.

Surprisingly, control is mentioned as the main aim by almost all participants, but the main approach for control in the literature is not widely mentioned as an approach to manage uncertainty. No contractual or organizational structure focused on separation and allocation was mentioned as a main way to enact control, except in case 1. This may indicate that this approach is not perceived by IPM team members as a way to deal with uncertainty. In the other cases, control is mainly enacted through risk management by both the public client and the contractor, thus focusing on collaboration rather than separation.

Table 19: Control and flexibility as applied in the cases.

Case	Control	Flexibility
Case 1	- organisational structure - Requirements and responsibilities - Risk management	- Mainly from the contractor - Openness for new ideas - People's attitudes and way of working
Case 2	- Risk management - Clear requirements and processes	- Openness in the competitive dialogue - Reserve budget - Learning strategy
Case 3	- Risk management - Monitoring of environment	- Adjusting risk register using a pilot
Case 4	- Risk management - Requirements and responsibilities	- People's roles and experience

6.5 Implications of the research

The findings of this research point towards a confirmation of what was stated in the introduction: Uncertainty continues to be an important feature of construction projects which manifests in different aspects of the project. And dealing with uncertainty in the management of projects is considered essential for the success of the project. All categories of uncertainty in the literature were found in the cases, and different approaches were applied by project teams of public clients to be prepared for uncertain impacts from these uncertainties. Building upon these findings, several implications can be deducted from this research.

The first and foremost implication is the close relation between uncertainty and complexity. Renovation projects showed to be most uncertain in the state of the object, often in combination with the construction method. Dealing with this uncertainty is the main challenge of such projects, where most surprises are encountered in the object itself, which is in a different state than expected.

This state can be seen as a structural complexity of the project which is unknown for a considerable part. And therefore, the structural complexity of these renovation projects is an uncertainty itself. This indicates that uncertainty is not only present in the form of dynamic complexity, but also merely in structural complexity. In other words, uncertainty is not necessarily experienced by things that change suddenly over the course of a project, but it is rather experienced by things that are already there, and yet have to be identified and discovered. Also, given the expected increase of maintenance projects in the Netherlands, the uncertainty in the state of objects could be considered a main challenge for the future. Interestingly, project teams are well aware of this uncertainty before the start of the execution phase, but still face surprises that have a considerable impact on the project. Perhaps, more can be done to prepare for such known uncertainties.

Secondly, in the management of uncertainty in complex construction projects, the IPM teams of public clients studied showed mainly focus on control when preparing for uncertainty. This means that they want to reduce uncertainty as much as possible. This is done through risk management processes and mitigation of risks through control measures. Flexibility is less actively steered on, and is mainly created by implicit factors. Flexibility was not found to go further than having back-up plans and options and redundancy in the budget. These back-up plans are not established at the level that they can be implemented directly in the project. Also, little steering is seen on the consideration between different plans to execute the project and being ready to switch between different plans of action. There is room for improvement here: More flexibility can be created by considering different plans in projects that are readily implementable.

Thirdly, risk management stands out as a main practice to prepare for uncertainty. The aim is to explore and identify risks that can impact the final outcome of the project. Nearly all the uncertainties are translated to risks. For example, there is uncertainty in the user's demands, which is translated into a risk of scope change. Risks are identified, quantified, shared, discussed, mitigated and updated to prepare for uncertainty. The risk management approach is not only embedded in the organizational and contractual structure as a planning stage strategy. But it is also embedded in the learning strategy, especially in the competitive dialogue procedure. The learning approach is partly based on discussions in the competitive dialogue, where risks are thoroughly discussed and control measures are put in place. Therefore, risk management is the core structure used in all cases to prepare for uncertainty. This makes the management of uncertainty less directed towards uncertainties and more towards the possible impacts of uncertainty. This also demonstrates a different focus compared to the literature. The literature focuses on being adaptive to the complexity of projects, whereas practice focuses on identifying possible impacts of uncertainty on project objectives. In line with the previous paragraph and with the literature, we suggest that this focus is shallow and not sufficient to prepare for uncertainty effectively. Rather, focus should be more directed to understanding an mapping the complexity behind the risks, and making plans that allow for adaption during the project.

Fourthly, although several approaches are used to represent complexity, not all complexity can be represented from the front-end of projects. Often, something pops up in the project that is beyond the perception of the project team. Some structural aspects may be overlooked (see the first point in this section). Or in other cases, the team may be aware of an uncertainty, but it impacts the project beyond expectation (case 2, 3). Therefore, it is important to raise awareness about both the incompleteness of the initial risk profile shaped by project teams and the fact that things that were thought about beforehand may play out differently than expected. However, the latter seems to impact renovation projects the most.

And lastly, some approaches were not mentioned by the participants as ways to prepare for uncertainty, whereas they might be used effectively to do so in their projects. Integrated project teams are not used in the cases. However, this may be a suitable approach to prepare for uncertainty which may actually be tried by public clients. Some public clients make use of bouwteams in the procurement of construction projects, which may be regarded as a similar concept. A team with specialists from the public client, contractors and consultants is then used to provide a possible design to execute the project. However, bouwteams end their collaboration after the procurement phase, which is not the case for integrated project teams. Integrated project teams continue managing the project until the final delivery of the project. Proceeding with integrated project teams would introduce two challenges: 1) how are the responsibilities allocated to each party and 2) the possibility of rigid representations of complexity which are difficult to adapt when formed in a close collaboration, as stated in the literature by Floricel et al. (2016).

Selectionism is also not found in the cases. Project teams do consider multiple solutions to the same problem, but they do not pursue them simultaneously to select the best option. Whether selectionism can or should be considered by public clients as a viable way to prepare for uncertainty, remains a difficult question to answer. The resource intensity required to adopt this approach may be an obstacle for construction projects. And other factors may play a role, such as technical developments and the level of uncertainty accepted in a project. More research would be needed to gain insight about the feasibility of selectionism in the management of construction projects.

7. Discussion

The outcome of this research has put forward the different uncertainties that play a role in complex construction projects and the main approaches used by two large Dutch public clients to prepare for uncertainty in the project. The results show a variety of aspects that are uncertain in those construction projects and a somewhat similar set of approaches used by these public clients. This set of approaches is mainly focused on the representation of complexity through project development processes that focus on new knowledge and organizational structures that focus on collaboration and integration. The results contribute to the answers to two sub-questions of this research:

1. What uncertainties are involved in construction projects?
3. How do public clients manage construction projects in preparation for uncertainty?

The relevance of this research lies in the exploration and mapping of the uncertainties involved in projects and approaches implemented by public clients in relation with the uncertainties and approaches found in the literature. That allows to compare the approaches in practice with approaches in the literature, which can be used to answer the main research question: *How can the management of complex construction projects by public clients be improved in preparation for uncertainty?* The approaches in the literature can be used to suggest improvements in the way public clients manage uncertainty. The approaches in the literature that were not found in practice can be a first step towards improvement. Improvement is possible in the introduction of integrated project teams and the increase of focus on flexibility by actively considering the ability to switch between multiple ways of delivering the project.

This chapter discusses the findings of this research by regarding the views of practice vs literature (7.1), the contribution to the existing literature on project management of uncertainty in complex projects (7.2) and the limitations of this research (7.3).

7.1 Gaps between theory and practice

This research has revealed some differences between the theory in the literature and the practices of practitioners. There are perceptional differences in how uncertainty is viewed and what it means to manage in preparation for uncertainty. This offers the opportunity to interchange perspectives and see how they can enrich each other. What does the theory have to offer to practice? And the other way around, what does practice have to offer to the theory? In this section, the main differences between theory and practice are pointed out, based on the findings. Two topics are discussed: Uncertainty and management in preparation for uncertainty.

Uncertainty: In practice, uncertainty seems to viewed as something that is a combination of different interrelated aspects that are uncertain. This was seen in the partial overlap between different aspects explained by the interviewees. The perception of the literature is based on different aspects of the project that are/may be uncertain. The idea that those aspects are interrelated is not widely supported in the literature. Aspects that are uncertain are often discussed separately, either in different papers or different sections of papers. Part of the literature aims to account for interrelations between aspects through the theory of project complexity. However, this theory does not provide a link to uncertainty by explaining the interrelation between different aspects.

Managing in preparation for uncertainty: Another idea that has been clarified by the input from practitioners in the interviews is the concept of managing in preparation for uncertainty. This is a concept that is not explicitly defined in the project management literature. Practitioners provided

more insight in the nature of the actions that they view as preparatory management approaches. This nature is mainly collaborational. There is much emphasis on interaction between people when looking at the types of actions described by the participants. There is also more emphasis on aspects that exist implicitly or formed unintentionally. Trust, expertise and escalation were mentioned as key factors that make the management of uncertainty successful. The concept of management in preparation for uncertainty is mainly regarded by the literature as a way to organize projects deliberately to deal with complexity. This counts for the approaches of learning and representing complexity. The main aim here is not necessarily collaborational, as seen in practice.

Considering these differences, There is a misalignment between what the theory says and how practitioners think. The literature and the practical field have different understandings of the same concepts. What is regarded by the theory as representing complexity, is regarded by practice as interacting and collaborating with each other. Assuming that theory and practice can both strengthen each other, the following implications may apply:

1. The theory can benefit from practice by regarding uncertainty as a combination of different uncertainties and relating this to complexity. And in the management of complexity, the literature can focus more on the role of trust, collaboration and interaction and how it impacts the management of uncertainty.
2. Practice can benefit from the theory by increasing awareness about complexity involved in construction projects and by understanding that their main approach to managing uncertainty can be seen as the representation of this complexity.

7.2 Contribution to the literature

The results resonate with a large part of the literature. Risk management is indeed used as main practice in construction projects, which had been inferred by Miglinskas and Ustinovichius (2006). And risk management is mainly focused on negative impacts and threats rather than opportunities, which is the main criticism from Ward and Chapman (2003). Regarding complexity theory, we found that uncertainty can arise from an incomplete or incorrect perception of complexity, which is also pointed out in the literature (J. Geraldi et al., 2011; Vidal & Marle, 2008). In addition, several aspects of uncertainty in the literature were also found to be uncertain in construction projects. And several approaches, especially with regards to managing complexity, were found to be practiced by public clients in complex construction projects. Altogether, this research has come across and confirmed various ideas which were already discovered in previous studies.

Building upon these previous studies, this research provided more insight in the eight aspects of uncertainty in the literature in the context of complex construction projects. We know more about which aspects are perceived as uncertain in construction projects and how different uncertain aspects are interrelated in the project. The role of uncertainty was also linked to complexity: Some uncertainties are interwoven with each other, and especially the role of structural complexity in renovation projects turned out to impact uncertainty. The uncertainty in the state of the object was significant in renovation projects, which is not pointed out in the literature. Furthermore, this research showed how and why different aspects were uncertain in construction projects and how public clients form similar perceptions of uncertainty, which provides a clearer understanding of uncertainty in this context. This has not been elaborated in the literature on project- and construction management yet.

This research also explored which managing approaches in the project management literature are being implemented in construction projects. It turns out that some of these approaches are being

used by public clients in a tailored approach, especially the approaches that are aimed to manage complexity. New insights were gained in the involvement of strategic decision making, which can be done by increasing mandates, escalating issues and closely involving decision makers in matters of the project management team. The literature has only advocated for a close relationship between strategic and operational decision-making processes, without pointing out how this relationship can be established. Next to the management of complexity, learning is also implemented in renovation projects to learn from the environment of construction projects, in a way that fits the frame of the literature (Pich et al., 2002; Sommer & Loch, 2004). Learning is also seen in the project development process focusing on new knowledge, which was described by Floricel et al. (2016).

Where the literature primarily focused on case studies of infrastructure projects, this research looked at the perspective of diverse projects, focusing on buildings, a tunnel and a waterway. It turned out that more or less similar approaches are used throughout these projects. Selectionism, an approach which was put forward by Pich et al. (2002) to prepare for uncertainty in innovative projects, is not used by public clients in complex construction projects. Another approach from the literature that was not apparent is the use of contractual structures to prepare for uncertainty, which is said to target uncertainty related to structural complexity (Floricel et al., 2016). This can mean three things:

1. It may challenge the theory of Floricel et al. (2016) that the definition of interfaces in contracts contributes to the management of structural complexity through the uncovering of hidden interactions, which helps to prepare for emerging behaviour of the project.
2. It may indicate that structural complexity itself is not perceived as a source of uncertainty by project teams of public clients.
3. The idea that contractual structures are chosen based on the level of uncertainty in the project, set out by the RVB, is either not widespread through the project organization, or it is not pervasive.

7.3 Limitations of this research

This research has several limitations. First of all, only four cases were studied in this research. Therefore, the results cannot be fully generalized. The results are also specific to Dutch construction projects, which most likely experience a specific set of uncertainties that exist sector-wide. However, project-specific uncertainties also play a role in each project. This makes it difficult to draw conclusion about the role of uncertainty in construction projects in general.

Research data

In addition, the collected data depends on the perception of the project team members. This data may exclude approaches that have been used to prepare for uncertainty, simply because they may be overlooked, misperceived or implemented unconsciously. This research depended on what participants mentioned as preparatory practice, which may not give a full picture of all types of approaches. Especially the concept of preparing for uncertainty is new, which required some thinking by the participants before they could answer questions about it.

In the analysis of the data, the link between uncertainties mentioned by the participants and the aspects of uncertainty in the literature is sometimes ambiguous. Not all uncertainties fit clearly into one category. For example, the contract price was mentioned as an uncertainty by a participant. Despite this uncertainty being put in the results as a contract uncertainty, it may also fit as a market uncertainty, uncertainty in the state of the object or an uncertainty in the objectives. That is because the price uncertainty has much to do with the uncertain scope of the work due to inaccurate

drawings. The same ambiguity was involved with uncertainty mentioned in the permits, which can be considered as an environmental and stakeholder uncertainty. Although these uncertainties were placed in one category, the link with other categories was also listed in the results and analysis.

