Underlying Mechanisms for Managing the Cost of Rework Related to Constructability from a Dutch Design and Engineering Firm Perspective

Master thesis report

J.J. Schutte

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PREFACE

This document, titled 'Underlying Mechanisms for Managing the Cost of Rework Related to Constructability from a Dutch Design and Engineering Firm Perspective' is my master thesis. The thesis aims to identify the underlying mechanisms for managing the cost of rework related to constructability in Dutch marine infrastructure projects.

This thesis is conducted to obtain the degree of Master of Science in Construction Management and Engineering at Technical University Delft, faculty of Civil Engineering & Geosciences. This thesis has been made possible with the collaboration of the company WSP. The research was performed between May 2020 and April 2021. The COVID-19 pandemic covered the entire research period, which resulted in online meetings and working from home. However, technologies such as Microsoft Teams and continued motivation enabled the progress and completion of the thesis.

I could not have completed this thesis without a strong support group. First, my graduation committee members at the Technical University Delft, Professor Paul Chan and first supervisor, Marian Bosch-Rekveldt, and second supervisor, Aad van der Horst, provided excellent advice. They taught me valuable lessons, feedback and guidance throughout the research process. Second, my supervisors at WSP, namely Fokke Westebring and Maurice de Kroon, provided guidance, advice and help throughout the research process. Thank you all for your much-appreciated support. In addition, I am grateful to all of the respondents, without whose cooperation I would not have been able to conduct this research.

Lastly, I am thankful to my parents, family, and girlfriend for supporting me with understanding, motivation, and love.

Jordy Schutte

Zwijndrecht, April 8, 2021

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SUMMARY

This research aims to identify the underlying mechanisms of the cost of rework related to constructability in Dutch marine infrastructure projects. Despite extensive previous research on the cost of rework, and constructability, the underlying mechanisms within executed projects in the Netherlands have not yet been observed from research. Notwithstanding the thorough previous research, indicates a need to identify the prevailing underlying mechanisms. This research addresses the following main question:

What are underlying mechanisms for managing cost of rework related to constructability in Dutch marine infrastructure projects?

The known underlying mechanisms for managing the cost of rework related to constructability were derived from the literature. These mechanisms were verified and extended through exploratory semi-structured interviews. The interviewees were senior experts from a client company, a design and engineering firm, and a contractor. Besides, the applied and unapplied mechanisms in Dutch marine infrastructure projects were observed from two case studies. The case studies included further semi-structured interview sessions.

The literature review identified 38 known prerequisites or must-have mechanisms to include constructability in a project. However, the perceptions of constructability were not easily described in words in the interviews. The client, contractor, and consultant interviewees did not align the characteristics to define constructability. The contractor's perceptions were broader than those of the design and engineering expert's or the client's perceptions. Nonetheless, the interviewees indicated 32 mechanisms. Most (21) were already known from the literature, but 11 additional mechanisms were suggested in the exploratory interviews.

The case studies resulted in applied and unapplied mechanisms in executed projects. These mechanisms were analysed across the cases and compared and aligned with the literature review and exploratory interviews.

The findings from the three sources introduced themes regarding the mechanisms for constructability inclusion. The themes included a set of related mechanisms, which addressed the main research question. The inclusion and application of these themes in the project could minimise the cost of rework related to constructability in Dutch marine infrastructure projects. The identified themes were as follows:

- Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products.
- Inclusion of experienced expertise or knowledge (early) in the process.
- Awareness of human contributions or obstruction to changing, learning, improving, innovating, and performing in teams.
- Stick to the plan and process by all stakeholders after awarding.
- Awareness of the obstacles in the competitive market, without reimbursement for additional effort or ideas.

The answer to the main research question is provided in an overview of the most relevant themes and must-have mechanisms in Figure 1. The most pertinent themes caused the changes and rework observed in the case studies and are indicated as manageable by the design and engineering firm. This overview includes known must-have mechanisms and newly identified or operationalised must-have mechanisms, as indicated by the term 'new'.

Inclusion of experienced expertise or knowledge (early) in the process

- Presence of experienced expertise or knowledge in the initial stages of the project to transfer construction knowledge and experience
- Using experts experienced in the field of designing

Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products

- Learn from mistakes or previous experiences
- Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all of the team members
- Reviewing plans and presenting feedback to designers
- NEW: Substantiation of design assumptions
- NEW: Paying attention to handover of models, documentation, information and knowledge
- NEW: Early checking and on-going verification of assumptions, standards, calculation methods or other essential parts of the calculations
- NEW: Information shared fully with the entire organisation

Stick to the plan and process by all stakeholders after awarding

- NEW: Ensuring the input remains constant (right person at the table)
- NEW: Stick to the plan
- NEW: Prevention of modifications in the project teams
- NEW: Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management

Figure 1: Prioritised manageable must-have mechanisms to include constructability in a design and engineering firm

Limitation of the research were only two case studies, digital interview sessions, and missing quantification of the mechanisms' contributions and relevance. Some interesting results from this study were the unwillingness to learn, improve, and share previous insights and experiences of person in the Dutch marine infrastructure sector. This reluctance indicates the complexity of the subject of constructability. The diverse perspectives, current market developments of the project approach and contracting, and the human contribution and obstruction were additional findings of this research.

The recommendations for practice align with the answer to the main research questions. The most relevant recommendation for practice is the application of the manageable must-have themes including the underlying mechanisms. Recommendations for further research are 1) to test the validity and causes of the newly identified mechanisms; 2) to identify individual contributions and obstructions to the project, and 3) to quantify the effect of the mechanisms on scope, time, money, quality, personal health, and safety.

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LIST OF ABBREVIATIONS

BIM	Building Information Model
CoGQ	Cost of Good Quality
CONQ	Cost of Non-Quality
CoPQ	Cost of Poor Quality
CoQ	Cost of Quality
D&C	Design and Construct
DBFM	Design, Build, Finance and Maintain
INCOSE	International Council on Systems Engineering
RAW	Rationalisatie en Automatisering Grond-, Water- en Wegenbouw
UAV-GC	Uniforme Administratieve Voorwaarden voor Geïntegreerde Contractvormen
VTW	Verzoek tot wijziging (RFC – Request for Change)

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CHAPTER

1

Introduction

1 INTRODUCTION

Constructability and buildability have been the focal points of many studies since the early 1960s (Kifokeris & Xenidis, 2017). However, the topic of constructability was formally introduced in 1986 by the Construction Industry Institute. Constructability is generally defined as the optimum use of construction knowledge and expertise in the conceptual planning, detail engineering, procurement, and field operations phases to achieve the overall project objectives (Construction Industry Institute, 1986).

Previous research has elaborated on several sectors, such as the building environment and heavy industry. The marine infrastructure sector, which falls under civil engineering, has not been investigated extensively. More recently, various researchers have summarised and aligned future objectives for research on constructability and the cost of quality issues (Dimitrantzou, Psomas, & Vouzas, 2020; Kifokeris & Xenidis, 2017; Schiffauerova & Thomson, 2006).

1.1 PROJECT LIFECYCLE

Projects follow a sequence of phases from starting to end, referred to as the project life cycle (Nicholas & Steyn, 2017) or system life cycle. The life cycle describes the project as a system. The term 'system' refers to ‘A set of interrelated elements working together towards some common objective’(Nicholas & Steyn, 2017). The system life cycle is associated with the INCOSE life cycle of systems as defined in norm ISO-15288. The system life cycle stages are described as follows: concept, development, production, utilisation and support, and retirement.

Constructability is part of the entire project life cycle, although its level of influence changes over time. The concept stage has a significant influence on the project, whereas the production stage has less influence. The project expenditures vary; the concept stage includes low expenditure, and the production stage incurs high expenditure. The pre-construction phase is notably shorter than the construction phase but it has the most substantial influence on cost overruns (Cantarelli, van Wee, Molin, & Flyvbjerg, 2012). This phenomenon is shown in Figure 2. In the MacLeamy curve on the right figure, the flexibility and costs of design changes are shown as lines, and the traditional design workflow is shown in the area shaded in pink.