In case 1, the data about uncertainties and managing approaches is partly outdated due to a lack of memory. The project had finished almost three years before the start of this research. Several participants indicated that they do not remember all details about the project, which makes some uncertainties and managing approaches rather superficial and abstract. Little concrete examples were mentioned to support the explanation of certain approaches. Regarding other cases, these are filled with more concrete examples as they are currently in execution.

Research topic

The topics that were addressed in this research do not unlock a full understanding of how the management of uncertainty can be improved. Most importantly, the link between managing approaches and uncertainties is not established clearly in this research. It is therefore important to acknowledge that some conclusions cannot be made. These are:

- **How uncertainties are reacted on:** Although it has been briefly described in the interviews, this research does not go in detail into the way public clients manage in reaction to uncertain events. Therefore, the relation between preparing and reacting is not elaborated. The only indication of a relationship is that the preparatory approaches allow for a quick engagement between the public client and project parties to solve the effects of uncertainty, but this is not widely demonstrated by concrete examples in this research.
- **How effective the approaches are, or what makes an approach effective:** Three of the four cases are still in execution and have only executed a minor part of the work. Therefore, the final recommendations about the implementation of other approaches are not grounded on empirical success. For the one case that has been completed, we see that success is mainly attributed to the strong cohesion between project parties and the extensive use of risk management processes. However, there remains a lack of clear explanations of the effects of certain approaches on specific uncertainties.
- **The relation between complexity and uncertainty:** This theme has recently entered the literature. Although a clear link was found between structural complexity and uncertainty, this remains a complex topic with many different possible conceptualisations. It is not possible to conclude a causal relationship between uncertainty and complexity based on this research.

Validity of results

Despite the limitations, the four cases have shown a relatively similar way of thinking about uncertainty and managing uncertainty in different projects at two of the largest public clients in the Netherlands. Especially the three renovation projects, all currently in execution, show very similar ways of addressing the research topics. And within each case, there is much overlap between what participants stated. No contradictions were spotted in the explanation of uncertainties and managing approaches, which was quite surprising. As a consequence, there is little ground on which the validness of the data can be questioned. The results are considered to be fit to answer the research questions.

8. Conclusion

This research explored the role of uncertainty in complex construction projects and the approaches used by public clients to managing this uncertainty. The findings of the case study offered more insight into this topic, which can be used to answer our main research questions. In addition, recommendations can be made for the practical field.

8.1 Answer to research questions

This section answers the main research questions.

1. *What uncertainties are involved in construction projects?*

All eight categories of uncertainty in the literature were found throughout the cases: Objectives, methods, market, resources, stakeholders, contract, technology and environment. The most prominent categories found in the majority of the cases were the stakeholders, objectives and environment. A new category was found: The state of the object. This was an uncertainty in three renovation projects studied. Uncertainty in technology was less prominently present in the construction projects that were studied.

2. *What project management approaches can be used to prepare for uncertainty?*

In the project- and construction management literature, several approaches can be found surrounding three themes: Learning, selectionism and representing complexity. Whereas learning and selectionism are seen as distinct approaches, the latter being predominantly discussed in the context of highly complex and innovative projects, the representation of complexity contains different types of approaches. These are the involvement of decision making, planning stage strategies in shaping organizational and contractual structures on one hand and project development processes on the other hand, and governability, which focuses on cohesion, resources, flexibility and generativity to prepare for complexity and uncertainty.

3. *How do public clients manage construction projects in preparation for uncertainty?*

Public clients manage uncertainty mainly by representing the complexity of projects and by learning from the project environment. Thereby, they focus on risk management processes that are embedded in these approaches. Representing complexity is done by establishing an organizational structure that focuses on collaboration and integration of the project organization, involving decision-makers to increase support in case things go differently than expected and by installing governability in the form of cohesion between project parties and redundancy in financial resources. Learning is done in part by a project development process that focuses on new knowledge, and in another part by experimenting on and off site with construction methods, construction components and exploring and monitoring the environment of the project site.

4. *How can the project management approaches in the literature improve the approaches in practice?*

Several approaches in the literature are being used by public clients. Improvements can be suggested by looking at other approaches in the literature that are not being implemented by public clients. Public clients can consider working with integrated project teams that manage complex construction projects until completion. For this to work, they should consider the challenges related to the division of (contractual) responsibility within the team. In addition, selectionism may offer an outcome only if the intensity of resources required does not provide significant constraints for the

public client. However, more research is required to how selectionism can be implemented in complex construction projects without using too intense resources. Lastly, improvement can be made by increasing focus on flexibility in projects. This focus should lead to developing multiple options in projects which are ready to be implemented without disrupting the project.

How can the management of complex construction projects by public clients be improved in preparation for uncertainty?

Although this research has not provided insight into the performance of managing approaches, there may be improvements in the approaches used by public clients when looking at the literature and the case study. The literature suggests that selectionism and integrated project teams are effective approaches to manage uncertainty, which were not found to be used by public clients in this research. The use of contractual structures to deal with uncertainty is sporadic. These approaches may be implemented more by public clients to manage uncertainty in construction projects. Looking at the case study, improvement is possible in the approaches that are currently used: Governability can be pursued more in terms of creating flexibility in projects and generativity in solutions. Three main factors were mentioned that increase the success of managing uncertainty: 1) Trust within the project team and between the project team and the contractor, 2) escalation of project affairs in case of uncertain situations and 3) Expertise of members of the project team and the contractor.

8.2 Recommendations for practice

In addition to the answers to the research questions, further navigate on the road to dealing with uncertainty. Three recommendations can be summarised for public clients:

1. **Try new approaches:** The implications of this research (see 7.3) showed that some approaches are not used by public clients. These approaches in the literature that were not found to be used by public clients may be introduced into the management of construction projects. This can offer new insights into the effectiveness of these approaches compared to other approaches.

2. **Understand the role of the contract with regards to uncertainty:** Public clients, especially RVB, should invest more in understanding how contracts can be used to prepare for uncertainty. The main reason for this is that the literature and the documents of the RVB agree on the notion that contractual structures deal with uncertainty, but the people involved in the management of projects do not seem to carry this idea widely.

3. **Increase focus on flexibility:** Lastly, public clients are recommended to focus on the ability to adapt the project strategy or switch between different project strategies. This redirects some of the focus from control (mainly) towards flexibility. The case study shows some attention for flexibility by having back-up plans, but these do not seem to be readily implementable in the project. More can be done to make different plans which are continuously evaluated and ready to be applied in situations of uncertainty.

8.3 Recommendations for further research

To follow up on this research, a number of studies are recommended to contribute to the understanding of the role of uncertainty in construction projects and the ways in which projects can be managed successfully in the face of uncertainty.

More research can be done to the management of uncertainty by public clients as a reaction to manifestations of uncertainty in the project. This can contribute to the establishment of a possible relationship between managing approaches in preparation for uncertainty and in reaction to uncertainty. This research has not provided concrete answers on how the approaches interact with uncertainty. Therefore, future studies can also focus on the relation between managing approaches and specific aspects of uncertainty.

The role of the contract structure in preparing for uncertainty remains unclear. This research showed that structural complexity has an impact on uncertainty, especially in renovation projects in the form of unknowns in the state of the building. However, the contract structure was not used clearly as a preparation for this uncertainty. The literature has indicated that contractual structures can be used to deal with structural complexity (Floricel et al., 2016). This finding demands for more research on how contracts can be used to manage uncertainty related to structural complexity.

More research can also be done to figure out if the approaches that were not used by public clients are applicable and how. Selectionism needs to be further investigated for implementation in Dutch construction projects.

References

Afweegkader contractvorm. (2020).

Ahern, T., Leavy, B., & Byrne, P. J. (2014a). Complex project management as complex problem solving: A distributed knowledge management perspective. *International Journal of Project Management*, *32*(8). https://doi.org/10.1016/j.ijproman.2013.06.007

Ahern, T., Leavy, B., & Byrne, P. J. (2014b). Knowledge formation and learning in the management of projects: A problem solving perspective. *International Journal of Project Management*, *32*(8). https://doi.org/10.1016/j.ijproman.2014.02.004

Atkinson, R., Crawford, L., & Ward, S. (2006). Fundamental uncertainties in projects and the scope of project management. *International Journal of Project Management*, *24*(8). https://doi.org/10.1016/j.ijproman.2006.09.011

Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. In *European Journal of Operational Research* (Vol. 253, Issue 1). https://doi.org/10.1016/j.ejor.2015.12.023

Baccarini, D. (1996). The concept of project complexity - A review. *International Journal of Project Management*, *14*(4). https://doi.org/10.1016/0263-7863(95)00093-3

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework. *International Journal of Project Management*, *29*(6). https://doi.org/10.1016/j.ijproman.2010.07.008

Brady, T., & Davies, A. (2014). Managing structural and dynamic complexity: A tale of two projects. *Project Management Journal*, *45*(4). https://doi.org/10.1002/pmj.21434

Brady, T., Davies, A., & Nightingale, P. (2012). Dealing with uncertainty in complex projects: revisiting Klein and Meckling. *International Journal of Managing Projects in Business*, *5*(4). https://doi.org/10.1108/17538371211269022

Bryde, D. J., & Volm, J. M. (2009). Perceptions of owners in German construction projects: Congruence with project risk theory. *Construction Management and Economics*, *27*(11). https://doi.org/10.1080/01446190903222403

Chapman, C., & Ward, S. (2000). Estimation and evaluation of uncertainty: A minimalist first pass approach. *International Journal of Project Management*, *18*(6). https://doi.org/10.1016/S0263-7863(00)00016-8

Chapman, C., & Ward, S. (2011). How to Manage Project Opportunity and Risk - why uncertainty management can be a much better approach than risk management. *OCLC Systems Services*, *22*(4).

Collyer, S., & Warren, C. M. J. (2009). Project management approaches for dynamic environments. *International Journal of Project Management*, *27*(4). https://doi.org/10.1016/j.ijproman.2008.04.004

Cooke-Davies, T., Cicmil, S., Crawford, L., & Richardson, K. (2007). Mapping the Strange Landscape Oe Complexity Theory , and Its Relationship. *Project Management Journal*, *38*(2).

Dunović, I. B., Radujković, M., & Škreb, K. A. (2014). Towards a New Model of Complexity – The Case of Large Infrastructure Projects. *Procedia - Social and Behavioral Sciences*, *119*. https://doi.org/10.1016/j.sbspro.2014.03.082

Eisenhardt, K. M. (1989). Eisenhardt 1989. *The Academy of Management Review*, *14*(4).

Flage, R., & Aven, T. (2015). Emerging risk - Conceptual definition and a relation to black swan type of events. *Reliability Engineering and System Safety*, *144*. https://doi.org/10.1016/j.ress.2015.07.008

Flage, R., Aven, T., Zio, E., & Baraldi, P. (2014). Concerns, Challenges, and Directions of Development for the Issue of Representing Uncertainty in Risk Assessment. *Risk Analysis*, *34*(7). https://doi.org/10.1111/risa.12247

Floricel, S., Michela, J. L., & Piperca, S. (2016). Complexity, uncertainty-reduction strategies, and project performance. *International Journal of Project Management*, *34*(7). https://doi.org/10.1016/j.ijproman.2015.11.007

Floricel, S., & Miller, R. (2001). Strategizing for anticipated risks and turbulence in large-scale engineering projects. *International Journal of Project Management*, *19*(8). https://doi.org/10.1016/S0263-7863(01)00047-3

Geraldi, J. G., & Adlbrecht, G. (2007). On Faith, Fact, and Interaction in Projects. *Project Management Journal*, *38*(1). https://doi.org/10.1177/875697280703800104

Geraldi, J., Maylor, H., & Williams, T. (2011). Now, let's make it really complex (complicated): A systematic review of the complexities of projects. In *International Journal of Operations and Production Management* (Vol. 31, Issue 9). https://doi.org/10.1108/01443571111165848

Giezen, M. (2012). Keeping it simple? A case study into the advantages and disadvantages of reducing complexity in mega project planning. *International Journal of Project Management*, *30*(7). https://doi.org/10.1016/j.ijproman.2012.01.010

Giezen, M., Bertolini, L., & Salet, W. (2015). Adaptive Capacity Within a Mega Project: A Case Study on Planning and Decision-Making in the Face of Complexity. *European Planning Studies*, *23*(5). https://doi.org/10.1080/09654313.2014.916254

Gil, N., Tommelein, I. D., & Schruben, L. W. (2006). External change in large engineering design projects: The role of the client. *IEEE Transactions on Engineering Management*, *53*(3). https://doi.org/10.1109/TEM.2006.877447

Gosling, J., Naim, M., & Towill, D. (2013). Identifying and Categorizing the Sources of Uncertainty in Construction Supply Chains. *Journal of Construction Engineering and Management*, *139*(1). https://doi.org/10.1061/(asce)co.1943-7862.0000574

He, Q., Luo, L., Hu, Y., & Chan, A. P. C. (2015). Measuring the complexity of mega construction projects in China-A fuzzy analytic network process analysis. *International Journal of Project Management*, *33*(3). https://doi.org/10.1016/j.ijproman.2014.07.009

Hertogh, M., & Westerveld, E. (2010). Playing With Complexity. Management and Organisation of Large Infrastructure Projects. *World*.

Howell, G., Laufer, A., & Ballard, G. (1993). Uncertainty and project objectives. *Project Appraisal*, *8*(1), 37–43. https://doi.org/10.1080/02688867.1993.9726884

Huemann, M., & Martinsuo, M. (2016). In project management, uncertainty is a great opportunity. In *International Journal of Project Management* (Vol. 34, Issue 6). https://doi.org/10.1016/j.ijproman.2016.06.001

Jaafari, A. (2001). Management of risks, uncertainties and opportunities on projects: Time for a fundamental shift. *International Journal of Project Management*, *19*(2). https://doi.org/10.1016/S0263-7863(99)00047-2

Jaafari, A. (2003). Project Management in the Age of Complexity and Change. *Project Management Journal*, *34*(4). https://doi.org/10.1177/875697280303400407

Kader systeemgerichte contractbeheersing Rijksvastgoedbedrijf. (2017).

Kallio, H., Pietilä, A. M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. In *Journal of Advanced Nursing* (Vol. 72, Issue 12). https://doi.org/10.1111/jan.13031

Kardes, I., Ozturk, A., Cavusgil, S. T., & Cavusgil, E. (2013). Managing global megaprojects: Complexity and risk management. *International Business Review*, *22*(6). https://doi.org/10.1016/j.ibusrev.2013.01.003

Kiridena, S., & Sense, A. (2016). Profiling Project Complexity: Insights from Complexity Science and Project Management Literature. *Project Management Journal*, *47*(6). https://doi.org/10.1177/875697281604700605

Klinke, A., & Renn, O. (2002). A new approach to risk evaluation and management: Risk-based, precaution-based, and discourse-based strategies. *Risk Analysis*, *22*(6). https://doi.org/10.1111/1539-6924.00274

Knight, F. H. (1921). Risk Uncertainty and Profit Knight. In *Quarterly Journal of Economics* (Vol. 36, Issue 4).

Kolltveit, B. J., Karlsen, J. T., & Grønhaug, K. (2005). Exploiting opportunities in uncertainty during the early project phase. *IEEE Engineering Management Review*, *33*(1). https://doi.org/10.1109/EMR.2005.25174

Koppenjan, J., Veeneman, W., van der Voort, H., ten Heuvelhof, E., & Leijten, M. (2011). Competing management approaches in large engineering projects: The Dutch RandstadRail project. *International Journal of Project Management*, *29*(6). https://doi.org/10.1016/j.ijproman.2010.07.003

Kreye, M. E., Cash, P. J., Parraguez, P., & Maier, A. (2019). Dynamism in Complex Engineering: Explaining Uncertainty Growth Through Uncertainty Masking. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2019.2937570

Leijten, M. (2017). What lies beneath: Bounded manageability in complex underground infrastructure projet. In *TU Delft University*.

Lenfle, S. (2011). The strategy of parallel approaches in projects with unforeseeable uncertainty: The Manhattan case in retrospect. *International Journal of Project Management*, *29*(4). https://doi.org/10.1016/j.ijproman.2011.02.001

Lenfle, S., & Loch, C. (2011). Lost roots: How project management came to emphasize control over flexibility and novelty. *California Management Review*, *53*(1). https://doi.org/10.1525/cmr.2010.53.1.32

Levander, E., Engström, S., Sardén, Y., & Stehn, L. (2011). Construction clients' ability to manage uncertainty and equivocality. *Construction Management and Economics*, *29*(7). https://doi.org/10.1080/01446193.2011.595423

Loch, C. H., de Meyer, A., & Pich, M. T. (2007). Managing the Unknown: A New Approach to Managing High Uncertainty and Risk in Projects. In *Managing the Unknown: A New Approach to Managing High Uncertainty and Risk in Projects*. https://doi.org/10.1002/9780470172377

Long, P., & Cheok, M. Y. (2019). *IDENTIFYING A BETTER MANAGEMENT METHOD IN PROJECT MANAGEMENT PRACTICE UNDER UNCERTAINTY CIRCUMSTANCES: A SYSTEMATIC LITERATURE REVIEW*. https://doi.org/10.20472/bmc.2019.009.003

Love, P. E. D., Matthews, J., & Fang, W. (2021). Reflections on the Risk and Uncertainty of Rework in Construction. *Journal of Construction Engineering and Management*, *147*(4). https://doi.org/10.1061/(asce)co.1943-7862.0002030

Luo, L., He, Q., Jaselskis, E. J., & Xie, J. (2017). Construction Project Complexity: Research Trends and Implications. *Journal of Construction Engineering and Management*, *143*(7). https://doi.org/10.1061/(asce)co.1943-7862.0001306

Mak, S., & Picken, D. (2000). Using Risk Analysis to Determine Construction Project Contingencies. *Journal of Construction Engineering and Management*, *126*(2). https://doi.org/10.1061/(asce)0733-9364(2000)126:2(130)

Maylor, H., Vidgen, R., & Carver, S. (2008). Managerial Complexity in Project-Based Operations: A Grounded Model and Its Implications for Practice. *Project Management Journal*, *39*(1_suppl). https://doi.org/10.1002/pmj.20057

Meyer, A. de, Loch, C. H., & Meyer, D. (2002). *Managing project uncertainty: From variation to chaos Managing project uncertainty: From variation to chaos Citation Citation*. https://ink.library.smu.edu.sg/lkcsb_research

Migilinskas, D., & Ustinovichius, L. (2006). Uncertainties in construction's decision making. *International Conference on Operational Research: Simulation and Optimisation in Business and Industry*.

Mulholland, B., & Christian, J. (1999). Risk Assessment in Construction Schedules. *Journal of Construction Engineering and Management*, *125*(1). https://doi.org/10.1061/(asce)0733-9364(1999)125:1(8)

Notitie Stabiele IPM teams. (2020).

Padalkar, M., & Gopinath, S. (2016). Are complexity and uncertainty distinct concepts in project management? A taxonomical examination from literature. *International Journal of Project Management*, *34*(4). https://doi.org/10.1016/j.ijproman.2016.02.009

Perminova, O., Gustafsson, M., & Wikström, K. (2008). Defining uncertainty in projects - a new perspective. *International Journal of Project Management*, *26*(1). https://doi.org/10.1016/j.ijproman.2007.08.005

Pich, M. T., Loch, C. H., & de Meyer, A. (2002). On uncertainty, ambiguity, and complexity in project management. *Management Science*, *48*(8). https://doi.org/10.1287/mnsc.48.8.1008.163

PMI. (2017). A Guide to the Project Management Body of Knowledge Guide, 6th Edition. In *Project Management Institute, Inc.*

Russell, M. M., Hsiang, S. M., Liu, M., & Wambeke, B. (2014). Causes of Time Buffer and Duration Variation in Construction Project Tasks: Comparison of Perception to Reality. *Journal of Construction Engineering and Management*, *140*(6). https://doi.org/10.1061/(asce)co.1943-7862.0000819

RVB Kader IPM . (2021).

Salet, W., Bertolini, L., & Giezen, M. (2013). Complexity and uncertainty: Problem or asset in decision making of mega infrastructure projects? *International Journal of Urban and Regional Research*, *37*(6). https://doi.org/10.1111/j.1468-2427.2012.01133.x

Schatteman, D., Herroelen, W., van de Vonder, S., & Boone, A. (2008). Methodology for Integrated Risk Management and Proactive Scheduling of Construction Projects. *Journal of Construction Engineering and Management*, *134*(11). https://doi.org/10.1061/(asce)0733-9364(2008)134:11(885)

Shenhar, A. J. (2001). One size does not fit all projects: Exploring classical contingency domains. *Management Science*, *47*(3). https://doi.org/10.1287/mnsc.47.3.394.9772

Sommer, S. C., & Loch, C. H. (2004). Selectionism and learning in projects with complexity and unforeseeable uncertainty. *Management Science*, *50*(10). https://doi.org/10.1287/mnsc.1040.0274

Spiegelhalter, D. J., & Riesch, H. (2011). Don't know, can't know: Embracing deeper uncertainties when analysing risks. In *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* (Vol. 369, Issue 1956). https://doi.org/10.1098/rsta.2011.0163

Thomé, A. M. T., Scavarda, L. F., Scavarda, A., & Thomé, F. E. S. de S. (2016). Similarities and contrasts of complexity, uncertainty, risks, and resilience in supply chains and temporary multi-organization projects. *International Journal of Project Management*, *34*(7). https://doi.org/10.1016/j.ijproman.2015.10.012

Thunnissen, D. P. (2003). Uncertainty Classification for the Design and Development of Complex Systems. *3rd Annual Predictive Methods Conference*.

Tran, D. Q., & Molenaar, K. R. (2014). Impact of Risk on Design-Build Selection for Highway Design and Construction Projects. *Journal of Management in Engineering*, *30*(2). https://doi.org/10.1061/(asce)me.1943-5479.0000210

Vidal, L. A., & Marle, F. (2008). Understanding project complexity: Implications on project management. *Kybernetes*, *37*(8). https://doi.org/10.1108/03684920810884928

Ward, S., & Chapman, C. (2003). Transforming project risk management into project uncertainty management. *International Journal of Project Management*, *21*(2). https://doi.org/10.1016/S0263-7863(01)00080-1

Ward, S., & Chapman, C. (2008). Stakeholders and uncertainty management in projects. *Construction Management and Economics*, *26*(6). https://doi.org/10.1080/01446190801998708

Whitty, S. J., & Maylor, H. (2009). And then came Complex Project Management (revised). *International Journal of Project Management*, *27*(3). https://doi.org/10.1016/j.ijproman.2008.03.004

Williams, T. M. (1999). The need for new paradigms for complex projects. *International Journal of Project Management*, *17*(5). https://doi.org/10.1016/S0263-7863(98)00047-7

Winch, G. M. (2015). Project organizing as a problem in information. *Construction Management and Economics*, *33*(2). https://doi.org/10.1080/01446193.2015.1021703

Wynne, B. (1992). Uncertainty and environmental learning. Reconceiving science and policy in the preventive paradigm. *Global Environmental Change*, *2*(2). https://doi.org/10.1016/0959-3780(92)90017-2

Xia, bo, & Chan, A. P. c. (2012). Measuring complexity for building projects: A Delphi study. *Engineering, Construction and Architectural Management*, *19*(1). https://doi.org/10.1108/09699981211192544

Xiang, P., Zhou, J., Zhou, X., & Ye, K. (2012). Construction Project Risk Management Based on the View of Asymmetric Information. *Journal of Construction Engineering and Management*, *138*(11). https://doi.org/10.1061/(asce)co.1943-7862.0000548

Yin, R. K. (2003). Case study methodology R.K. Yin (2003, 3rd edition). Case Study Research design and methods. Sage, Thousand Oaks (CA)..pdf. In *Case Study Research: design and methods*.

Zheng, X., Lu, Y., & Chang, R. (2019). Governing Behavioral Relationships in Megaprojects: Examining Effect of Three Governance Mechanisms under Project Uncertainties. *Journal of Management in Engineering*, *35*(5). https://doi.org/10.1061/(asce)me.1943-5479.0000701

Zhu, J., & Mostafavi, A. (2017). Discovering complexity and emergent properties in project systems: A new approach to understanding project performance. *International Journal of Project Management*, *35*(1). https://doi.org/10.1016/j.ijproman.2016.10.004

APPENDIX 1: Uncertainty factors

Table 20: Factors of uncertainty in the literature.

Source	(Ward & Chapman, 2003) (Ward & Chapman, 2008)	(Mulholland & Christian, 1999)	(Maylor et al., 2008)	(Kolltveit et al., 2005)	(Kreye et al., 2019)	(Atkinson et al., 2006)	(Gosling et al., 2013)	(Russell et al., 2014)	(Perminova, 2008)	(Xiang et al., 2012)	(J. Geraldi et al., 2011) (J. G. Geraldi & Adlbrecht, 2007)	(Tran & Molenaar, 2014)	(Meyer et al., 2002)	(Howell et al., 1993)	(Williams, 1999)	(Xia & Chan, 2012)	(Jaafari, 2001)	(Gil et al., 2006)
Uncertainty factor																		
Objectives	■		■			■			■			■		■	■	■		
Importance of intangible benefits			■															
Strategic fit of project in organisation					■													
Too many, too ambitious or conflicting				■														
Methods	■		■			■			■			■		■	■	■		
Markets		■			■		■											
Supply chain of products							■											
Selection of contractors		■																
Availability of external resources					■													
Resources			■	■	■		■	■	■		■	■						
Availability of internal resources					■													
Timely provision of resources by client											■							
Resource interdependencies with other projects			■									■						
Storage and work space							■											
Availability of equipment and tools							■	■	■									
Labour resources							■	■	■									
Access to technical expertise				■														
Timely provision of resources by client																		
Stakeholders	■				■	■				■	■	■						
Interorganisational arrangements												■						
Behaviour of project players	■				■					■								
Motivation of project parties	■					■												
Communication across interfaces	■																	
Involvement of multiple organisations, departments and people	■																	
Capability of stakeholders	■										■							
Change in amount and characteristics of stakeholders	■																	
Complex relations between stakeholders	■										■							
Contracts	■	■	■	■			■					■						
Contractual conditions	■			■								■						
Contract mechanisms for coordination and control	■																	
Payment mechanisms							■											
Multiple contracts												■						
Liability		■																
Specification of responsibilities	■																	
Technology		■	■	■	■	■							■					■
Multiplicity of technical interfaces			■															
Size of solution space			■															
Level of product customisation													■					
Choice of technology				■														
Large amount of engineering components																		■
Scientific knowledge of technical products					■													
Design changes		■				■												■
Environment				■	■	■		■	■		■	■	■			■	■	■
Natural conditions								■	■			■	■			■		
Uncontrollable external factors					■	■											■	
Operating conditions						■												
Changing regulations																	■	■
Changes to project environment											■							
Local support of the project				■														
Technological fit with environmental context				■														
Volatility of environment					■													

APPENDIX 2: The IPM model

This chapter elaborates the management of public clients with regards to uncertainty. First, the general approach of managing construction projects by Dutch public clients is outlined. Then, several mechanisms are explained in this managing approach that prepare for uncertainty.

General project management (From RVB Kader IPM , 2021)

IPM (Integral Project Management) is used to manage projects at most Dutch public clients (such as Rijkswaterstaat and Rijksvastgoedbedrijf). The main reason for using the IPM model is the increasing complexity of construction projects, both from a technical and organisational point of view. Projects are becoming larger: There are more organisations, interests and objectives and objects involved. As a response, the IPM model should offer an inclusive perspective of all the different interactions in the project and its environment.

Three distinctions need to be made regarding IPM, keeping in mind that the three elements are closely linked to each other:

1. IPM thinking
2. IPM model
3. IPM roles

IPM thinking

The implementation of IPM is based on a philosophy. It is about recognising and considering the different interests in the project. These interests are then jointly considered in a project team that looks at it in an integral way to ensure a best possible performance. The bottom line is to unravel the tensions between interests from technical, environmental, contractual and social points of view.