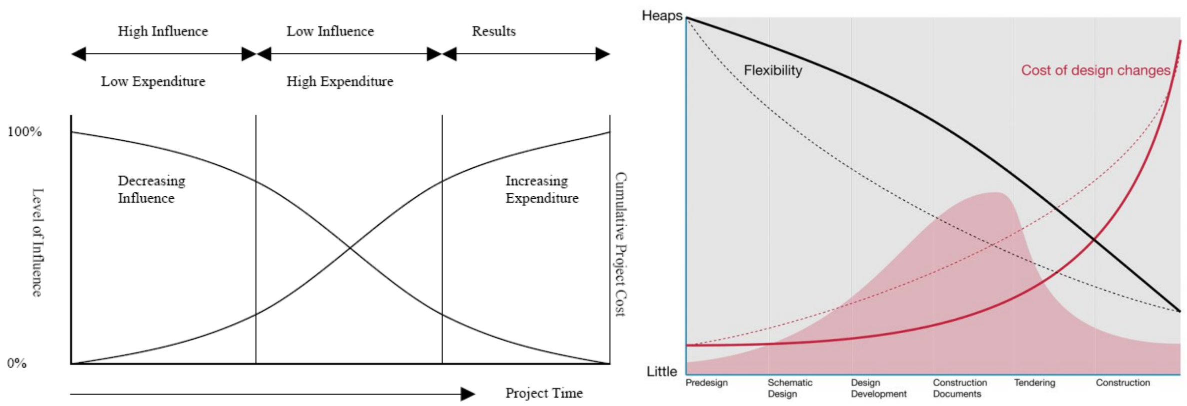

Figure 2: Level of influence related to project costs(Zolfagharian, Nourbakhsh, Mydin, Mohamad zin, & Irizarry, 2012) and Macleamy curve (Davis, 2016)

1.2 CONTRACT MODELS

The Dutch marine infrastructure sector involves both small and large projects, with different contract types. The traditional design-bid-build contract separates the design and execution stages of the project. In the Netherlands, several building contract models exist: the traditional model, the model of early contractor involvement, the integrated model, and the alliance model (Chao-Duivis, Koning, & Ubink, 2008). The last three models include the early participation of the contractor.

The traditional model is characterised by a classical triangle comprising the client, the design and engineering firm, and the contractor. This model positions the client in the customer's role, the contractor as the supplier, and the engineering firm as an adviser. According to Odeh and Battaineh (2002), calls have been made to improve the traditional building contract model. Love, Edwards, Watson, and Davis (2010) concluded that rework costs did not vary significantly among procurement methods for civil infrastructure projects. The applied definition of rework is 'the total direct costs of re-doing work in the field regardless of the initiating cause'.

1.3 PROJECT SUCCESS AND PERFORMANCE

Project success is the aim of every project. Such success is judged according to specific pre-determined criteria. The most common approach is a three-dimensional concept involving the dimensions of cost, time, and scope (Turner, 2009). Literature and practitioners often call this concept the 'project triple constraint' (Cuellar, 2010) or the 'iron triangle' (Atkinson, 1999). Alternatives to these descriptions include, for example, the exchange of scope for requirements (Nicholas & Steyn, 2017). Project success should be measured within the constraints of scope, time, cost, quality, resources, and risks (Rose, 2013). Traditional performance measures are necessary to examine, such as time and cost, and the project team members' satisfaction (Love & Edwards, 2004a).

The different ways of describing project success imply a lack of standardised definition of the term. The actual performance is often lower than the target, which results in a performance gap. This gap indicates the need for performance improvement (Turner, 2009). In the Netherlands, cost overruns are an area in which projects do not achieve their maximum potential (Cantarelli et al., 2012; Love, Ahiaga-Dagbui, & Irani, 2016). This performance gap, identified by Turner (2009), is a concrete problem, according to a knowledge session of the Port of Rotterdam Authority. That knowledge session was focused on constructability and buildability in design and was arranged in November 2019. The session indicated the need and urgency to improve constructability in Dutch marine infrastructure projects.

1.4 CONSTRUCTABILITY AND COST OF QUALITY

Before the knowledge session at the Port of Rotterdam Authority, Josephson and Hammarlund (1999) had identified constructability as the leading cause of rework. In current projects in the building engineering sector, constructability is one of the top reasons for rework (Balouchi, Gholhaki, & Niousha, 2019; Yap, Low, & Wang, 2017). However, research on maritime infrastructure projects has not clearly identified the underlying mechanisms associated with the cost of quality. Nevertheless, it is assumed that constructability is a main cause. Insufficient inclusion of constructability can decrease the quality of projects, which results in additional costs. These costs are discussed in literature as the cost of quality (CoQ), a concept introduced by Juran (1951). The definition of CoQ is usually understood as the sum of both conformance and non-conformance costs (Schiffauerova & Thomson, 2006).

The CoQ model provides insight about the partial contributions of various elements. The behaviour of these elements can be examined with mathematical models. According to Plunkett and Dale (1988), several different models of quality-cost relations are identifiable.

The concepts of constructability and CoQ have both been researched extensively in the past in many countries. Examples of such research are the contribution to rework in civil engineering in Australia

(Love et al., 2010) and the variables that cause rework in Spain (Forcada, Gangolells, Casals, & Macarulla, 2017). The civil engineering sector has been investigated, but not widely in the Netherlands. The joint concepts of constructability and CoQ have not yet been examined. Cantarelli et al. (2012) stated that awareness should lie on the pre-construction phase when attempting to find causes and solutions regarding cost overruns, at least for the Netherlands.

This research focusses on avoidable and preventable failure costs. The minimisation of manageable failure costs is represented in Figure 3. This figure illustrates the current and future distribution of the internal and external failure costs and appraisal and prevention costs. The reduction of internal failure costs is within the scope of this research, but the distribution compared to the other aspects is not considered.

Almost all forms of rework are preventable (Love, 2002b). Preventable rework leads to actual failure costs as part of the cost of poor quality (Schiffauerova & Thomson, 2006). The knowledge session discussed earlier revealed manageable failure costs that contribute to CoQ; these manageable costs are essential for reducing the CoQ. By contrast, non-manageable failure costs, such as additional costs from the COVID-19 pandemic, must be accepted.

Manageable causes for rework have been identified in previous studies. Taneja (2019) defined 124 leading indicators for reworking or changing the order in construction. Based on that research, 32 manageable indicators were defined that can be managed with best practice strategies by the Construction Industry Institute (CII) (Safapour & Kermanshachi, 2019). These indicators are used to determine the manageable underlying mechanism to improve constructability within maritime infrastructure projects.

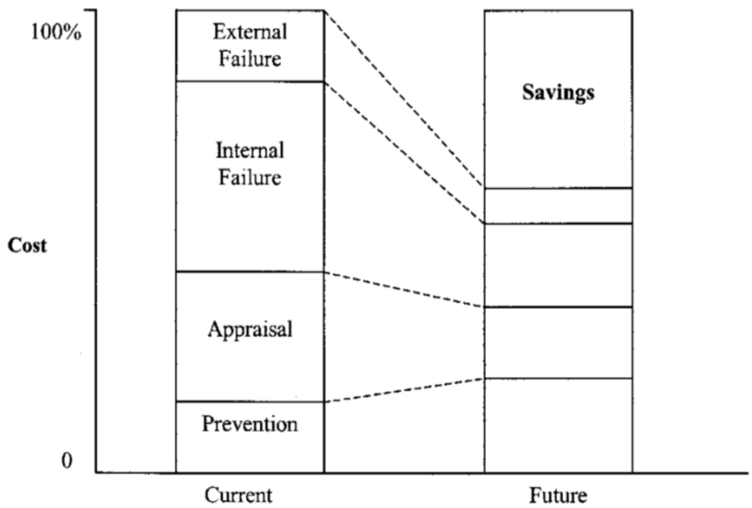

Figure 3: Graphical representation of the future relations within the COQ (Love & Li, 2000)

1.5 GRADUATION COMPANY: WSP

The research is done at WSP as the graduation company. WSP is a multidisciplinary consultancy and engineering firm in the sectors of construction, infrastructure, water, and the environment (Lievense, 2020). Lievense was founded in 1964 and was taken over by International Company WSP in 2019. During the course of this study, the company's name was changed to WSP.

WSP Netherlands is spread across ten offices, with a total of 375 employers in the Netherlands. The company department for supervision is the Waterbouw section in the infrastructure department. WSP Netherlands is an engineering consultancy firm that provides engineering services to clients and contractors in the Dutch marine infrastructure sector. These services are delivered through an integrated contract model as well as through traditional contract models.

1.6 STRUCTURE OF THIS REPORT

This chapter concludes with a brief description of the thesis. The structure of the report and its relationship to the research question is displayed in Figure 4. The first part of the thesis is the introduction, which consists of this chapter and the next. The second chapter introduces the research design, research objective, research type, research questions, motivation and relevance of the research, the methodology, and type of data.

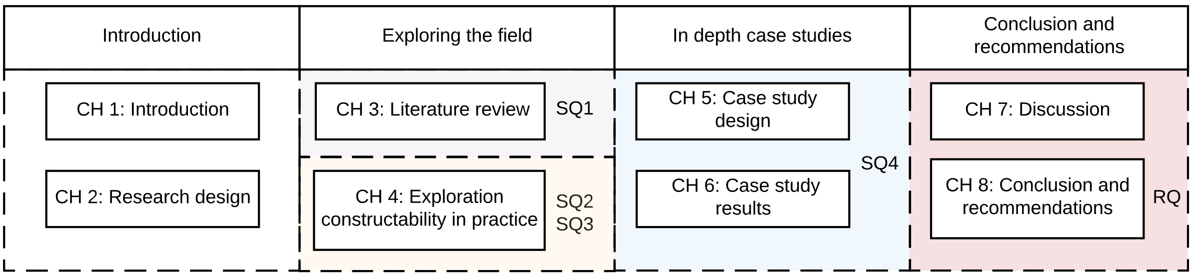

Figure 4: Report structure (own illustration)

The third and fourth chapters explores the field. Previous and current views of CoQ related to constructability in literature are elaborated in the third chapter. The literature review includes a description of the methodology, the concept of constructability, and the concept of CoQ. Then, the connection between constructability and CoQ is explained. Identifying underlying mechanisms of rework, measures to improve constructability, and concluding remarks are focus points of the third chapter.

Chapter 4 explores constructability in practice. This chapter elaborates the interview setting, the characteristics of the interviewees, and the interview results. It concludes with a comparison to the literature review.

The findings of the research are elaborated in Chapters 5 and 6. The fifth chapter describes the case study design and elaborates on the case study approach, case study protocol, and selection of cases. In Chapter 6, the case study results are presented and compared and aligned with previous findings.

The final part of this thesis addresses the findings in the discussion in Chapter 7. The conclusion and recommendations are presented in Chapter 8, and the references are listed in the reference list.

CHAPTER

2

RESEARCH DESIGN

2 RESEARCH DESIGN

The questions of 'what', 'why', and 'how much' are described in this section. The structure of this chapter is adopted from Verschuren, Doorewaard, and Mellion (2010), with a conceptual research design consisting of four elements. The first element is the research objective, described in Section 2.1, including the research type. The second element is the research question and an explanation of the sub-questions, in Section 2.2. In addition to these elements from Verschuren et al. (2010), the motivation and relevance of the research are presented in Section 2.3. The methodology section (Section 2.4) includes the research approach and strategy and the gathering of data.

2.1 RESEARCH OBJECTIVE

Research associated with constructability and CoQ is not new for the field. Literature reviews have been conducted on these topics; for example, Dimitrantzou et al. (2020) indicated that 94 articles related to CoQ were published between 2010 and 2018. The usability and verification of constructability are timely because of the complexity of modern projects; however, the concept has been researched and reconceptualised over the last five decades (Kifokeris & Xenidis, 2017). The current study focuses on the lack of contribution regarding constructability, which lowers project performance and results in a performance gap.

The goal of this research is to identify the underlying mechanisms of the cost of rework related to constructability in Dutch marine infrastructure projects. These underlying mechanisms are examined for potential improvements in projects. The currently known mechanisms were derived from literature, and perceptions of constructability and additional known underlying mechanisms were probed in exploratory interviews. The underlying mechanisms were further examined in a case study of two Dutch infrastructure projects. This practical addition, in combination with the theory, identified potential improvements to minimise the cost of rework related to constructability in Dutch marine infrastructure projects.

2.2 RESEARCH QUESTION

The combination of constructability and CoQ in a Dutch marine infrastructure project leads to interesting research opportunities. The main research question in the current work is as follows:

What are underlying mechanisms for managing cost of rework related to constructability in Dutch marine infrastructure projects?

The following sub-questions support the main research question:

SQ 1 Which underlying mechanisms for managing the cost of rework related to constructability are known?

SQ 2 What are the perspectives of clients, contractors, and design and engineering firms regarding constructability, in the context of traditional contracts?

SQ 3 Which underlying mechanisms regarding managing the cost of rework related to constructability are observed in exploratory interview?

SQ 4 What variables are associated with the cost of rework related to constructability in executed projects in the Dutch marine infrastructure sector?

SUB-QUESTION 1

The first sub-question examined the nature of constructability, CoQ, and the cost of rework. The identification of the terms and the relationship between the definitions provides a literature basis. The currently known underlying mechanisms for managing the cost of rework related to constructability were thus obtained, while clarification of the definitions and the known underlying mechanisms are derived from the literature.

SUB-QUESTION 2

Perceptions related to constructability, from the perspective of the client and the contractor, are unclear for the Netherlands. Such perceptions contribute to people's interpretation of contract documents and handovers. Previous research has examined perceptions about rework (Love et al., 2010), barriers to constructability in the early 1990s (O'Connor & Miller, 1994), the causes of construction delay (Odeh & Battaineh, 2002), and familiarity with the concept of constructability (Uhlik & Lores, 1998).

Consumers' needs and wishes must be researched and identified so that products and services can be designed to provide better living in the future (Deming, 2018). The implications of consumer needs and wishes can indicate perceptions to inform suitable products. These perceptions in the Netherlands have not been the focus of previous research; in this study, they were probed through interview sessions with the employees of a client, contractor, and engineering firm.

SUB-QUESTION 3

The underlying mechanisms for managing the cost of rework related to constructability were observed in exploratory interviews. The interviews were conducted with experts who had extensive experience in Dutch marine infrastructure projects. The results of interviews provided a large sample of underlying mechanisms that were identified.

SUB-QUESTION 4

The answer to the fourth sub-question was based on case studies. Two case studies were applied to define the prevailing mechanisms in executed projects. They included interview sessions with the client, design and engineering firm, and contractor. The mechanisms were then compared with the results from the literature and exploratory interview sessions.

2.3 MOTIVATION AND RELEVANCE OF THE RESEARCH

Personal motivation is described in Section 2.3.1, and the motivation of the graduation company is described in Section 2.3.2. The societal and scientific relevance is addressed in Sections 2.3.3 and 2.3.4.

2.3.1 PERSONAL MOTIVATION

The author's personal motivation for optimising CoQ related to constructability is derived from his educational background. This research is the capstone of the Master of Construction Management and Engineering programme, sequentially completed after the accomplishment of the Bachelor of Applied Science of Civil Engineering programme. This practice-oriented educational form results in a practical, driven mindset. Beyond education, the author is familiar with civil engineering and marine infrastructure projects. This experience started before the author could even define civil engineering. Several of his family members work in the Dutch marine infrastructure sector and the author's interest and motivation thus began in childhood.

The specific motivation for optimising and gaining knowledge about perspectives and novel procedures, techniques, and methods came from the master courses related to process and project management. Electives like 'Business Process Management and Technology' and 'Technology, Strategy, and Entrepreneurship' also contributed.

2.3.2 MOTIVATION OF THE GRADUATION COMPANY

WSP's motivation for this research is focused on optimising the output delivery of clients and contractors in engineering services. Work output is not optimised in most cases, according to the Head of the infrastructure department. Several critical indicators can be determined, but the actual influence on projects is unknown and varies. WSP provides engineering services to all kind of clients, whether private or public, and their revealing contract models.

2.3.3 SOCIETAL RELEVANCE

Optimising costs in any manner is relevant for all parties involved in any sector. Besides the tangible factors of cost, time, and scope, intangible factors – such as the loss of reputation – should not be underestimated (Schiffauerova & Thomson, 2006). The entire supply chain could benefit if the CoQ related to constructability is optimised. The client procures projects with an optimal price and executability. The contractor then delivers the project within the constraints of the optimal price, and the engineering firm delivers the services.

2.3.4 SCIENTIFIC RELEVANCE

The projects included in this research were both traditional and integrated contracts, according to the research recommendations of Uher and Toakley (1999). Kifokeris and Xenidis (2017) concluded that the implementation of novel methodology and automation of constructability tools were areas for future research. Dimitrantzou et al. (2020) provided an overview of research suggestions based on prior research. The difference between designers and contractors, and their engagement in the design process to optimise the constructability input, was a further research area suggested by Pulaski and Horman (2005). However, these studies have mainly focused on other industries and non-Dutch countries. Hence, there is a need to investigate the marine infrastructure sector within the Netherlands.

2.4 RESEARCH METHODOLOGY

The research methodology is informed by the definitions of Verschuren et al. (2010). The elements of research approach, strategy, and data gathering are elaborated in Sections 2.4.1 and 2.4.2.

2.4.1 RESEARCH APPROACH

A qualitative research approach was applied in this research. Qualitative research fits the research goal of identifying the underlying mechanisms of the cost of rework related to constructability in Dutch marine infrastructure projects. These underlying mechanisms are not easy to interpret as number and figures. This difficulty in counting and calculating indicated the project's qualitative nature and the need to observe, compare, and interpret the results.

2.4.2 RESEARCH STRATEGY AND GATHERING DATA

Verschuren et al. (2010) described five major research strategies. These strategies informed the selection of a research approach and question. The five strategies are survey, experiment, case study, grounded theory approach, and desk research. The research approach selected was qualitative, as indicated above. The research questions are answered by findings from the literature, interviews, case study, and practical experience and knowledge.

The first sub-question entailed a literature review; hence, literature survey was the first strategy applied to this first sub-question. This strategy was chosen to review previous findings on constructability and CoQ. The literature was stored in a reference manager called Endnote to categorise and track the literature investigated. Literature retrieval was based on keywords and synonyms for words or phrases related to constructability and CoQ. The data were stored and categorised in Endnote by subject and relevance, ranked according to the number of citations in follow-up research.

The second sub-question examines the perceptions of constructability. These perceptions were probed through interviews with Dutch experts, and the answer to the third sub-question was also sought through the interviews. The underlying mechanisms of rework or changes in Dutch marine infrastructure projects were examined. Interviews with experienced experts were chosen instead of a questionnaire so that follow-up questions or clarification could be asked. The interviewees' experiences provided the basis for answering the question about perceptions of constructability. The interviews were semi-structured and held in-person and were recorded with the approval of the interviewee to verify the observations.