The integral consideration of all kinds of interests is done on a risk-based view. This means that risks are identified, explored, monitored and controlled on their impact on objectives (or control factors) such as time, cost, quality, scope and information. The managers involved should explore the interfaces and tensions between interests as early as possible to allow an integrated decision-making process.

Decisions are only made when all the arguments are known and traded-off in the team. Every member of the project team shares information, knowledge and risks from his/her point of view. Eventually, the project management responsibilities are shared equally between all the team members. and

IPM model

The core of the IPM model is risk management. IPM cannot be practiced without risk management, as it would facilitate endless discussion and distraction from the key contents of the project. Next to risk management, there are surrounding disciplines of technical, contract and environment and project management to support the identification and assessment of risks. The basic principle is that the interests of these disciplines are equally powerful in the discussion that leads to a final decision. The disciplines have to work together on equal foot to decide what is best considering the risks involved. If the interests from the different fields do not provide a clear outcome on which decision is best, the project manager makes a decision, as he/she bears the final responsibility of the project.

IPM Roles

There are five roles in the management of projects using the IPM model: Project management, contract management, technical management, environment management and project control management.

1. Project management is related to managing overall delivery of the project. It concerns the achievement of objectives in the project, with regards to performance aspects. The project manager is responsible for setting up and executing the project, including the setup and leading of the project organisation with all the IPM roles. This role also oversees all relations, communication and coordination between the project and the stakeholders: The public client, contractor and other external stakeholders in the environment.
2. Contract management involves the procurement of the project and the strategy of all involved transactions. It is related to the market. The contract manager is responsible for setting up the needs for procurement, establishing the procurement plan, preparing the contract, selecting a contractor through a procurement procedure and manging the contract during project execution regarding time, cost, quality and risk. In contracts where the contractor is responsible for managing the quality of the final deliverable, public clients use a system-based contract management process (SCB). This process helps public clients to verify and guarantee that contractors are managing the quality adequately (*Kader Systeemgerichte Contractbeheersing Rijksvastgoedbedrijf*, 2017).
3. Technical management focuses on realising the physical system that fulfils requirements and specifications and the desired (technical and/or architectural) quality. The technical manager determines the strategy to manage the quality in the contracting phase and the integral fit of the physical system. He or she is responsible for the technical quality in the project, including analysing the client needs, conducting feasibility studies, estimating the costs adequately and coordinating technical aspects with the contractor, public client and consultants.
4. Environment management concerns the management of the project in relation to its physical and social environment. This includes maintaining the relations with other projects and all stakeholders of the project. It focuses on planning strategies to manage relations with stakeholders, creating support in the environment, obtaining permits, making arrangements and investigating the environmental infrastructures (cables, pipes) and states (ground conditions and safety).
5. Project control management involves the management of all performance factors: Time (planning), budget (financial), scope (change management), quality and information (documentation). Risk management is a key task associated with this role. It offers continuous insights on the presence of risks and control measures. Risk is defined as a possibility of unplanned events or uncontrolled processes in the project and in its external physical and political environment.

Each of these roles often has a team behind it to conduct the activities that are associated with that role.

Rijksvastgoedbedrijf

At the Rijksvastgoedbedrijf, the IPM model is a clear and unified approach to manage projects, which is relatively new in the organisation. There are some minor differences of IPM within this organisation in relation to the ‘’original’’ organisation of IPM at Rijkswaterstaat. For example, the project manager of Rijksvastgoedbedrijf includes the role of the environment manager. As a consequence, the IPM team consists of four roles instead of five.

Rijksvastgoedbedrijf manages complex construction projects using IPM. These projects are design-build or design-build-maintain projects characteristed by the use of system-based contract management (systeemgerichte contractbeheersing or SCB).

The risks of implementing IPM at the Rijksvastgoedbedrijf lies in 1) finding the people in terms of quantity and quality to perform the roles of the IPM model and 2) Consciously or unconsciously showing old patterns of behaviour in practice.

There are several important points of attention to fulfil the IPM roles adequately:

Context

An important form of interplay exists between the project manager and the political/governance of the project in the public client organisation. The interplay depends on the entire project environment. Hence, the public client organisation (which ‘’produces’’ the political/governance influences) and the project manager should be aware of the interplay between these influences.

Collaboration

Because the IPM project team has equal contributions to the decisions in the project, collaboration between the members of the project management team is crucial. The team members are expected to perform the project management tasks together, coordinate their (intermediate) results, share information and make decisions. Especially if the members of the IPM team have not worked together before, time and efforts are needed to improve collaboration.

Responsibility

At the Rijksvastgoedbedrijf, the IPM team does not have responsibility of reporting to the higher managers in the client organisation. This is done via a line managers (each team member has a line manager related to the specific field of discipline).

The IPM team is jointly responsible for delivering the project, including:

- Managing interfaces between IPM roles
- Considering adequate content for analysis by involving people with the right expertise
- Identifying, addressing and proposing changes in the project where necessary
- Overseeing risks and opportunities in the medium- and long term
- Making decisions based on joint coordination
- Leading their teams of employees that contribute to realising the project objectives

Flexibility

To implement IPM in a way that matches unique characteristics of projects, there are some points of flexibility in the organisation of IPM in the Rijksvastgoedbedrijf:

- Help each other and organise the division of tasks
- Organise non-IPM role-aspects within the IPM team if possible and necessary
- Flexibility in knowledge, competences and experience to take over tasks of other roles
- Use IPM roles and principles as a guide only, and decide within the team how to organise the roles and tasks
- Organise the IPM roles and tasks depending on the situation and the project

Stability (From Notitie Stabiele IPM Teams, 2020)

The stability of IPM teams is important to manage a project properly. The stability of an IPM team partly relies on the replacement of managers in the team. This replacement should follow a controlled process that considers time, professionality, fluid take over and minimising information loss to keep the IPM team stable.

Stability improves the collaboration within the team and with the stakeholders in the project. The team members also know their strengths and weaknesses. Project start-ups (PSU) and follow-ups (PFU) should enhance the collaboration and cohesion between team members.

To increase stability in IPM teams, it is possible to work with fixed IPM teams who work together permanently on multiple projects. This can reduce fragmentation and enhance efficiency, clarify the allocation of capacities in the team and ease the shifting of focuses within the team. However, there is also potential downside to working in stable teams. Fixed teams can reduce the potential for learning, create isolated perceptions or blind spots and reduce motivation due to a lack of diversity.

APPENDIX 3: Data collection protocol

The steps and questions in the interviews are outlined here. The interview has three different phases: An introduction, questions on uncertainty in the project and questions on the management of uncertainty in the project.

1.Introduction

This interview is about uncertainty in complex construction projects. Such projects often experience unforeseen events, developments and situations that have a significant impact. Some uncertainties are foreseen in the preparation phase of projects, but some of those uncertainties are not foreseen. In both cases, there is no basis to know the possible outcomes nor the probability of outcomes in the project.

The interview discusses two aspects regarding uncertainty respectively:

1. What kinds of uncertainty play a role in construction projects
2. How IPM teams manage projects in preparation for uncertainty

These two topics are central in this interview.

First, some questions are asked about the person to interview.

1. Can you tell something about yourself?
    a. How much experience do you have in managing construction projects?
    b. What projects have you worked on?
    c. What made this project complex and uncertain?

2.Uncertainty in projects

Complex projects are uncertain in different aspects. This interview explores how uncertainty plays a role in different aspects of construction projects. Hence, some questions are asked about the uncertainties that played a role in projects. Depending on how deep certain factors are addressed, follow up questions may be asked. In addition, questions are asked about the different causes of uncertainty and how they are perceived to cause project uncertainty.

2. What uncertainties were involved in the project?
    a. How did these uncertainties play a role in the project?
    b. Which uncertainties develop and unfold?
    c. How did these uncertainties impact the project?
    d. Which uncertainties were thought of beforehand? And which not?

Causes of uncertainty in projects

3. What were the main causes of the uncertainties that you experienced in the project?
    a. Are there differences in how these uncertainties were caused in the project?

This was the end of the first part.

3.Managing uncertainty in projects

The second part of the interview addresses the topic of management in preparation for uncertainty in construction projects. There are different ways of managing the uncertainty of projects before they occur in the project. This part of the interview explores how the IPM team managed the project in preparation for uncertainty. Specific focus is on the uncertainties that were involved in the project.

In complex construction projects, uncertainty can be managed in preparation. This means that management strategies and decisions are adopted to make the project able to deal with unforeseen events and developments. This helps the project to react to uncertain situations.

First, general questions are asked about the use of managing strategies that were in place to prepare for uncertainties discussed earlier. Then, more specific questions are asked to unveil strategies that were specifically aimed to install flexibility.

1. How does/did the project management prepare for uncertainty in the project?
    a. What approaches were used?
    b. How do these approaches aim to deal with uncertainty?
    c. How exactly were these approaches put in place?
    d. How have these approaches dealt with uncertainty in the project?
    e. How did these approaches allow for a better management of uncertainty in reaction?
2. How was the project prepared for uncertainties that impacted the project?
    a. What was done to prepare for these uncertainties?
    b. How did the management react to these uncertainties?
    c. How did the management in preparation for uncertainty influence the management in reaction?

A common way of public clients to prepare for uncertainty is to focus on control. This is often done by structuring the tasks, responsibilities and risks between the client and contractor. This structuring can be made using contractual and organisational structures. Control is about increasing predictability in processes and communication.

3. How was control installed in the project?

Another general way to prepare for uncertainty is by creating flexibility in the project. This can be done using several approaches.

4. How was flexibility created in your project to prepare for uncertainties?
5. How were trade-offs made between control and flexibility in the project?

This is the end of the interview. The participant is thanked for his/her contribution.

Appendix 4: Case results

This appendix showcases the results of the four cases studies in this research. For each case, the outcomes of the interviews are discussed regarding the uncertainties and the approaches to prepare for these uncertainties.

Case 1: European Medicines Agency (EMA)

This section sets out the results of the EMA case study.

1.1 Uncertainty

Various uncertainties were mentioned by the participants. In total, eight aspects have been mentioned to be uncertain in the project. These uncertainties were known to exist in the project before the execution phase started. In addition, there were uncertainties in the project that were unknown by project team prior to execution. These uncertainties are discussed in the subsection about unknown uncertainties.

Known uncertainty

The project team was aware of eight uncertainties in the preparation of the project. Most of those factors are uncertain in almost all projects. But in the EMA project, these aspects were especially uncertain. These aspects gave rise to uncertain situations in the project.

Table 21: Uncertainties in the EMA project.

	Procurement	Permits	Delivery	Politics	User	Planning	Contractor processes	Contract discussion
Project manager	■	■	■	■	■			
Contract manager (pre procurement)	■		■		■	■		
Contract manager (post procurement)	■	■			■	■	■	■
Risk manager			■		■	■	■	
Government client	■				■	■		

Procurement

The procurement process experienced an uncertain event which put more tension on the project. Multiple parties were involved in the procurement process, which involved a dialogue procedure. However, unexpectedly, one of the market parties withdrew from the process, leaving the project with only one market party in the procurement process. This made the procurement an uncertainty, as mentioned by almost all participants. Another uncertainty in the procurement was that another market party joined the selected contractor to do the job. According to the project manager and contract manager (pre procurement), this had a positive effect on the project finishing on time.

Permits

The procedure for receiving the permits for construction was also an uncertainty. There is limited knowledge of how this process will unfold. Until the permit is granted, it is an uncertainty whether

this will be completed in time and whether complaints will be made. The project manager and contract manager (post procurement) pointed out this uncertainty.

Delivery

Another uncertainty was experienced in the delivery of the construction materials and components. Especially steel components could not be delivered in time at the start of construction, which came as a surprise to the project manager, risk manager and contract manager (pre procurement). Despite that, the project team was aware of this uncertainty in the procurement stage. The uncertainty in the delivery process impacted the project when the core of the building was constructed. After that, it took several weeks (2-4) before the steelwork was started. This had to do with the delivery and the engineering of the components. The contractor had to work extra outside regular working time to make up for the delay.

Politics

The political environment of the public client, including the ministry of health (VWS), the ministry of Internal Affairs and the second chamber of parliament, was also a source of uncertainty in construction project. There are always uncertainties with regards to who resigns. And in the EMA case, European politics was also involved. The European commission and parliament wanted to know many things about the project. There were 19 countries that competed to offer a new home office for EMA. Eventually, only one country could win it, which resulted in 18 countries that lost the contest. According to the project manager, some unpleasant things happened in the press. And Italy enacted a lawsuit against the decision of the European commission to move EMA to the Netherlands. The project manager mentioned this as a source of uncertainty which is beyond control of the project team. However, this uncertainty did not have a surprising impact on the project.

User

The users of the building are also a form of uncertainty which play a role in construction projects. In this case, it was the EMA organisation. The project team did not know what EMA wanted and EMA was not involved in the request and bidding procedure of the European commission. There was a risk of new requirements arising from EMA, which could delay the project, which already had a tight planning. The project team had set a deadline, after which the user could not come with new requirements.

However, EMA came with changes even after the deadline. The organisation had been busy with moving to a temporary office building, which shifted their attention away from their needs in the new building. The users came with a surprising requirement as the construction process just started, which required a relatively large change in the building. However, the project manager had agreed with the contractor not to make changes. One of the rooms had to be adjusted. The decision was made to put that section of the building on hold and continue with the rest of the work. That section would be adjusted later. Eventually, this change was managed well within the time-frame and the needs of the user.

Planning

This is probably the most significant uncertainty in the EMA project: The planning. This was mentioned by all participants, except the project manager, who mentioned it implicitly when discussing the uncertainties in the user and in the delivery process. The whole project was about time. The Netherlands promised to deliver the building on 15 november 2019, which meant that there was 2 years to deliver the building from scratch and 1,5 years to construct the building after

procurement. Many processes had to be fast-tracked and done in parallel, which introduced many dependencies and interfaces, and as a consequence, risks.