The fourth and final sub-question involves the manageable underlying mechanisms related to constructability, as observed in executed projects. The variables driving the rework or changes related to constructability were determined and investigated using the case studies of two executed projects in the Dutch marine infrastructure sector. The application of a case study fulfilled the need to identify these variables of rework and changes related to constructability. The determination of causes required more depth than breadth, which fits the case study strategy. The case study design, including data gathering, is described in Chapter 5.

CHAPTER

3

EXPLORATION OF LITERATURE

3 EXPLORATION OF LITERATURE

This chapter details the previous and current views of CoQ related to constructability. The leading causes of non-optimised CoQ are described in the exploratory literature review. Furthermore, various views of constructability are discussed. The methodology of the exploration chapter is described in Section 3.1, and the literature review on constructability is described in Section 3.2. Section 3.3 covers literature that addresses the concept of CoQ. The relationship between the concepts of constructability and CoQ is described in Section 3.4, and the underlying mechanisms for rework are defined in Section 3.5. Finally, Section 3.6 presents the current measures to improve constructability.

3.1 METHODOLOGY OF THE LITERATURE REVIEW

The purpose of this section is to examine the previous research related to the objective of the current study. This review of literature demonstrates a research gap that this study addresses. First the definitions of constructability and CoQ are given; then, their relevance to this research are illustrated. The current perceptions of constructability in literature are another element of this literature review.

The relevant literature was assessed using the search engine Google Scholar and the TU Delft repository. The search terms used to obtain relevant literature were as follows: 'constructability', 'buildability', 'constructability improvements', 'improve constructability', 'rework', 'causes of rework', 'rework causes', 'manageable rework', 'project success', project performance', 'triple constraint', 'traditional contract', 'cost of quality', 'quality costs', 'cost of poor quality', 'COQ', 'CONQ', 'COPQ', and 'COGQ'.

3.2 CONCEPT OF CONSTRUCTABILITY

The concept of constructability has been a topic for many studies since the early 1960s (Kifokeris & Xenidis, 2017), as mentioned in the introduction. Since the early 1960s, many definitions of constructability arose. This section contains a summary of constructability definitions and identifies the most suitable definition of constructability for this research.

3.2.1 DEFINITION OF CONSTRUCTABILITY

As described by Kifokeris and Xenidis (2017), constructability has been studied for the last five decades. Recent research has presented a thorough literature review of constructability. However, the term 'constructability' has different meanings within the field of construction. The concept of constructability as such is the basis for other meanings of the term.

Constructability is commonly understood as 'the optimum use of construction knowledge and expertise in the conceptual planning, detail engineering, procurement, and field operations phases to achieve the overall project objectives' (Construction Industry Institute, 1986). From its first conception, constructability has had many new definitions, based on individual project needs and requirements (Jergeas & Put, 2001). The concept of constructability is thus a relative rather than absolute term. Its value lies in increasing the optimisation capacity of resources – such as workforce, time, costs, quality, and working environment conditions (Jadidoleslami, Saghatforoush, & Zare Ravasan, 2018). 'Buildability' is used synonymously with constructability. However, buildability is an integral part of constructability, because buildability is only encountered to construction efficiency in the design phase and constructability covers all project phases (Kifokeris & Xenidis, 2017; Wong, Lam, Chan, & Shen, 2007).

According to Wong et al. (2007), there are 13 main definitions of constructability and seven for buildability provided in previous research. However, the definition from the Construction Industry

Institute, given above, provides the basis for many other notations and is most widely accepted. Hence, that definition is used in this study.

3.2.2 CONSTRUCTABILITY APPLICATION

The second meaning is a best practice to improve the performance of the projects (Safapour & Kermanshachi, 2019). This best practice can also be explained as the application of the concept of constructability as described by O'Connor, Rusch, and Schulz (1987). Such application and best practice are incorporated in so-called constructability programmes. These programmes integrate engineering design, executive knowledge, and experiences to achieve better performance in projects (Jadidoleslami et al., 2018).

Constructability is one of the techniques that connect the implementation and construction phase to the design and planning phase (Samimpey & Saghatforoush, 2020). The connection between these two stages provides a direct link between the consultancy and engineering firm and the contracting firm. Constructability can thus be influenced across the entire project life cycle, as evident in the link between these stages.

Arditi, Elhassan, and Toklu (2002) identified the advantages of applying constructability in design firms. These advantages are as follows: improved relationships with customers and contractors, fewer lawsuits, earning a reputation in construction, gaining professional satisfaction, and creating effective designs. Russell and Gugel (1993) described constructability's advantages for the entire project, classified into qualitative and quantitative categories. The quantitative advantages are the direct reduced time and construction costs and reduced engineering costs. The qualitative advantages include an increased commitment of project members, reduced duplication, increased team cooperation and communication, improved productivity, and enhanced safety. In the application of this process, the main-contractor and sub-contract, employer, consultant, suppliers, and producers all play essential roles (Samimpey & Saghatforoush, 2020).

3.2.3 PREREQUISITES FOR CONSTRUCTABILITY

A recent review established the prerequisites for constructability implementation. These prerequisites are also called the needs for constructability. Samimpey and Saghatforoush (2020) conducted a systematic literature review of 859 articles on constructability, of which only 21 articles remained after a five-step selection process. The constructability needs were then extracted from the 21 selected articles and grouped into 22 overall prerequisites.

The extracted needs were classified as managerial, technical, or environmental needs. These prerequisites are shown in Figure 5. Most of the constructability prerequisites were managerial, which indicates that intra-organisational decisions tend to be related to decisions by the organisation's managers. These senior managers play an essential role in the awareness of the significance of constructability. Furthermore, the absence of these prerequisites can be examined as a mechanism of why constructability is not optimised.

Managerial

- Increasing communications, integration, coordination, and mutual respect among all project stakeholders
- Sharing and exchanging information through databases, documenting previous projects and lessons learned, and fast and easy access to this information by all team members
- Creating a strong support program and its development
- Existence of correct planning to achieve project objectives
- Knowledge of project stakeholders regarding constructability and its advantage
- Enhancing team-building skills
- Increasing integration among all project stakeholders
- Using new methods of information and communication technology and development tools and equipment
- Preferring new contracts to traditional ones
- Allocating cost for constructability training and implementation
- Commitment and participation of employers and understanding their needs

Technical

- Familiarity with and use of new, creative methods of construction and new technologies
- Using experts with experience in the field of designing
- Integrating knowledge and experience of all team members
- Identifying, visualizing, and reviewing the project environment before construction
- Reviewing plans and presenting feedback to designers
- Participation and presence of contractors in the initial stages of the project to transfer construction knowledge and experience
- Using computer models to enhance the identification of the project situation
- Using related checklists

Environmental

- Paying attention to design and construction standards
- Considering environmental factors (technology, economic, and social, etc.)

Figure 5: Constructability prerequisites (Samimpey & Saghatforoush, 2020)

The need to improve constructability due to developments in the construction sector was also indicated by Kifokeris and Xenidis (2017). There are many reasons why the usability and verification of constructability are more timely than ever. They include the complexity of projects, the need for innovation, the chaotic and ambiguous amount of information, the ongoing financial recession, new stakeholder relations, and the growing implementation of powerful methodological and software tools.

3.3 CONCEPT OF COST OF QUALITY

Measuring and identifying quality costs can be accomplished in different ways. The concept of CoQ is a method that was introduced by Juran (1951), as described in the introduction. The CoQ concept has been developed and applied in the manufacturing industry (Mohandas & Raman, 2008). Its definition is given in Section 3.3.1, and models of CoQ are elaborated in Section 3.3.2.

3.3.1 DEFINITION OF COST OF QUALITY

There is no general agreement on the broad definition of CoQ, in line with Machowski and Dale (1998). The definition of CoQ is usually understood as the sum of both conformance and non-conformance costs (Schiffauerova & Thomson, 2006). Conformance costs represent the cost of preventing poor quality and providing quality appraisal. The costs for poor quality and failure are classified as non-conformance costs.

The CoQ is also known as 'quality costs' (Love & Smith, 2018). The literature also includes words such as 'error', 'defect', 'snag', 'failure', 'non-conformance', 'fault', 'quality failure', 'quality deviations', and 'rework'. Such terms are used interchangeably to describe imperfections in construction (Forcada et al., 2017; Love, Smith, Ackermann, Irani, & Teo, 2018; Rosenfeld, 2009). These interchangeable notions of the same phenomenon are often applied in the building industry. The research field is not yet mature because of the missing uniform keywords (Rosenfeld, 2009).

The main goal of a CoQ approach is to improve minimal project performance by eliminating poor quality (Mohandas & Raman, 2008). This improvement is accomplished by identifying and measuring quality costs, thus reducing the CoQ and improving project performance (Mohandas & Raman, 2008).

3.3.2 MODELS FOR COST OF QUALITY

The CoQ models provide insight into the relative contribution of each element to total CoQ. The behaviour of these elements can be modelled mathematically. Plunkett and Dale (1988) indicated several models of quality-costs relations. Feigenbaum (1956) introduced the first model of CoQ, focused on the sum of the cost of good quality (CoGQ) versus the cost of poor quality (CoPQ). The CoGQ includes prevention and appraisal costs, whereas the CoPQ comprises internal and external failure. This notation is summarised as a P-A-F model, which covers prevention, appraisal, and internal and external failure costs.

The various models were generically described by Schiffauerova and Thomson (2006). The generic models are the P-A-F model, Crosby's model, the opportunity or intangible cost models, the process cost models, and the ABC models. The P-A-F model was adopted for this research because it is most commonly implemented in practice (Schiffauerova & Thomson, 2006). Its schematic representation is shown in Figure 6.

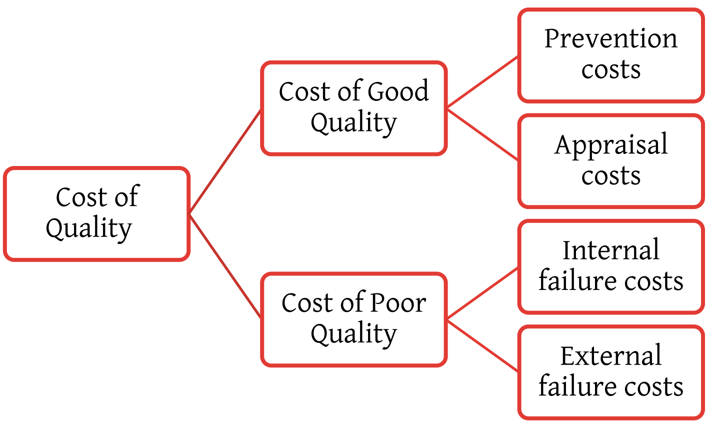

Figure 6: Relationships between elements in cost of quality (own illustration)

The prevention costs that are part of CoGQ include activities directed towards preventing common variations or defects in the quality of work. The appraisal costs include costs related to measuring, testing, and evaluating the project quality to determine whether it conforms with the required standards and specifications (Mahmood, 2010). The appraisal and prevention costs are 'willing to spend' costs (Rosenfeld, 2009).

The CoPQ can be viewed as the cost of low quality (Rosenfeld, 2009). Internal and external failure costs are included in this element. Internal failure costs are associated with the product's failure before it is delivered to the client. External failure costs occur after delivery of the product to the client (Mahmood & Kureshi, 2015). Failure costs include reworking, taking corrective action, vendor defects, re-testing, redesigning, material downgrades, material review, scrapping, re-inspecting, and various other defects (Mohandas & Raman, 2008). Internal and external failures are 'forced to spend' costs (Rosenfeld, 2009).

The actual cost of internal failure is higher than the formally quantifiable costs (Rosenfeld, 2009). Quality failure bears substantial hidden costs, including an impaired company reputation, loss of customers, project delays, increased overheads, and liability payments (Rosenfeld, 2009). The aim of minimising the CoPQ is to prevent failure costs and minimise the appraisal costs (Mahmood, 2010). Hence, in this study, minimising CoPQ implies that failure costs must be prevention and appraisal costs minimised.

3.3.3 CONTRIBUTION OF REWORK TO COST OF QUALITY

Rework plays an essential role in the success or failure of a project (Safapour & Kermanshachi, 2019). As elaborated in the previous section, rework is a major contributor to CoPQ. The concept of rework is thus used interchangeably with CoQ, as described above.

The most broadly used definition of rework from a construction perspective was provided by Robinson-Fayek, Dissanayake, and Campero (2004). They described rework as ‘The total direct costs of re-doing work in the field regardless of the initiating cause, which excludes change orders and errors caused by off-side manufacture’. However, errors and omissions in contract documentation and changes initiated by the client and end user, are the primary causes of rework (Love & Li, 2000; Love et al., 2010). Therefore, change orders and errors are included in this research. The applied definition of rework is thus shortened to ‘the total direct costs of re-doing work in the field regardless of the initiating cause’.

Rework remains a problem in construction, even after substantial research. The absence of standard concepts and a common language to identify and describe the systemic characteristics of rework is one reason for the lingering problem (Love & Smith, 2018). Love, Smith, Ackermann, and Irani (2019) indicated that rework is a 'known-unknown' phenomenon because of the lack of standard measurement procedures and processes. Thus, the need for rework is a risk that companies are aware of, but the size and effect of this risk is unknown.

The performance of a project is affected by rework. Love (2002a) stated that cost and schedule increases are correlated with direct rework costs, which suggests that rework can adversely influence the project's performance. Building projects incur higher rework costs than civil engineering projects (Forcada et al., 2017). However, procurement methods do not significantly influence rework costs, according to Love (2002b).

Research has indicated that safety incidents occur relatively frequently when rework is performed. Hence, when rework is reduced, safety improves (Love et al., 2019; Love, Teo, et al., 2018; Yap, Rou Chong, Skitmore, & Lee, 2020). Rework also has an adverse effect on inter- and intra-organisational relationships and the psychological well-being of individuals (e.g. stress; (Love & Edwards, 2004b). Having to execute rework can adversely influence workers' morale, increasing their stress and resulting in absenteeism (Love & Smith, 2018). These effects of rework are related to its hidden costs.

3.4 CONSTRUCTABILITY AND COST OF QUALITY

As indicated in Section 3.3, this research regards rework as the CoQ. The contribution of constructability to rework costs has been discussed in the literature. The poor constructability of a design and misunderstanding of the design by an executive operator is the second-ranked cause of rework, according to Balouchi et al. (2019). Lack of constructability in a design significantly contributes to non-conformance and rework (Balouchi et al., 2019; Yap et al., 2017). Such research indicates that constructability is positively related to rework costs. Therefore, improving constructability is a robust strategy for reducing errors; it focuses on the ease and efficiency of how a structure can be built (Love & Smith, 2018). Overall, constructability and its strategies can reduce the cost of rework (Safapour & Kermanshachi, 2019). The application of constructability can decrease internal failure costs.

3.5 UNDERLYING MECHANISMS FOR REWORK

The underlying mechanisms in non-optimised constructability have not been explicitly described in the literature. However, the causes of rework and its synonyms are identified. Specific underlying mechanisms related to constructability are discussed in this section.

There is no single strategy to adopt to reduce design errors and improve safety and project performance (Lopez, Love, Edwards, & Davis, 2010). While the reasons for rework appear to be relatively straightforward, closer examination of rework events reveals a complex and interrelated array of factors contributing to its occurrence (Love & Edwards, 2004b). This diversity means that a single strategy is insufficient to improve the complex factors that cause rework.

The underlying factors in rework events were identified by Love and Edwards (2004b). These factors were as follows: poor standard of workmanship, failure to understand end user requirements, lack of quality focus, low consultant fees, poor contract documentation, and inadequate supervision and inspection. Organisational obstacles are the most significant problem in constructability (Jadidoleslami et al., 2018). Examples are resistance to change, commitment to the status quo, reluctance regarding innovation and creativity, insufficient knowledge, cultural barriers due to traditional views, lack of systematic organising structure, and reluctance of executive staff to offer pre-implementation consultation.

Scope changes are the foremost important reason for contract changes in transportation infrastructure projects, closely followed by technical necessities, according to Verweij, van Meerkerk, and Korthagen (2015). Additionally, owner changes and design errors or omissions are considered the root causes of rework, as they have a greater cost impact than do other factors (Habibi, Kermanshachi, & Rouhanizadeh, 2019; Hwang, Thomas, Haas, & Caldas, 2009; Love, Lopez, & Edwards, 2013).

Acknowledging that rework is a problem and being willing to redress its occurrence are the first steps for an organisation to reduce and contain its rework (Love & Smith, 2018). The causes of rework must be recognised. There is also a need to systemically understand 'why' and 'how' errors are made at the individual, team, and organisational levels, according to Love, Teo, et al. (2018). This acknowledgement depends on the learning capacity of the employers. Practitioners in the civil engineering industry find it difficult to learn from their mistakes regarding the identification and prevention of design errors (Love, Edwards, & Irani, 2008). This difficulty increases the obstacles regarding project performance.

Work processes, policies, procedures, and behaviour must change if rework is to be reduced (Love, Edwards, & Smith, 2016). The implementation of technological communication practices or the use of building information modelling (BIM) alone do not reduce the incidence of rework. Design inconsistencies and reliance on IT application output when projects are subjected to tight schedules are considered significant factors of rework (Lam & Wong, 2009).