Contractor processes

Like the users, this is an uncertainty which is said to play a role in almost any project. It concerns the processes that the contractor uses to deliver the building according to the right requirements and specifications in the contract. The contractor also has to check and verify these requirements to prove to the client that they delivered what they were asked to deliver in the contract. The risk manager and the contract manager (post procurement) addressed this as an uncertainty in projects. They basically stated: You do not know for sure that the contractor conducts the verification processes correctly. In the EMA project specifically, this uncertainty played a role after the procurement phase was over. This led to some unexpected deviations and changes. A deviation was found in the stairs, which had a different bronze color coating than specified in the design. This was not known until architect of the public client noticed this when he walked over the floor at the construction site. This affected the trust in the processes of the contractor.

Contract discussion

The contract manager mentioned uncertainty related to discussions about the contract. This is about whether the contract is clear with all requirements and whether the contractor understood what is asked by the public client. Changes in the contract are always uncertain according to the contract manager (post procurement). They can lead to discussions about whether things need to be changed and what price to use to pay for the change. It is also uncertain whether both parties solve the discussion in time and continue to work further in the project. The contract manager after procurement mentioned a discussion that occurred in the project. It was about the costs of a design change to fit the requirements of the local authority. The contractor held the public client responsible for the costs. The public client did not agree with that. The contract manager that was responsible after procurement saw this change as an unexpected surprise. Another discussion was about the space available at the backside of the building. The design turned out to have a flaw: It did not allow Trucks to park on the backside of the building due to a turning circle which was too large for the design. This led to many discussions about who is responsible (the contractor or the client). The issue has only been solved recently (after the project), according to the contractmanager (pre procurement). The contract manager during the procurement phase was surprised of this issue in the design.

Unknown uncertainty

In addition, some uncertainties were not known beforehand and led to complete surprises in the project. These uncertainties were not in the risk register, nor was the project team aware of those uncertainties prior to the execution phase.

Interface between ICT and construction

The representative from the government client (VWS) mentioned the interface between ICT equipment and the building during the construction process. The risk manager also mentioned this uncertainty which was overlooked in the preparation of the project. The application of ICT equipment in the building was overlooked. The representative had assumed that ICT equipment was included in the contract. In reality, the Rijksvastgoedbedrijf only contracted the construction of the

building including audio and video (AV) equipment. The furniture and ICT equipment had to be added to the project assignment, in order to deliver the complete building on time. In practice, the ICT equipment turned out to cause many uncertainties, according to the client representative. Because of the tight time frame, the ICT equipment was installed during the regular construction process. As the construction processes progressed, it turned out that the installation of ICT components needed space at the construction site which was practically not there. This was not accounted for beforehand in the planning. This introduced a new uncertainty in the project, which can be described by the following quotes from the representative of VWS and the risk manager:

Storm

Another unexpected incident was when heavy rainfall occurred on the building site. This happened six weeks before the planned delivery date. The tight planning resulted in many construction processes being conducted in parallel. The structural work was still unfinished when the installation of the facades and interior (electronics, floor isolation etc.) started. So the building was not wind- and waterproof. During the storm, water reached the inside of the building, causing considerable damage to the floor and electronics. Work had to be redone to restore the components of the building. The contractor still managed to restore the components and deliver the building in time.

1.2 Preparing for uncertainty

Several approaches were used in the EMA project to prepare for uncertainty. These approaches can be divided into four themes: Anticipation, dialogue procurement procedure, collaboration and risk management.

Anticipation

The project was prepared for uncertainty by keeping multiple options in place to carry out the project in case things go differently than planned. Another way to anticipate on future outcomes was by starting a procurement procedure well before knowing whether the housing of EMA would be awarded to the Netherlands or not. This was a measure to control the risk of delivering too late if the decision was made to host EMA in the Netherlands. In addition, a parallel trajectory was implemented in which two processes were done simultaneously to save time in the project:

1. The procurement procedure was started to put the assignment on the market and select a party that would build it.
2. The application process for receiving permission for the budget of the project was started at the same time.

Dialogue procurement procedure

A competitive dialogue procedure was used in the procurement phase to discuss the challenges of the project with market parties. In a certain period, the dialogue meetings were three times a week. The project manager described those meetings as long and intensive.

Another example of preparing for uncertainty in the dialogue is that the contractor had two suppliers for the most important components of the building: The steel and the facades. This prepared them so that if one of the suppliers was not able to deliver components, the other supplier would be available to take over. This was also discussed in the dialogue.

Also in the dialogue, the decision was made to split the design of the core (building structure) and the shell (facades) of the building. The public client This allowed the design of the core to be finished earlier, so that construction could start earlier. In the meantime, the design of the shell would be

completed and the construction of the shell would start after. The project team accepted this as a request form the contractor. But in turn, they demanded from the contractor to control the interface between core and shell.

Collaboration

A main theme that is addressed in this project as a means to prepare for uncertainty is collaboration. This was demonstrated through early communication efforts, short lines of communication and trust.

Early communication

The project team communicated early with the municipality about the permits. 4-5 months Before the EU decided to move EMA to the Netherlands, the project team was actively speaking with the municipality about the procedures for the permits, as if the project had already started. The supervisor of the local area was also involved. The plans were discussed, including aspects as fire safety, construction safety and aesthetics.

The market was also informed early by starting a procurement procedure. The selection of a contractor for the project was also done early in the process. The procurement process was started 5-6 months before the final decision was made to move EMA to the Netherlands. This was done to be on schedule in case EMA would definitely move to the Netherlands.

The project manager also informed the organisation of EMA early about the construction process and EMA's needs. That way, they knew what to expect and when they can provide input in the process.

Short lines of communication

The project manager, contract managers and government client manager mentioned that the communication between them and other parties in the project were short. It was easy to contact each other on a frequent basis. The project manager had short lines of communication with the project management team (contract manager, technical manager, risk manager). The communication line between the project manager and the manager of VWS was short. They were closely involved with each other to manage the expectations. They had weekly meetings.

The communication between the project team and the organisation of the user was characterised by a short line. The contractor and the project manager were also easily accessible. The project manager had weekly meetings with the contractor. These conversations were not only about the progress (planning, costs, changes etc.), but mainly the collaboration within the project teams and between the contractor and client.

The usefulness of a short line of communication is demonstrated when the architect of the RVB discovered a mistake in the bronze coating of the stairs in the building. A conversation followed soon, where the client asked the contractor how it happened, how to solve it and how they will make sure that it does not occur in the future.

Trust

Trust was an important factor that allowed the project team to collaborate in preparation for uncertainty. This was done on different levels and between different people and organisations. However, when it comes to how trust allows for a better preparation for the specific uncertainties

that played a role in this project, there are no tangible answers with concrete examples from the participants.

Trust within the project team

A small team with experienced managers was deliberately set up to be decisive in the project. The project manager played an important role to make a small team of competent people to manage the project. Both contract managers also described the importance of this aspect. The core team in this case was the project manager, contract manager and technical manager. According to the contract manager (post procurement), the trust in the core team allowed them to shift smoothly in preparation for uncertainty.

Trust in the contractor

The trust between the client and the contractor is something that appears clearly from the interviews. The project manager had a good relation with the project director of the contractor. They knew each other from a project in the past.

In addition, the project team had an open attitude towards the contractor during the discussions in the dialogue and in the discussions about changes in the contract. The open attitude was characterised by sharing concerns, discussing possibilities and offering help. However, the open attitude was combined with a strict attitude when things would go differently than planned. And with regards to the split between the design of the core and the shell, the public client stressed the responsibility of the contractor for the design and the management of risks involved. And after the construction process unexpectedly stopped because of issues with the delivery of steel components, the public client met with the contractor on a higher level to discuss the delay. This was a firm discussion.

Trust from the government client

VWS gained trust in the public client (RVB) as the project progressed. The trust between the representative of the government client and the project manager was especially highlighted in the interviews with those people. The representative played a role in the uncertainty regarding the installation of ICT components during the construction phase. This was an uncertainty that was not expected in the project. He would communicate with the project leader that was responsible for the ICT part about issues and concerns that were expected by the project leader during construction. Another way of preparing for uncertainty was by having clear roles and responsibilities. This helped to keep trust between the manager of the government client and the project manager. That way, they could make quick decisions about uncertainties without having to consult their superiors.

Risk management

Another frequently mentioned way to prepare for uncertainty in the project is risk management. A risk manager was involved that kept a risk register up to date with risks and control measures from all the project disciplines (environmental, technical, contractual and planning). Risks were also presented graphically to produce an oversight on the total impact of all risks with regards to project performance aspects: Time, cost, quality, safety and reputation. This also revealed the most important risks for each aspect.

Several control measures were taken, based on risk management. This includes the measures mentioned before: Starting procurement early and setting a deadline for the user to make changes to the design. But also other measures were taken to tackle smaller uncertainties. The technical risks were mostly put down as requirements in the contract. This includes façade panels, which were

considered as a critical part of the building, because they had to fit a specific design and be delivered in time. Audits were conducted to check if the contractor conducted its risk management process accordingly. These audits were organised on the basis of risks that were perceived as most important and risks of which the public client did not have complete trust in the contractor's processes to deal with them. Risks were also shared with the contractor. This was about risks that only the contractor could control. These were discussed, and topical risks that popped up were communicated to enable the contractor to deal with them.

Case 2: Breedplaatvloeren Turfmarkt (JuBi)

This section presents the results of the Turfmarkt case study.

2.1 Uncertainty

Four aspects have been pointed out as uncertain by the project team members. These are the building method, installations, users and the price. These uncertainties were foreseen before the execution phase. In addition, two uncertainties were mentioned to be unknown and thus unforeseen.

Table 22: Uncertainties in the Turfmarkt case.

	Building Method	**Installations**	**Users**	**Price**
Program manager				
Project manager				
Contract manager (pre procurement)				
Contract manager (post procurement)				

Known uncertainty

Building method

One of the most significant uncertainties was the building method. As the client is dealing with a structural issue that had only been discovered recently, there were no validated building methods that guaranteed a successful restoration of the strength of the floor. In addition, the methods of calculating the strength of floor elements are not unanimously agreed upon. There are no laws and regulations with regards to strength requirements. Simply said, it was not known what method will work under which circumstances. This uncertainty was widely acknowledged at the time of procurement, before a contractor was selected.

There were two methods involved in the project: Boring and liming. The boring method involved boring into the floor and installing anchors to increase strength. The liming method involved liming panels underneath the floor to keep the floor elements attached together. The contractor that was selected had boring as the main method to carry out the work. However, during the late engineering phase, the boring method would not work in some cases. And although the contractor had agreed to use the liming method as a back-up option, they were not sufficiently prepared for it, causing significant delays (6-7 months) in the validation process of the liming option. The validation process also involved some discussions, hic-ups and mistakes.

Installations

The role of the installations was uncertain in this project. This counts for both installations within the floor structure and installations which were mounted underneath the floor. First, the main installations need to be protected to keep the building functioning, while space still needed to be created in places where the floor had to be restored. Second, It was unknown where exactly the floors needed to be restored and which method should be used to restore it correctly. And the

methods determined how much space is needed. So it was also unknown which critical installations would create problems at which places. On top of that, the drawings of all the installations were known to be inaccurate. As a result, the role installations remained a big question for the project team.

This uncertainty had an impact on the project when different types of installations within the floor were hit regularly during execution. This happened even with the use of a scanner that could detect most metallic components in the floor. It also turned out that there were plastic pipes in the floor to accommodate for future flexibility. These pipes were difficult to detect, and when such a pipe was hit, it turned out that the boring method would not reach the desired strength. This damaged the installations to an extent that was not foreseen in the project. As a consequence, the project is delayed by several months and experiences a significant amount of cost overruns.

Users

The users (two ministries) also form source of uncertainty. The ministries that work in the building have specific requirements with regards to hindrance. The building had to stay operable during execution. This means that places and times of working had to be coordinated, noise and dust should be limited, but also the aesthetics of the building should be maintained. The role of the users concerning those requirements was uncertain in the project.

This led to a surprise in the project: The public client had conducted a study to assess which floors exactly had to be restored in the building. The users decided to have this study conducted again by another party because they were unsure about the safety of their building. This led to the conclusion that the outcome of the initial study was not completely valid. As a consequence, the project team had to take extra measures to control the risks associated with keeping the building safe and operable.

Price

The uncertainty in the price resulted from the uncertainty in the installations. Because there are many different types of installations in and underneath each floor, it could take months to calculate the costs and it would add process costs to the project. Through the time pressure and the political pressure, this uncertainty was initially overlooked, but during the dialogue in the procurement phase it was picked up by the project team. It led to some long discussions in the dialogue.

Unknown uncertainty

Amount of floor elements to restore

One of the uncertainties that was completely unexpected in the project was when similar projects showed that some floor elements with pipes and channels in them could lead to new insights in the calculations. This increased the amount of floor elements that had to be restored in the Turfmarkt Building. The team discovered this in the middle of the procurement phase. The program manager addressed this as an unexpected surprise which was not foreseen.

Steel beams in the higher floors

In some of the highest floors (above floor 34), it was discovered that steel beams need extra restoration work. This was unforeseen by the project team and it is still being investigated at the moment of this research. The execution phase has not reached these floors yet, so there is time to clarify the problem and prepare for those works.

Contractor processes

Another unexpected uncertainty that emerged during the project was about the. This was pointed out by the contract manager that took over after the procurement phase. The contract form included processes (for risk management for example) that the contractor was required to follow. However, this turned out to cause a substantive amount of effort from the contractor's side to conduct these processes. It also resulted in unclarity from both the client and contractor's side.

2.2 Preparing for uncertainty

Several measures were taken by the project team to be prepared for the known uncertainties in the project. First and foremost, the strategy was chosen to work with the higher floors (10-37) in the towers first. These floors were mostly comparable and repetitive. That way, the project team can learn about the different kinds of installations and challenges in the construction methods. The lower floors (1-9) will come later on. These are also more diverse and complex, according to the project manager.