3.6 MEASURES TO IMPROVE CONSTRUCTABILITY

In literature, some solutions to improve constructability are described. The following improvement measures are covered in this section:

- To create effective communication between the design team and the executive team (Balouchi et al., 2019).
- The use of executive forces in the design team as consultants (Balouchi et al., 2019).
- The cause of rework in a construction supply chain was poor information flow and the absence of a quality focus (Love, Li, & Mandal, 1999).
- The design-review team was independent of the design team; it should be staffed with senior design engineers or field personnel to assign the design (Glavinich, 1995).
- A critical approach to enhancing buildability is through benchmarking. This creates an incentive for designers to strive for best practice as new benchmarks are recognised. Through benchmarking, buildability clients and design teams have additional influence on their project's outcome (Lam & Wong, 2009).
- Implementing error management, which includes the need to prevent errors and acknowledging that errors do happen (Love & Smith, 2018).
- Building mutual trust and credibility between designers and contractors that can be maintained over a long time (Jergeas & Put, 2001).
- Quantified assessments of designs, constructability reviews, and the implementation of constructability programmes at various project stages are the standard measures to improve constructability (Wong et al., 2007).

3.7 CONCLUDING REMARKS

This chapter addresses the first sub-question of this research: 'Which underlying mechanisms for managing the cost of rework related to constructability are known in the current literature?' There has been a long-standing interest in applying constructability principles to minimise the cost of rework. Constructability is not new in research and it can substantially decrease the cost of rework. However, the mechanisms for managing constructability to decrease rework remain largely unknown.

The literature review discovered 38 known prerequisites or must-have mechanisms to include constructability in a project. The current prerequisites are presented in Table 1. The perceptions about constructability among clients, contractors, and engineering and design firms are presented in the next chapter. The mechanisms discussed by these experts are then compared with the findings of this chapter.

Table 1: Constructability prerequisites based on literature

No	Must-have mechanism	Literature
1	Learn from mistakes or previous experiences	(Love et al., 2008)
2	Understanding 'why' and 'how' errors are made at the individual, team and organisational level	(Love, Teo, et al., 2018).
3	Stimulate quality focus	(Love & Edwards, 2004b)
4	Sufficient knowledge	(Jadidoleslami et al., 2018)
5	Appropriate consultant fee	(Love & Edwards, 2004b)
6	Commitment and participation of employers and understanding their needs	(Samimpey & Saghatforoush, 2020)
7	Existence of correct planning to achieve project objectives	(Samimpey & Saghatforoush, 2020)
8	Familiarity with and using new and creative methods of construction and new technologies	(Samimpey & Saghatforoush, 2020)
9	Knowledge of project stakeholders about constructability and its advantage	(Samimpey & Saghatforoush, 2020)
10	Changing work processes, policies, procedures and behaviour	(Love, Edwards, et al., 2016)
11	Identifying, visualising, and reviewing the project environment before construction	(Samimpey & Saghatforoush, 2020)
12	Increasing communications, integration, coordination, and mutual respect among all project stakeholders	(Samimpey & Saghatforoush, 2020)
13	Preferring new contracts to traditional ones	(Samimpey & Saghatforoush, 2020)
14	Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all the team members	(Samimpey & Saghatforoush, 2020)
15	Using experts experienced in the field of designing	(Samimpey & Saghatforoush, 2020)
16	Using new methods of information and communication technology and development tools and equipment	(Samimpey & Saghatforoush, 2020)
17	Prevention of owner changes and design error/omission	(Habibi et al., 2019; Hwang et al., 2009; Love et al., 2013)
18	Willingness to innovation and creativity	(Jadidoleslami et al., 2018)
19	Prevention of contract changes	Verweij et al. (2015)
20	Participation and presence of contractors in the initial stages of the project to transfer construction knowledge and experience	(Samimpey & Saghatforoush, 2020)
21	Management of cultural barriers due to traditional views and flexible vision	(Jadidoleslami et al., 2018)

22	Design consistency and reliance on IT application output	(Lam & Wong, 2009)
23	Adequate supervision and inspections (off and on-site)	(Love & Edwards, 2004b).
24	Existence of systematic organising structure and reluctance of executive staff to offer pre-implementation consultation	(Jadidoleslami et al., 2018)
25	Understanding end-user requirements	(Love & Edwards, 2004b)
26	Allocating costs for constructability training and implementation	(Samimpey & Saghatforoush, 2020)
27	Considering environmental factors (technology, economic, and social)	(Samimpey & Saghatforoush, 2020)
28	Creating a strong support programme and its development	(Samimpey & Saghatforoush, 2020)
29	Enhancing teambuilding skills	(Samimpey & Saghatforoush, 2020)
30	Increasing integration among all project stakeholders	(Samimpey & Saghatforoush, 2020)
31	Integrating knowledge and experience of all team members	(Samimpey & Saghatforoush, 2020)
32	Paying attention to design and construction standards	(Samimpey & Saghatforoush, 2020)
33	Reviewing plans and presenting feedback to designers	(Samimpey & Saghatforoush, 2020)
34	Using computer models for better identification of project situation	(Samimpey & Saghatforoush, 2020)
35	Using related checklists	(Samimpey & Saghatforoush, 2020)
36	Sufficient contract documentation	(Love & Edwards, 2004b)
37	Superior standard of workmanship	(Love & Edwards, 2004b)
38	Promotion of change and the consent of the status quo	(Jadidoleslami et al., 2018)

CHAPTER

4

EXPLORATION OF CONSTRUCTABILITY IN PRACTICE

4 EXPLORATION OF CONSTRUCTABILITY IN PRACTICE

The second and third sub-questions of this research are addressed in this chapter. The second sub-question is 'What are the perspectives of client, contractor and engineering and design firms regarding constructability in the context of traditional contracts?' The third sub-questions is 'Which underlying mechanisms regarding managing the cost of rework related to constructability are observed in exploratory interview?'

Perceptions regarding constructability in practice were obtained and compared. Individual interviews were held digitally to collect the perceptions about constructability in practice by experts in the Netherlands. The interview set-up is described in Section 4.1. Section 4.2 covers the characteristics of the interviewees, and the results of the interviews are presented in Section 4.3. In Section 4.4, the findings from the interviews are compared with the previous literature.

4.1 INTERVIEW SET-UP

Interviews are used in research as a way to collect data by gaining knowledge from individuals (Doody & Noonan, 2013). There are three main types of research interviews: structured, semi-structured, and unstructured (Gill, Stewart, Treasure, & Chadwick, 2008). As described in the introduction, the purpose of these interviews was to identify the perceptions about constructability in practice.

Semi-structured interviews were suited for exploring the perceptions and opinions of respondents (Barriball & While, 1994). According to Cohen and Crabtree (2006), when interviewees are interviewed only once, a semi-structured interviewing method is best. This method involves the use of predetermined questions, enabling the researcher to seek clarification about the answers (Doody & Noonan, 2013). The order of the questions may change. These arguments provide a clear playing field for the researcher and interviewee.

The semi-structured interviews were personal, which provided advantages over paper interviews for data collection. These advantages include overcoming the poor response rate of questionnaire surveys and being suited for the exploration of attitudes, values, beliefs, and motives. Furthermore, comparability is enhanced by ensuring that all questions are answered by each respondent (Barriball & While, 1994). Semi-structured interviews allow informants the freedom to express their views in their own terms (Cohen & Crabtree, 2006).

4.1.1 FRAMEWORK FOR THE SEMI-STRUCTURED INTERVIEWS

The interviews were arranged according to the framework of Kallio, Pietilä, Johnson, and Kangasniemi (2016). The semi-structured interviews were planned as face-to-face interactions, but because of the COVID-19 pandemic at the time, video calls were arranged and recorded. The guideline for the semi-structured interviews in Dutch is provided in Appendix A. The global guide included the following:

- General introduction of researcher and thesis topic.
- Can you state some details about yourself? Examples are working experience, profession within projects, and current role in the organisation.
- How do you define the concept of 'constructability'?
- What examples of issues with constructability occur in your practice?
- What mechanism causes the non-optimising of constructability?

4.1.2 INTERVIEW RECORDING

The interviews were recorded via Microsoft Teams. Interviewee permission was sought before the interview was held. The use of audiotapes, permitted by the respondent, ensure that an identical replication of the contents of each interview is available, facilitating analysis (Barriball & While, 1994). This audiotaping was accomplished by recording the entire interview as a video, including the audio. Audio taping reduces the potential for interviewer error from recording data incorrectly or logging an answer to a question that was not even asked (Barriball & While, 1994). Capturing respondents' answers while conducting an interview often results in inaccurate notes and detracts from the development of rapport between interviewer and interviewee (Cohen & Crabtree, 2006).

The combination of the COVID-19 measures for video calls and the advantages of recording interviews resulted in the proper handling of the interviews. The outcomes of the interviews were all anonymised due to the privacy and competition preferences of most of the interviewees.

4.1.3 CRITERIA FOR INTERVIEWEES

The experts identified to approach for interviews were categorised into the traditional roles in projects, namely client, contractor, and design and engineering firm. The plan was to choose a minimum of three interviewees per role to obtain diversity in the data. The three interviewees were required to work for different companies.

Several other measures were taken to obtain the highest willingness to participate in the research and interviews. These measures include the ability to speak English or Dutch, sharing the thesis results with all participants, and anonymous interview results. The interviewees must meet the criteria for participation. Different roles in obtaining diversity and different perspectives were essential for the validity of the results. The criteria for the interviewees in the interview session were that the interviewee must

- be available within the required timeframe
- have a senior role in the company
- have experience with projects that face constructability issues which increase CoQ
- have been involved in projects in the Dutch marine infrastructure sector.