With regards to the building methods, a market consultation was done in 2019 in which different contractors presented their building method in an empty building with comparable floors as in the Turfmarkt. In addition, the project team worked with a team of construction experts that were specialised in the specific floor construction and the methods to restore the floor and validate the strength. On top of this team, an independent consultant is involved in case of escalation of constructive matters. At the time of publishing this report, this escalation level has not been used. Another measure to prepare for the uncertainty of the building methods was by having an external party do research to the amount of floor components to be restored. The results were presented in a report that was included with the contract. In addition, an extra step of validation was required for the building method. This made sure that the different methods proposed by contractors in the procurement phase were good enough to implement. An external party would do a test on the validity of the building method.

With regards to the installations, several measures were taken. The strategy to start with the least complicated floors unexpectedly helped to detect the issue with the steel beams in the upper- floors. It allowed the team to work on the easiest floors first, and exploring the state of the other floors in the meantime. The uncertainty in the installations was also reduced by working with scanners. But these scanners cannot detect everything with 100% certainty. Especially non-metallic components are hard to detect. The fire sprinkler installation was shut off when the floor was worked on, so that in case a sprinkler pipe is hit, there is no water pressure and damage is limited. Despite these measures, the amount of damage made to installations is significant, and this remains significant in the execution phase. When damage is made to an installation, the contractor is required to restore the damage as fast as possible. This has been the case regularly, resulting in delays and extra costs. The project team responded by taking a variety of measures to prevent damages in the future: They. However, these measures do not reduce the amount of damage done to the floors. The contractor improved its scanning protocol, they tried a different way of scanning, changed the way of boring anchors and warmed up the installations to allow better scanning. Many other measures were taken to try to reduce the damage, but they do not have a reducing effect.

The project team prepared for uncertainty on the user's side by having noise and dust tests before execution to assess how much space is needed to work safely in the building. Representatives of the

user were invited to assess the noise personally, with different contractors simulating the work. This way, clear requirements were put down in the contract about when and how to work in the building. Up until now (approximately one-third of execution complete) no unexpected hic-ups have entered the execution process when it comes to the users' interests.

The price uncertainty was prepared for by discussing the risks in the dialogue phase. Eventually, two floors were selected as an average sample to be calculated for the whole building. And that would be the fictive price of the contract. If the final costs of the work would deviate significantly from the fictive price, then the price would get adjusted based on an open book policy.

Financial reserve

A part of the budget was saved as a buffer to allow for changes and solutions to unexpected impacts. The reserve also allowed for extra work on damaged installations in floors. As the project had to start as fast as possible, the managers realised that a contingency in the budget was appropriate.

Dialogue procurement procedure

A dialogue phase was included in the procurement process, in which the main risks were discussed and shared with parties. One of the main risks that was discussed was about the building method. How the contractor will show that his solution meets the strength requirements. During the market consultation, an installation in the floor was damaged when the boring method was used. This was discussed in the dialogue as a risk which the contractor should do something about. And also the hindrance in the building was discussed, especially how the contractor is planning to deal with that. In general, the dialogue was mainly about how the contractor thinks he should work, how to deal with the uncertainties with the validation of the building methods, the installations and the users.

Structured meetings

One of the ways the project team uses to prepare for uncertainty is through an organisational structure in which regular meeting take place. This is done both within the project team itself and with other parties. The project team of the public client meet regularly to discuss the risk register and anticipate on future possibilities. The regular meetings with the contractor were also addressed by the project and program manager as a way to prepare for uncertainty. When the damage to the floor installations became excessive, the project team arranged a meeting to discuss how things can be improved and how they can help the contractor with certain problems. The project manager, contract manager and the program manager also have weekly meetings with representatives of the users of the building to discuss the progress of the project and the safety and operability of the building.

Risk management

Uncertainties in the project were mapped by a risk analysis that explored risks with regards to the technical part and with regards to the user. Because the building had to be available during execution, this created risks for the users. The project team explored those risks too and looked at which risks can be controlled by the public client and which by the contractor. What must be said is

that the risk analysis contains mainly technical risks and that the risk management process was not done extensively. Risks from other disciplines were not included in the risk register and no control measures were taken based on the risks involved. The steering on basis of risk management measures was done after risks occurred. With regards to the damage that is caused to the installations in the floor, the project team aimed to mitigate this risk after it turned out that the damage is significant. Then, they demanded from the contractor to revise its scanning protocol and take mitigating measures to prevent damage. Regarding the uncertainty surrounding the user, no serious risks occurred, but it took time to set down the right requirements for managing the risks of hindrance.

Case 3: Julianakanaal Berg-Obbicht (JBO)

This section presents the results of the JBO case study.

3.1 Uncertainties

Five uncertainties were pointed out by the participants. The most important uncertainties were the channel bottom and the construction method. In addition, the stakeholders, flora and fauna and the dikes play a role as uncertainties in the project. These uncertainties were identified before the procurement phase was over.

Table 23: Uncertainties of the JBO case.

Role/Uncertainty	Channel bottom	Method	Stakeholders	Flora and fauna	Dikes
Portfolio manager					
Project manager					
Environment manager					
Contract manager					
Project control manager					

Known uncertainties

Channel bottom

The bottom of the river is an uncertainty that plays a role in this project. The channel lies up to 17 meters higher than ground level, which makes waterproofness of the bottom of the channel essential. If a leak occurs, water will quickly flow in all directions in the direct environment. It is uncertain what lies in the bottom of the channel, because the channel is around 100 years old and works have been executed several times. It is also unknown what the real state is of the bottom, especially regarding the strength, objects in the soil and the required amount of maintenance. The documents and drawings are. This had several impacts on the project. For instance, an industrial pipe on the bottom of the channel was hit during the installation of sheet piles. An airplane bomb was found in the bottom near the trajectory. And, more significant in this project, several leaks arose during execution. This resulted in significant delays and extra costs. This uncertainty was prepared for by conducting investigations on the bottom of the channel to observe the situation and the risks involved.

A large leaking hole arose in the bottom during execution, which caused an unsafe situation in the near environment, with a couple of basements that flooded. As a consequence, the client instructed the initially selected contractor to stop the work and a new procurement procedure was started in 2020. As the initial contractor had already carried out a considerable amount of work on the channel, it is also uncertain whether this work was carried out properly. The contractor had repaired the leak initially, but it was still leaking when the new contractor started construction. Additionally, the bottom protection layer was not of sufficient quality at some locations.

A new contractor was selected to complete the widening of the channel, restore the leak and control the groundwater levels in the environment. This was done successfully, and newly arising leaks are being detected and closed effectively by means of a pilot. Active measuring and monitoring of the groundwater levels around the channel is done to detect leaks in the channel. Scanning methods are also used to detect objects on the bottom of the channel, but this is a costly measure that is only used in some parts of the channel as an experiment. The progress of these measures appears to be positive: The risk of water leaks in the environment is under control, but it remains a top risk according to the project team. The general way of preparing for uncertainties of the channel bottom is for the contractor to monitor and establish its work in detailed documents and warn the client in case of incidents and emerging situations.

Method

Another uncertainty which closely linked to the bottom of the channel, is the method used to execute the works. The shipping has to continue during the works, which limits the space available to work on the channel. The method used by the first contractor turned out to cause problems to the channel bottom and environment. A ship was used to dig into the bottom of the undrained channel. The new contractor uses a different method, by draining part of the channel and making a construction pit. The project team had expressed its concerns about the previous construction method in the procurement phase. This was represented in contract documents, but also in a competitive dialogue procedure where the client entered into deep conversations with contractors. As a result, the bidding contractors refrained from the method used initially. However, Whether the new method is safe and maintains the shipping processes is not certain. The project team has started a pilot in which this method is being tested at the site. All kinds of measurements are being taken to draw conclusions on the feasibility of the method. The results of the pilot are expected in September 2022, which is 3 months after the time of data collection. However, the intermediate results of the pilot seem to be within control, increasing the confidence of the project team.

Stakeholders

The main stakeholder that introduces uncertainty in the project is the shipping industry. They were concerned with the available width of the channel as the construction pit would take considerable space. There was a risk that this industry can take decisions to protest. This has led to many discussions with the shipping industry. The ongoing pilot is supposed to check the space available and the sailing speed. In addition, surveillance is used to guide the ships along the construction pit.

Flora and fauna

Another uncertainty that plays a role in this project is the possible presence of protected species, especially animals. It is an uncertainty which plays a role in almost all infrastructure projects. It is unknown by the team whether such species will appear near where construction takes place. This uncertainty is known by the project team, but it has not had a surprising impact on the project (yet). According to the project control manager, it is almost impossible to prepare for this uncertainty. A probabilistic planning that accounts for the effects of this risk is used to be prepared for its impact. No check rounds were done and not measures were taken to make the environment unsuitable for protected species.

Dikes

The state of the dikes was also uncertain in this project. It was unknown whether they are strong enough to keep stability during construction. Investigations were done to verify how the dikes are

built and what the risks are that parts of the dike are not strong enough to withhold the pressure of ships sailing through the channel. No unexpected events have occurred yet which were related to the stability of the dikes.

Unknown uncertainty

Next to the uncertainties that were known to play a role in the project, there were some unidentified uncertainties that turned out to impact the project.

Channel edge

A uncertainty that was overlooked or underestimated according to the environment manager is the role of the channel edge. This is an impermeable layer of soil that is located on parts of the edge of the channel. The consequence is that leaks that occur in the channel result in high groundwater levels outside the channel that cannot be controlled easily because of the impermeability of the layer.

Translation waves

During the construction phase, it turned out that ships experienced hinder from translation waves when sailing along the construction pit. The waves also create safety risks for the workers in the construction pit. This issue appeared shortly after the procurement phase and it is being investigated in the pilot, which is supposed to take 3 months.

Channel bottom

The environment manager also pointed out the awareness of unforeseen uncertainties regarding the state of the channel bottom and objects in it. The project manager mentioned the age of the channel, which increases the probability that leaks occur regardless of the works. They know that something unexpected can happen at any time.

3.2 Preparing for uncertainty

Risk management

Risks are being discussed openly in meetings with the contractor (each two weeks) and shared with each other. These are mainly technical risks. These discussions serve as an input for the risk register, which is used to make a probabilistic planning. Risks are also quantified in terms of money, quality, safety and reputation.

Budget reserve

A financial reserve is set up by the project team to account for unknown-unknowns. This reserve is larger than in average projects, because of the unpredictability in the bottom of the channel. It is used for risks such as flora and fauna and when unexpected objects are found in the bottom.

Expertise

The project team views the technical expertise and experience of the team members as an important factor to prepare for uncertainty. The portfolio manager and the project control manager addressed this aspect. The contractor is also specialized in this type of work.

Involving decision-making

The involvement of higher levels in the client organization in case of uncertainties is being used as a way to prepare for uncertainty. The project manager mentioned the close communication with top levels at Rijkswaterstaat and the Ministry of Infrastructure about the development of risks and emerging matters in the project. This is done to incorporate the different perspectives of the internal decision-makers and to reduce the risk of overlooking certain interests. The environment manager mentioned the crisis organization (involving fire brigade and the army) in case of catastrophies.

Case 4: Renovation Eerste Heinenoordtunnel (REH)

This section shows the results of the REH case.

4.1 Uncertainties

In total, five uncertainties were mentioned by the participants. They are found in the table below.

Table 24: Uncertainties in the REH case.

Role/Uncertainty	Development and integration of tunnel systems	State of the Tunnel	Permits	Stakeholders	Middle tunnel channel
Project manager					
Contract manager					
Project manager tunnel systems					

Known uncertainty

Development and integration of tunnel systems

Next to the regular maintenance of the tunnel structure, the tunnel is also equipped with a new package of standard/universal tunnel systems, which is still in development and will find its first application in the Heinenoordtunnel. It was uncertain whether the development of the package would be completed in time for the design of the renovation activities. The development of ICT components. And indeed, in 2019 it turned out that the package would not be ready on time to serve in the Heinenoordtunnel. But Rijkswaterstaat's internal organization still decided to aim for application of the standard systems in the tunnel. Rijkswaterstaat included this assignment in the renovation project and outsourced part of the development to a market party in a separate procurement procedure. In addition, there were some organizational changes in the market parties that resulted in changes in their approach to develop the systems, which put the development under pressure.

As a result of time pressure, the project team decided to split the tunnel systems in different functional parts, of which several parts were actively developed to see how long it takes to develop certain parts. And a sliced approach is being used where functional parts of the package are completed separately and sent to the design team to integrate the systems into the tunnel design. However, this creates the risk of mis-integration of interfaces and rework if information about finished and unfinished parts are not transferred well to the design team. In addition, there is a risk of work overload for the people working on the development of the tunnel systems. So, to reduce the impact of this uncertainty, the development of the systems is done in parallel with the constructive design work. To prepare for upcoming uncertainties in the development, a deadline is set so that it has to be finished before the start of the construction in 2023. Until that time, the systems have to be developed as universal as possible. The part that is incomplete will be fitted with a unique design for the tunnel. Continuous monitoring of the development is done to check if all systems will be ready before the construction phase. The sub-project is still on track to finish on time before the renovation starts.

State of the tunnel

The plans and drawings of the tunnel are not accurate, which introduces the risk of running into unexpected components at unexpected locations. It turned out that the concrete floor lies higher than expected, limiting the space available for maintenance in the tunnel. The state of the joints of the tunnel is also uncertain. And the state of the fire extinguishing system was worse than expected. The municipality demanded that the issue should be solved as soon as possible. These issues led to delays and costs, which are generally controllable, according to the contract manager. But the project manager addressed the relation between the municipality and the project that was affected by this issue. This may have an impact on the granting of the permit for re-opening the tunnel. Eventually, the project team engaged in close talks with the contractor about how to solve the problem. Extra work resources were used by the contractor to solve the issue with limited delay.

Permits

Receiving permits for doing the maintenance works and for opening the tunnel after the works. There is uncertainty about the granting of those permits. This has to do with whether all information is about the tunnel is available and whether the permitting authority decides to grant the permit or not.

Stakeholders

The political situation at the Municipality of Barendrecht is uncertain, and therefore also their interests. The municipality may require additional measures for the closure of the tunnel. Next to the municipality, there are businesses, users and other projects in the environment that play a role as stakeholder. Considerable hinder is expected in the environment near the tunnel, which impacts these actors. The tunnel will be closed twice for several weeks in the summer of 2023 and 2024.