4.2 CHARACTERISTICS OF INTERVIEWEES

In total, 11 interview sessions were conducted with individual persons. Seventeen invitations were sent to potential interviewees, but five people did not reply, and one was not available. During the research, one of the interviewees was changed to the company supervisor due to personal circumstances of the original supervisor.

The characteristics of interviewees were ordered according to their role within the project and working experience, shown in Figure 7. The experts' details are anonymised by listing only the anonymised numbers, company role, work experience, and current work role (see Table 2). An overview of their names, companies, and characteristics appears in the separately provided confidential Appendix A, which is only available for the graduation committee.

Table 2: Overview of interviewees' characteristics, company role, work experience, and current work role

#	Company role	Work experience	Current work role
1	Contractor	>20 years	Executive Manager
2	Contractor	15–20 years	Operations Manager
3	Contractor	>20 years	Project Manager
4	Design/engineering firm	15–20 years	Head of department Infra
5	Design/engineering firm	10–15 years	Project Manager
6	Design/engineering firm	5–10 years	Project Manager
7	Design/engineering firm	15–20 years	Managers Port and Waterways
8	Design/engineering firm	15–20 years	Project leader and adviser Infra
9	Client	>20 years	Supervisor/Project Manager
10	Client	>20 years	Contract Management Adviser
11	Client	>20 years	Project Coordinator

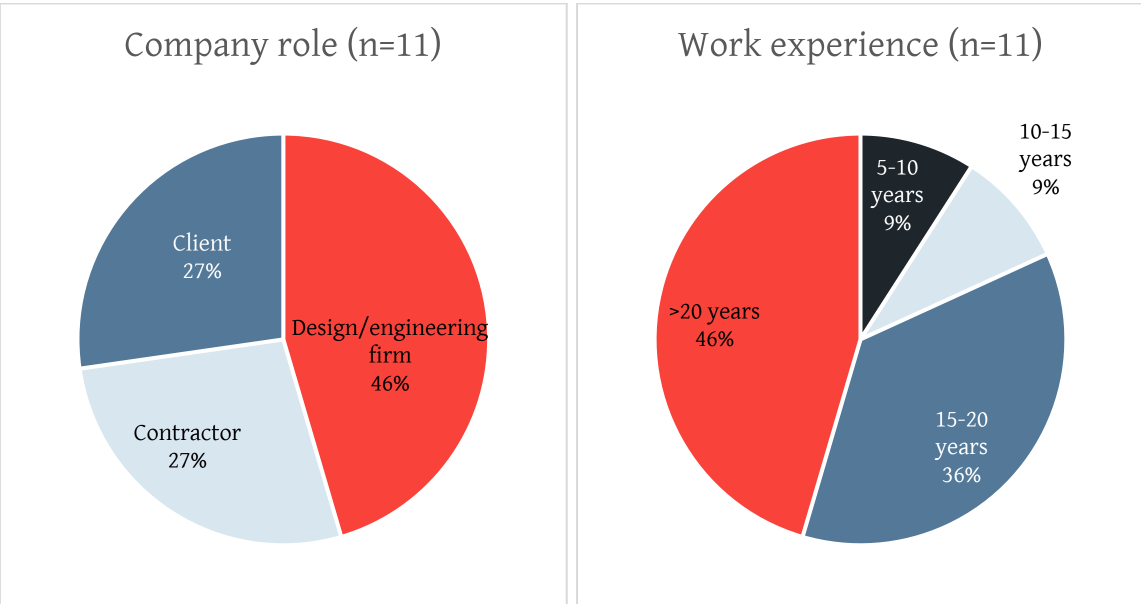

Figure 7 Interviewees' roles in the project (left) and work experience (right) (own illustration)

4.3 INTERVIEW RESULTS

The interviews were analysed based on the overall output and by watching the recordings again. The results were processed in an Excel sheet according to the interview question. Analysing these data provided insight into interviewees' practical knowledge, the meanings, and their perceptions in practice. Different elements in the interviews are mentioned here and elaborated in the next sections.

4.3.1 PERCEPTIONS OF CONSTRUCTABILITY IN PRACTICE

The first element of the interview was the perception of the term 'constructability' in practice. The interviewees did not easily describe these perceptions in specific definitions. The perceptions of constructability in practice were derived from the perspectives of the client, contractor, and design and engineering firm.

The first perspective regarding the perception of constructability in practice was obtained from the clients. The definition of constructability was diverse but limited as described by these interviewees. The client interviewees stated that constructability must be a constructable design, and that safety comes first and should be included and guarded in the design, construction, and maintenance phases. The design should be constructable by various contractors. The constructability boundaries are continually being pushed back and shifting. The project should be implementable with current available materials and equipment.

The desired output of the project was described according to its functional requirements; however, current and prevailing rules, directives, standards, and legislation are always applied. A reference design is arranged to verify the costs, planning, and risks in executing the tender bids. Object and site specifications lead to specific requirements in contracts, with risks being the most important. There are always risks, because unexpected events can surprise overtime in the projects.

Design and engineering firms provided the second perspective regarding constructability. These interviewees linked constructability to buildability. They stated that constructability must be included in the design phase of projects. Everything may seem to fit neatly on paper, but at the project site things become more challenging due to multiple factors – including environmental factors. The design and engineering firm must be aware of what the contract may require in the execution of the project. Constructability is strongly applicable in the first phases of the project and could have a higher impact early in the project, according to some interviewees. In the application of constructability principles in design, experience is vital.

The contract forms a crucial aspect related to constructability. The traditional and integrated contract types lead to differences between functional and direct requirements. The client's wishes and constraints are formulated and specified according to the relative importance of the client. Design and engineering firms translate these client wishes and constrains into project requirements. The contractor then interprets these requirements. These numerous interfaces and interpretations have a significant influence on constructability, and a close relationship between engineering office and contractor is desirable to enhance the constructability.

Furthermore, the design and engineering firm interviewees characterised constructability according to several aspects. The first was the executability and feasibility of the design in terms of its geometric challenges and limitations. Other aspects were safety, the effect on the environment, design responsibility, equipment, delivery time, and the availability of materials.

Contractors provided the final perspective about constructability in practice. They indicated that no single factor determines whether constructability occurs within a project. The term 'constructability' was interchangeable with two terms in Dutch, namely buildability and executability. Furthermore, constructability was explained as the relationship between the preconditions and the design and what can be executed. One interviewee defined an element of constructability as being the interface between engineering and execution; bringing together these worlds is vital to enhance constructability. The design and engineering firms are experts at calculation, but the execution itself is not part of their job was suggested by one of the interviewees.

Risk identification and mitigation is an essential step. Risk can always occur in projects, and not everything needs to be planned if there is an awareness of the risks. Risks can occur within the sphere of influence of the project team, but also out of the sphere of influence, such as magnifying a safe working environment.

Contractor representatives indicated a difference between building contracts and integrated contracts. A building contract depends on choices and interpretations of the client's demands by the design and engineering firm, which affects the relationship between the design and the preconditions. Generic designs, in building contracts, must be executable by various contractors. Small practical adjustments are possible from the contractor's side. By contrast, in integrated contacts, the contractor can incorporate their own experience, preferences, and influence into the design. This incorporation of the contractor can even occur at an earlier stage. The contractor interviewees stated that integrated contract forms are more satisfiable and enjoyable from their perspective.

The characteristics used to describe constructability, according to the three perspectives, are summarized in Table 3.

Table 3: Constructability characteristics based on the interviewee's role in the project

Role in project	Constructability characteristics
Client	Constructable design, safety, constructable by various contractors and application of current and prevailing rules, directives, standards, and legislation
Design and engineering firm	Executability, feasibility of design per its geometric challenges and limitations, safety, the effect on the environment, design responsibility, equipment, and the delivery time and availability of materials and interface management.
Contractor	Executability, constructable design, interface between engineering and executions, safety, risk identification and distribution feasibility of the design, executability with current equipment, design responsibility, delivery time and availability of materials, the need for auxiliary structures, the effect on the environment, design responsibility, equipment, lead time, and interface management.

4.3.2 PRACTICAL PROBLEMS RELATED TO CONSTRUCTABILITY

Practical problems related to constructability were probed during the interviews for all three perspectives. These problems are summarised and described in this section in a generalised manner to avoid damaging the participating organisations. One interviewee mentioned that 'problem' was not the best term. However, this word is used to refer to negative events related to constructability.

It is preferable to make different choices according to solutions. For example, contractors may have their own ways of doing things and can face problems if that approach is not provided for. Other examples of problems related to constructability in practice included substantial auxiliary work required to construct late changes in the superstructure. Furthermore, working in confined spaces, such as when welding, is neither safe nor desired. Underwater and underground components are always high-influence factors in a project, and these components are often more complicated than anticipated. Dealing with heavy parts in the final phase is all checked and approved; however, handling heavy parts in the intermediate phases is limited derived, such auxiliary constructions and materials or sufficient space to hoist.