Middle tunnel channel

Another uncertainty discussed by the contract manager and the project manager of the tunnel systems was the middle tunnel channel. This is a hallway through the middle of the tunnel that separates the two directions of traffic. The hallway is used for safety purposes during calamities. The Heinenoordtunnel does not have such a hallway. And such a hallway has never been constructed in an existing tunnel before. The construction of a 600m wall to create the channel in three weeks of tunnel closure is an uncertainty.

Mockups are used in the project to experiment with parts of the wall. The contractor is testing how long it takes to install parts of the wall, how tunnel systems are attached to the wall and how it can be installed efficiently. This should save time during the real construction phase.

Unknown uncertainty

Permit for the Tweede Heinenoordtunnel

An uncertainty that was overlooked or unexpected was the permit needed to work on the 2nd Heinenoordtunnel: a smaller tunnel near the 1st Heinenoordtunnel. This tunnel, used by slow-traffic, needs adjustments to facilitate bus traffic during the closure of the 1st tunnel. It turned out that a permit is needed to make those adjustments, but the project team did not expect that. This is an uncertainty that was introduced in the project shortly after the start of the execution phase (August 2021). It may impact the duration of the main works if the 2nd tunnel is not ready for extra traffic when the works start. The municipality required a permit procedure, which is expected to delay the project for several months and increase hinder in the environment during construction.

Material prices

As a result of the war in Ukraine, the prices of construction materials are increasing drastically. The project manager mentioned this as an uncertainty that was not anticipated.

Capacity

The organizational resources of the public client is also an uncertainty that was not taken into account. It is uncertain whether the project is able to keep enough people with sufficient experience and expertise. The project manager has recently been replaced, and some supporting teams have limited resources to manage the project.

4.2 Managing uncertainty

Four approaches to prepare for uncertainty were observed in this project.

BPKV plan

The known uncertainties were described and included in a list of risks, for which contractors involved in the bidding process had to write a plan to mitigate those risks. These plans were evaluated based on price and quality (BPKV) to select a contractor. This led to smaller risks, which are being managed by the project team.

Risk management

The project team engaged in risk management processes to prepare for uncertainties. Risks were identified, quantified and control measures were set in place. Risk sharing with contractors is done in regular meetings. In addition, internal meetings within the project team are held on a regular basis where top risks are on the agenda and new or upcoming risks are discussed.

Budget reserve

An extra budget was kept apart by the project team to account for unforeseen circumstances. These are mainly risks that were not on the register, or risks that were on the register, but had an unexpectedly bigger impact on the project.

Involving decision making

The project manager of the tunnel systems mentioned the use of extra financial decision-making authority to make quick decisions in dealing with uncertainty. Conversations with the portfolio manager are held when significant issues arise in the environment, and plans are made to give the project manager extra decision power. Extra mandate was also demanded when the development of tunnel systems were included in the renovation project. The project team asked to deviate from the regular processes of Rijkswaterstaat in the management of the tunnel systems. This gave them more freedom to manage the project. The project manager mentioned a similar strategy: Escalating problems to higher levels when the project team cannot solve problems themselves. Especially the uncertainty related to the resource capacity in teams was mentioned as an uncertainty that is managed in this way.

Appendix 5: Interview quotes

Table 25: Quotes from the EMA case study.

Nr.	Theme	Quote
1	Uncertainty: procurement	''The other party had to finish the procurement and come out as the winning party. That gives pressure. In this case, the procurement remains an uncertainty until the signature is made.'' (Project manager)
2	Uncertainty procurement	'' Both parties are big, but one of them is good at building and the other is good at systems engineering, design and engineering. I think that if they did not join for the job, it would be another story. So we had a bit of luck there.'' (contract manager pre procurement) ''Two contractors decided to join each other for the job, that was strong of them.'' (project manager)
3	Uncertainty: Permits	'' The procedure for the permits was uncertain because of the tight planning. There is uncertainty in the municipality and the permit authority, whether they are going to grant it. Or when complaints are made in the environment. In that case, you cannot do much more than informing or organising participation.'' (project manager)
4	Uncertainty: User	'' We were lucky to have a project team from the user organisation that moved to a new office location a few years ago. So they knew what to expect. But still, you have to agree with each other. Maybe they want some things which we did not think of. Or things we did not agree with the EU commission. That is also uncertain.'' (contract manager post-procurement)
5	Uncertainty: Planning	''Actually, the planning is one big uncertainty. I am convinced that the contractor changed the planning daily to solve issues, of which 99% I did not see. There were 3, 4 or 5 moments, or more, which made me really nervous. I do not completely remember those moments.'' (Government client)
6	Uncertainty: Contractor processes	''You do not want this. During the process, a choice was made to work with a different coating. But they did not communicate this to us. We got the feeling that we could end up with 1000 different colours of bronze in the building. '' (risk manager)
7	Uncertainty: Interface between ICT and construction	''I think that is sufficient uncertainty. Then you have to bring together two worlds who normally do not talk to each other. Who normally do not look to each

		other. Because normally, they do not need to.'' (Government client) '' Then you create new risks. During the project, we realised that these things had to be done during the project instead of after the project, which is normally the case. We did not see that coming.'' (Risk manager)
8	Managing uncertainty: Dialogue procurement procedure	''Intensive and long days, with many people at the table. We discussed the content: What do we want to make. But also the process: How do you verify the requirements and how do you treat suppliers. We shared our risk register and we had many conversations. The uncertainty regarding the delivery of steel components was discussed.'' (project manager) ''We thought about how to make sure that a supplier does not withdraw and how to get our components on time. These risks were kind of controllable: We could think of them and we could think about solutions.'' (project manager) ''That was a request from the contractor. We said OK, if you can show that you control the interfaces. Because, let's say you have to make openings for the façade because the design of the fit out. How does that work if you already have constructed the core structure? Then, they came with the idea to do SCRUM sessions.'' (contract manager pre procurement)
9	Managing uncertainty: Collaboration (early communication)	'' The authority that grants permits knew what to expect in march because we discussed it last summer. That helps a lot. And there were no complaints.'' (project manager)
10	Managing uncertainty: Short lines of communication	'' I think that helped with the EMA project. There were many short lines of communication, so things could be interacted quickly when we saw something. Many things could be recovered or prevented in the future.'' (contract manager post procurement) '' We prepared the project by keeping a small team from our side. The project manager did that. With a small team, you need less coordination and you can make steps more quickly.'' (contract manager pre procurement) '' And the accessibility. Everyone was accessible. If something happened, and everyone is accessible, you

		can have a quick discussion. Then you can continue.'' (contract manager post procurement) ''A small and decisive project team. Close to the government client. Close to the contractor. But also a clear division of roles: Who is responsible for what?'' (project manager)
11	Managing uncertainty: Short lines of communication (EMA)	'' We also had short communication lines with the user. In the beginning they were a bit distant. But eventually, we explained well: *This is what we are going to do. On this moment, I need a signature. On that moment, I will explain that and that. During construction, we will talk about so and so, then you need to make sure to have the right people at the table.* You have to guide them through what is happening. '' (Project manager) ''You know that they can be critical, so we arranged a short line of communication. We communicated clearly when they can ask for changes and when not. The project manager worked hard to be clear and strict.'' (contract manager pre procurement)
12	Managing uncertainty: Short lines of communication (contractor)	'' The contractor could always find me.'' (project manager) '' We agreed that progress belongs to the contract management and that we would mainly talk about: How is it going? Who suffers from each other? Where are things going rough? Who work against each other? Where do they misunderstand each other?'' (Project manager)
13	Managing uncertainty: Short lines of communication (VWS)	'' VWS was involved from the beginning up until the end.'' (contract manager pre procurement)
14	Managing uncertainty: Trust	''I started noticing more the importance of the right person at the right place. Everyone is good at something and less good at something else. And each project asks for something different. What is also important is a core team to work with, so that you can deal with uncertainty and have trust in the other. So that you can complement and understand each other. '' (contract manager post-procurement) ''Uncertainty is always there. You have to try to anticipate with some risk management, thinking through and having good people that know what can go wrong. But eventually, things go wrong. Sometimes you have a plan, but sometimes you do not. Then you

		have to find each other and solve it. That requires trust, obviously.'' (contract manager post-procurement) ''An interesting point is that we did not know each other before. But there was a lot of trust in each other and everyone valued each other's discipline and expertise. If someone said from his/her role that something is not possible, it was easily accepted.'' (contract manager pre procurement)
15	Managing uncertainty: Trust (contractor)	''We understand each other. In general, all people clicked with each other. We worked on that using the start-ups and follow-ups. That way, we made sure the teams (of the client and contractor) could understand each other in their function/role. A lot was discussed, so that little was over to discuss in the four-weekly meetings. It was informal all the time.'' (project manager) '' We shared out risks with contractor during the dialogue. Our concerns. The first thing the project manager said was: We have a big challenge, but we cannot do it ourselves. We need you.'' (contract manager pre procurement) '' You can be strict with the contract and looking up thins in the contract. But the main question I asked them was: How can I help you? That way, you share problems. That does not mean that I become the problem owner, but if I know that, I can see what I can do to help them further.'' (project manager) ''The other part is pure: How do you work together? How do you stand in the meetings? I think what we did helped for sure. We were mainly busy solving problems. Also the contractor. Everyone sat at the table to solve problems.'' (risk manager) '' If the project director says that will be solved, then it will be. That kind of trust.'' (government client)
16	Managing uncertainty: Trust (strict attitude)	'' But if I have the feeling that they are not making moves.. Well, then you have to try other ways to get them moving. Sometimes, that is a harsh conversation. Sometimes, that is escalating or stopping the payment. And sometimes it is arguing your stance confidently. This is necessary in some cases.'' (contract manager post procurement)

		''But it was harsh sometimes. They had a contract which they needed to fulfil.'' (risk manager) ''We said: Ok, we will go with that, including the SCRUM sessions. But we keep our roles and responsibilities. You are the designing party, you have the pen in hand and we are only there to explain the requirements.'' (contract manager pre procurement) '' We asked them whether they would still meet the deadline. And if so, how will you deal with and solve this delay? Then, a revised planning came that met the deadline, which was possible technically. So it was solved. But a firm discussion was the basis for this.'' (contract manager pre procurement)
17	Managing uncertainty: Trust (VWS)	''We were very transparent and he got more feeling that we were in control. That increases trust from VWS that we are doing the right things.'' (contract manager pre procurement) ''I was lucky to have a good project team, both at the VWS and especially the RVB side. We clicked and trusted each other.'' (government client) ''I do not know why, but it is just true. I trust her, she trusts me. It worked because of that. We are ready to allow the other to enter our domain.'' (government client) '' I could decide much. That is also a way to deal with uncertainty. The project manager and I could make many decisions together. That has to do with trust, also trust from our superiors that we would not do crazy things. But I took many decisions without consulting my superior. Then you can reduce uncertainties quickly.'' (government client)
18	Managing uncertainty: ICT and construction	''I did this to protect the relations within our project. If I let him speak to the RVB, it was not pleasant. Very often, I was close to him to know about problems and issues. Then I communicated them with the project manager. You do not foresee such things, so I could not prepare for it. But I could position myself in a way that it would become a problem.'' (government client)
19	Managing uncertainty: Risk management	''Risk management was implemented in a very extensive way in this project'' (project manager) '' We were continuously busy with risk management.'' (risk manager)

		'' I think especially giving graphical insights into the risks helped to show how the project is doing overall.'' (risk manager)
20	Managing uncertainty: Control	'' One of the agreements was that we would not surprise each other. That really is something. If you are working as a contractor and you suddenly find out that someone is lagging behind for a month, you know that is not possible in this project. I never read such a thing in any report.'' (project manager) '' Off course! All formal meetings were there, processes for quality management, deviations etc. That is how we worked. The contractor sent his reports. Our contract managers would check if it was alright. All regular processes were there.'' (project manager) ''We had a very clear project structure. I would not say rigid. But there were clear workstreams and clear mandates.'' (government client) '' We assessed from a distance: How heavy are the risks in the process that needs to be controlled? And how confident are that the contractor controls that process. Based on that, we decided which processes are risky and we took action with an audit or interaction.'' (risk manager)
21	Managing uncertainty: Flexibility (contractor)	'' I think that the contractor was mainly invested in that. They were very flexible in the project. And not in a contractor-way. They were really busy with: Where can I keep people working? Wat can be delivered now? How do we keep progress? '' (project manager) '' Go speak to the contractor. They were doing SCRUM sessions on a daily basis to be able to adjust the planning.'' (government client) ''When a deviation is detected, sometimes we analyse the causes: how did they deviate from the contract? And we also enact control measures. It is a part of learning that belongs to quality management. That is with the contractor.'' (risk manager) ''We could attend the SCRUM sessions of the contractor. That way, we could follow the design process and quickly respond to requirements etc. '' (contract manager pre procurement)

22	Managing uncertainty: Flexibility (client)	'' And we did the same. We looked at: Things go wrong. Why did it happen? And how are we going to change our approach or how are we going to deal with this in the future?'' (risk manager) ''It is flexible, but with expertise'' (contract manager pre procurement)
23	Managing uncertainty: Control vs flexibility	'' You create firmness in order to be flexible. The firmness helps to know for sure that you can contact your boss or an advisor or have a meeting. That allows you to react flexibly to uncertainty.'' (government client)

Table 26: Quotes from the Turfmarkt case study.

Nr.	Theme	Quote
1	Uncertainty: Method	'' Many methods were not certified as a good method that meets quality standards. So also an uncertainty.'' (program manager) ''There are no rules or regulations regarding the method, so we do not know what method will suffice.'' (contract manager post procurement) ''But that method does not work in all cases. The extent to which it works was unknown to us. The contractor was too positive about it.'' (program manager)
2	Uncertainty: Installation	'' So if you mess with the floor, there is a chance that you hit something. So, uncertainty about positions and what is in the floor.'' (program manager) ''In practice, it turned out to cause many damages. Many times it went wrong, and they had to learn a lot on location on how to deal with it.'' (project manager)
3	Uncertainty: User	'' One part had to be supervised in order to control the load on the floor. In some situations, spaces had to be closed off for use.'' (program manager) '' And especially the uncertainty of the user is a challenge: How do you treat them? When is there space to work and how long do we have?'' (project manager)
4	Uncertainty: Price	'' That was something that popped up during the procurement phase. It really became an uncertainty as in: How can we get a price for the assignment without transferring all risks to the contractor.'' (contract manager pre procurement)
	Unknown uncertainty:	''Another risk I did not expect was that the contractor would experience so many issues with the contract form. And that it would cause so much work and unclarity.'' (contract manager post procurement)
5	Managing uncertainty: risk management	'' Well, the risk matrix was purely focuses on technology an not on other aspects.'' (contract manager pre procurement) '' We engaged in risk sessions with the users beforehand. Thereafter, we conducted risk sessions with the contractor. That is what we steer on. Each month, we discuss the risks.'' (contract manager post procurement)
6	Managing uncertainty: Dialogue procurement procedure	'' Not immediately transfer risks, but looking at: Can you really control the risks? That was discussed each time within the team.'' (program manager) '' In the dialogue, I emphasised on the risk that installations get hit. I saw that as a risk. Then they showed me statistics

		from experiences, which were actually relieving.'' (project manager) ''We also talked about: How are you dealing with the method you use? How are you dealing with the hindrance? How much noise are you going to make? When are you going to make noise? How are you dealing with installations that hinder your work? Are you going to bore in places where there may be pipes in the floor? And how do you prevent hitting a pipe in the floor?'' (contract manager pre procurement)
7	Managing uncertainty: Structured meetings	''It is important to be clear, to present, to explain your problem and have people think with you. And not be too much in a tunnel vision.'' (program manager) '' The users were very closely involved in the project. I am also meeting with the representatives every week to discuss what is coming.'' (project manager)
8	Managing uncertainty: Financial reserves	''Financially, we prepared for a certain uncertainty. It is a kind of risk.'' (program manager) '' We tried to estimate everything we knew in financial terms. And the things we did not know were included as a reserve.'' (project manager) '' I formed the reserve together with a cost advisor. We discuss what we encounter and think about what the contractor needs or is struggling with.'' (project manager)
9	Managing uncertainty: Control	'' Different experts helped us with the procurement documents. They looked at the building to identify risks and challenges. That way, we managed them beforehand and eventually we had plenary sessions to speak about risks extensively.'' (project manager)
10	Managing uncertainty: Flexibility	'''You have to be flexible with things that were not foreseen in the planning. Flexible with the parties you are working with. That is difficult sometimes. Continuously steering. And it cost more hours than we ever thought.'' (program manager) '' First, we deliberately went for control. But when the damages kept occurring, we decided to be more flexible and sit on the chair of the contractor.'' (contract manager post procurement) ''The dialogue procedure is leading in how flexible the procurement is. We also had an open attitude which helps. This is a new complex problem. We do not know how to deal with it. Help us. If we did not have these conversations, we would not know about the price issue. '' (contract manager pre procurement)

Table 27: Quotes from the JBO case study.

Nr.	Theme	Quote
1	Uncertainty: Channel bottom	'' The Julianakanaal is 100 years old. And what you encounter may be different than what is shown in drawings.'' (portfolio manager) ''They runned into problems each time. Most of the time it was leaks. And we do not know where those leaks are.'' (project control manager) ''The channel may not be restored properly or new leaks may arise. The water can escape right outside the edge of the channel, or sometimes hundreds of meters away from the channel. This can damage the environment considerably.'' (environment manager) ''There is limited data about the state of the channel bottom. And it is especially sensitive to leaking.'' (contract manager)
2	Uncertainty: Method	'' An important risk that plays now is: Is the method acceptable with regards to the shipping availability and safety?'' (portfolio manager) '' If you install sheet piles, there is a risk that the dikes collapse if the groundwater level is too high. And this level is high in one part of the channel.'' (project manager) '' The groundwater level is being monitored within the dike, outside the dike and in the hinterland. If the level rises, we suspect there is a leak.'' (project control manager) ''We have seen all kinds of risks occur in this project. In this last part, we looked at how to deal with the risks. The contractor made a plan with construction pits, which is the only way to prevent large leaks.'' (environment manager)
3	Uncertainty: Stakeholders	''It has a lot of impact on the environment, so stakeholders in the near environment have to be informed.'' (project control manager) ''The shipping has to continue, so we have to figure out ways to work on the channel and let ships pass. Not only the groundwater levels impact the environment, but also the vibrations or hindrance from construction processes.'' (environment manager)
4	Uncertainty: Flora and fauna	'' If we encounter a protected species, you cannot just pick them up and move them away. It takes time and money.'' (project control manager)
	Uncertainty: Dikes	'' The dikes were built 100 years ago. And although some works have been done on them, the ships are heavier nowadays. This creates more pressure on the dikes.'' (environment manager)

		''You can imagine when there is a high groundwater level in the dike, and you start installing sheetpiles, it creates vibrations which do not coincide well with a saturated dike.'' (contract manager)
5	Unknown uncertainty: Channel edge, translation waves and channel bottom	'' I think the role of the channel edge was underestimated in this project.'' (environment manager) ''The translation waves only play a role at construction pits near a lock. And there, we are investigating what the consequences are. We did not know about it in detail.'' (contract manager) ''It could be that a leak occurs regardless of the work of the contractor.'' (project manager)
	Managing uncertainty: procurement	''During the procurement with the new contractor, we explained our concerns extensively. The facts about the collaboration with the previous contractor, the facts about the state of the channel and the political environment. We included that in documents and contracts, but also in the competitive dialogue.'' (project manager) '' That led to openness. If you see a risk, whether small or large, there is always room to discuss it. We want to reach the finish line together. So we really found each other. Not only a client-contractor relationship, but really a collaboration.'' (project manager)
5	Managing uncertainty: Risk management	'' Each two weeks, we meet with the contractor's team on site to discuss risks and new discoveries. They do not even have to be risks, but we are managing them.'' (project control manager) '' We regularly have risk sessions where we share our top 5 and top 10 risks with each other.'' (project manager) ''The risk sessions are important. Asking detailed questions about: *What are you going to do if..?* I think adequate protocols and scenarios have to be written. With leaks, it means having pumps and clay material at the site to solve leaks quickly.'' (environment manager) ''You also have the regular risk management. So we have a risk register and system-based contract management, which we use to control risks periodically and to adjust the risk register.'' (contract manager)
6	Managing uncertainty: Reserves	''We use a p85 planning. If we do not control some risks, the end date is later. You cannot always control risks.'' (project control manager)

		'' Regarding the areal of the channel bottom, we work in scenarios and reserve money for the risks that can occur, next to the control measures.'' (contract manager) '' Next to the reservation for risks, we have a reservation for unforeseen-unforeseen. We use both in this project.'' (project manager) ''But we know it is not enough. We had a lot of hassle with the pilot, where a complaint was initiated by the shipping industry. That took us 2 years of delay. Then there was a leak that was supposed to be repaired by the previous contractor. These are all things that costs extra time and the reserve is depleted quickly.'' (contract manager)
7	Managing uncertainty: Stakeholders	''We are continuously meeting stakeholders on different levels. In June, we will meet with representatives of the organisations on site.'' (portfolio manager)
8	Managing uncertainty: Expertise	''One of the most important requirements is expertise at Rijkswaterstaat and the contractor. People make the difference in such large projects.'' (Portfolio manager) ''The contractor is specialised in such works. And the people that work on this project have much experience, so there is a kind of automatism to shift quickly to tackle problems.'' (project control manager)
	Managing uncertainty: Investigations	'' We have standard investigations for cables, pipes, flora and fauna and explosives. A bureau tries to track where these things may be located. After that, there is a risk that remains, for which we use control measures and protocols if they occur.'' (environment manager) '' The groundwater levels are being monitored in the area, the dikes and the shores. So it could be that we need more clay to close leaks. But we are investigating and monitoring that.'' (project manager) ''We have inspections going on on the work of the previous contractor. That also leads to some rework. '' (contract manager)
	Managing uncertainty: Involving decision-making	'' If something huge happens, there are different levels of crisis that we can enter into. Then, we have to listen to the crisis organisation.'' (environment manager) '' Also in the collaboration with the internal organisation of Rijkswaterstaat and the ministry, we keep talking to them about risks and concerns.'' (project manager) '' We (Rijkswaterstaat and the contractor) know that this project is sensitive. That means you meet a lot at the table and be lenient towards the contractor to prevent hassle. That is on the level of the portfolio manager.'' (contract manager)

9	Managing uncertainty: Control	'' I think our standard approach is control, regarding the risks that can be controlled.'' (portfolio manager) '' We mentioned the risks or uncertainties in the procurement phase, and we keep asking about them and evaluating them.'' (project manager) ''I think within Rijkswaterstaat, we mainly aim for control. It is important to have risk sessions with the contractor and share each other's risks. And the protocols so that if something happens, we know what to do.'' (environment manager) ''Control is what I just said, we do this standard. We think about risks and control measures beforehand. And we reserve the budget for it.'' (contract manager)
10	Managing uncertainty: Flexibility	''Flexibility lies more in the risks that cannot be quantified or controlled.'' (portfolio manager) '' We have the fluidness so that when something happens, we can look at how to deal with it. That is why we have an amount of money set aside for unforeseen situations.'' (project manager) '' We try to keep the flexibility. Before procurement, we looked at three scenarios regarding the construction methods, safety, risks and costs. We do not look at one way only.'' (project control manager) '' The flexible way may be more suitable on a smaller project, but it is not do-able on such a large project.'' (environment manager) ''The pilot is an example. We thought about coaching the ships day-to-day, adjusting the maximum speed and constructive measures in the construction pit. These are all scenarios we are considering.'' (contract manager)

Table 28: Quotes from the REH case study.

Nr.	Theme	Quote
1	Uncertainty: Development and integration of tunnel systems	'' If you proceed with the development and notice that some things were not sliced well, you have to do rework.'' (contract manager) ''Next to the regular maintenance, we are doing an ICT development project. Such projects are characterised by uncertainty. We do not know if it will be finished in time.'' (project manager tunnel systems) '' The big uncertainty is: Will it fit together? The renovation and the development of tunnel systems.'' (project manager) '' We came up with the measure to drop parts of the development of ICT systems if they cannot be finished in time. Then we proceed with what we have.'' (project manager tunnel systems)
2	Uncertainty: State of the tunnel	'' Our areal is not completely correct. We continuously discover things that are different from what we expected.'' (contract manager) '' In a renovation, it is always the question what you encounter outside. Parts of the tunnel are being replicated to see how they are put together. But you still do not now what to expect in the real situation.'' (project manager) '' The fire extinguishing system did not have enough water pressure and some components were contaminated. This resulted in a huge amount of additional work and costs. '' (project manager tunnel systems)
3	Uncertainty: Permits	'' Tunnels became more complex, also in regulations. There is uncertainty in whether we receive the permits.'' (contract manager) '' The permits are also thrilling.'' (project manager)
4	Uncertainty: Stakeholders	''There are municipalities, businesses and users. Projects in the environment are also stakeholders.'' (contract managers)
5	Unknown uncertainty: Material prices	'' I think the material prices are a big uncertainty in this project.'' (project manager)
6	Unknown uncertainty: Capacity	'' We do not know if we will have enough qualified people throughout the project.'' (project manager)
7	Uncertainty: Middle tunnel channel	'' We are going to build a middle tunnel channel in an existing tunnel, which has never been done before. We shall see if it fits in the agreed time-frame.'' (project manager tunnel systems) '' Within three weeks of time, we have to construct a wall of 600 meters long which is collision proof. That is an uncertainty.'' (contract manager)

8	Managing uncertainty: BPKV plan	''If the contractor does not conduct the work according to the plan for which we determined the price, we will re-evaluate the plan. If the plan is worth less, the difference becomes the fine.'' (contract manager)
9	Managing uncertainty: Dialogue procedure	'' In the dialogue phase we have the first conversations with the contractor to see if they understood us.'' (contract manager)
10	Managing uncertainty: Risk management	''After selection of the contractor, we share our risk registers and discuss them. We combine our knowledge and skills.'' (contract manager) '' We challenge people in the IPM team to deal with with risks and control measures.'' (project manager) '' In procurement, we shared our risk register with the contractors and we asked them to think with us about the integration of the ICT systems with the renovation.'' (project manager tunnel systems) '' Having conversations about risks with the contractor and keeping the risk register up to date on a regular basis is our main way to manage uncertainty. '' (project manager tunnel systems) The core lies in the meetings where risks are on the agenda. In fact, all risks are continuously on the agenda.'' (contract manager)
11	Managing uncertainty: Budget reserve	'' We do not only reserve money for the risks that we see, but also for unforeseen circumstances. In principle, that suffices, but sometimes there is tension.'' (contract manager)
12	Managing uncertainty: Involving decision making	'' We asked for extra mandate to deal with the environment, the tunnel systems and with people. That helps to speed up the procurement process and have enough people. It reduces the chance of unpleasant surprises.'' (project manager tunnel systems) '' Sometimes you can solve things yourself. But sometimes, you need others. You have limited room to do things.
13	Managing uncertainty: Control	''That is looking at all opportunities to mitigate the risks. Continuously thinking and steering.'' (contract manager) '' I am mainly invested in control. Controlling as much as possible up front. If something unexpected happens, you have to deal with that differently. It is difficult, because if you control risks, you never know if it would have happened if you did not control it. It makes control unthankful, but I think that is the way to go.'' (project manager) '' We mainly aim for control. For the tunnel systems, we also arrange external and independent monitoring of the project to know which parts can be transferred on time and which

		not. That is reported to the steering group to increase confidence.'' (project manager tunnel systems)
14	Managing uncertainty: Flexibility	'' If something happens, we know from experience what we should do. Who is in the lead and who takes what on his lap. It is about how the IPM team functions as a whole.'' (contract manager) '' We do not have that actually. We changed our approach for the tunnel systems, but it was more to increase proximity and steer on it.