Another frequently mentioned problem was the erroneous cleverness of the designer. This was described as unsubstantiated over-optimisation of elements by the contractor or the design and engineering firm. A designer chose, for example, to optimise anchorage lengths of 40 m with variances of 20–40 cm, an extensive and unique variety of tube pile diameters and lengths of sheet piles. This variety was not easy for employers at the working site to identify, which could lead to mistakes. Other issues can be the delivery time for a large and unique variety of tube pile diameters. Besides these effects is the thinking and reasoning behind the optimisation not being given as Substantiation of design Some problems are related to the requirements of the client, such as 20-year-old design requirements. These old requirements were questioned for their feasibility in a good design. Another example of problems was last-minute changes. These may be useful for part A, but have also been tested for safety, further design steps, and other parts. The effects of last-minute changes are often overlooked.

4.3.3 MECHANISM FOR NON-OPTIMISING OF CONSTRUCTABILITY

One of the questions in the interviews covered the mechanisms for non-optimised constructability in projects. These mechanisms are elaborated in this section. The roles of the client, design and engineering firm, and contractor were all relevant to these mechanisms and many examples were provided by the interviewees.

The competitive market focuses on money. This was an often-stated mechanism related to traditional contract forms. Clients are guided by money instead of the intended quality and receive what is asked and nothing more. This mechanism can be explained by rivalry between competitors, both in the preparation phase (between the design and engineering firms) and between the contractors in the execution phase. Engineering services that are chosen at the lowest price led to minimum effort and only meet the minimum standards. The market in competition also has the mechanism to make the friendly competitor no wiser and smarter than they already are. Thus, commercial considerations are not advantageous for the entire chain.

The current commercial game of the Dutch Rationalisatie en Automatisering Grond-, Water- en Wegenbouw (RAW) contract form means that the entire system is not optimised. There is a clear separation of interests, such that clients are responsible for the design and contractors merely carry out what is asked for, and nothing else.

In addition to competitive markets, translation of the requirements from client to contractor were identified as mechanisms for non-optimisation. This translation is about the choices and interpretation of client demands into requirements as applied by the design and engineering firms. Furthermore, the contractor also interprets the description provided by the design and engineering firm. A clear-cut interpretation of technical requirements by the client's design and engineering firm does not address questions about functional requirements; it also leads to limited solution space for the contractors. The market knows how to build the project, but the design and engineering firm may reshape the design elements to meet the requirements. Besides this translation and possible handovers conflicts, contradictory technical requirements within the solution space are another mechanism for the non-optimisation of constructability. Often, one of the requirements must be eliminated to meet the other requirement.

In addition to the translation of client demands into contractor requirements, the lack of substantiation of design assumptions is another critical mechanism. The requirements are usually described in one line, but the underlying idea is not captured. The one-line description has been well considered but the thinking behind it has not been given.

The client could frame functional requirements as technical requirements, which would mean there is no freedom of design for a contractor. The market does not enable producing innovative solutions, as design and execution are two different worlds with different cultures and people. The separation of these worlds leads to possible mistakes in the interpretation of limited substantiated design choices and assumptions.

The late or overly late involvement of the executing party or execution knowledge was a frequently mentioned mechanism. Furthermore, involvement of the wrong person can affect constructability. The right person must have the interest, knowledge, and skills for their input to be incorporated during the project. For example, Person A indicates that something is possible, while Person B indicates that it is not. A change in staff or the lack of interest, knowledge, and skills could lead to the non-optimisation of constructability. Ensuring what is called for today is still be the case in a year's time.

Other mechanisms were also defined, such as issues of responsibilities and risks was indicated. These issues may not be directly related to constructability but can lead to changing circumstances in which the handling is not always explicitly expressed. Furthermore, a lack of trust between the various parties is a critical mechanism. From the contractors' and engineering firms' perspectives, the clients have relatively more trust in the market.

The expenditure of time and money early in the process and its tightness was cited as another reason for not optimising constructability. This involves the overestimation of parts that can be performed quickly. One example of spending less early in the process is about ground or other survey data. This data supply may be minimal, which may lead to surprises later in the project.

Another mechanism is the improvident over-optimisation of elements by the designer or engineer of a design and consultancy firm. These designers may think too simply about the feasibility of actions in the execution; they want to optimise an element, but their calculations are too frugal. In the execution of a project, mistakes or other interpretations can be minimised by sound design choices. ‘It is all about money’, as one interviewee mentioned. Non-constructability does not exist; the question is 'who pays the costs of adaptation?' Contractors want to make profit and clients want to spend as little as possible, so their interests seem to conflict. The clients want the best option but do not want to pay much for it. During the tender process, useful ideas are not reimbursed. The market is not challenged with a reward to get the best out of the tender design and plan. However, some projects may look expensive on paper, but in practice they could be a cheaper solution if mistakes and rework are avoided.

The last primary mechanism is the reluctance of the contractor market. Some contractors are not prepared to follow the latest developments and have a conservative attitude; 'We do it like we used to do it all the time'. It would be better for the entire chain in the Netherlands if products are procured better, constructable solutions are designed, and the involved parties learn from each other. These possible improvements indicate that learning and improving the market does not currently occur. This may be due to unique solutions, as projects are not always standard. It should be prevented to make the same mistakes again. Comparisons can be made across projects, but project-specific circumstances, such as subsoil or water, often have an influence.

4.4 CONCLUSION OF THE EXPLORATORY INTERVIEWS

This chapter answers the second sub-question of this research: 'What are the perspectives of clients, contractors, and design and engineering firms regarding constructability, in the context of traditional contracts?'

The interviewees were not able to easily describe the perceptions of constructability in practice. In addition, the characteristics used to describe constructability differed among the client, contractor, and consultant/design interviewees. The perceptions of contractors were broader than those of the design and engineering firm and substantially broader than those of the clients.

The third sub-question was also answered in this chapter: 'Which underlying mechanisms regarding managing the cost of rework related to constructability are observed in exploratory interview?' The mechanisms are filtered from the description above to provide a clear overview. Mechanisms discussed both in the literature and these exploratory interviews are listed in Table 4. The table shows 21 mechanisms. New mechanisms were also identified through the interviews, as shown in

Table 5.

The identified mechanisms were examined in the case study to verify whether these mechanisms occurred in practice. The case study design is described in the next chapter.

Table 4: Mechanisms for optimising constructability, presented in both literature and interviews

Must-have mechanism	Literature	Exploratory Interviews
Learn from mistakes or previous experiences	(Love et al., 2008)	✓
Understanding 'why' and 'how' errors are made at the individual, team and organisational level	(Love, Teo, et al., 2018).	✓
Stimulate quality focus	(Love & Edwards, 2004b)	✓
Sufficient knowledge	(Jadidoleslami et al., 2018)	✓
Appropriate consultant fee	(Love & Edwards, 2004b)	✓
Prevention of owner changes and design error/omission	(Habibi et al., 2019; Hwang et al., 2009; Love et al., 2013)	✓
Willingness to innovation and creativity	(Jadidoleslami et al., 2018)	✓
Changing work processes, policies, procedures and behaviour.	(Love, Edwards, et al., 2016)	✓
Prevention of contract changes	(Verweij et al., 2015)	✓
Participation and presence of contractors in the initial stages of the project to transfer construction knowledge and experience	(Samimpey & Saghatforoush, 2020)	✓
Commitment and participation of employers and understanding their needs	(Samimpey & Saghatforoush, 2020)	✓
Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all the team members	(Samimpey & Saghatforoush, 2020)	✓
Familiarity with and using new and creative methods of construction and new technologies	(Samimpey & Saghatforoush, 2020)	✓
Knowledge of project stakeholders about constructability and its advantage	(Samimpey & Saghatforoush, 2020)	✓
Identifying, visualising, and reviewing the project environment before construction	(Samimpey & Saghatforoush, 2020)	✓
Increasing communications, integration, coordination, and mutual respect among all project stakeholders	(Samimpey & Saghatforoush, 2020)	✓
Preferring new contracts to traditional ones	(Samimpey & Saghatforoush, 2020)	✓
Existence of correct planning to achieve project objectives	(Samimpey & Saghatforoush, 2020)	✓
Using experts experienced in the field of designing	(Samimpey & Saghatforoush, 2020)	✓
Using new methods of information and communication technology and development tools and equipment	(Samimpey & Saghatforoush, 2020)	✓

Table 5: Additional 'must-have' mechanisms identified in the exploratory interviews

Must-have mechanism	Exploratory Interviews
A competitive market for contractor and design and engineering firms	✓
Agreements about responsibilities and risks	✓
Critical optimisation of elements by the designer of engineer, with constructability considerations	✓
Substantiation of design assumptions	✓
Building trust between the stakeholders	✓
Early involvement of the executing party or execution knowledge	✓
Sufficient spending of time and money early in the process (no fixed budget)	✓
Reimbursed for effort or ideas	✓
Ensuring the input remains constant (right person at the table)	✓
Realistic estimation of parts that can be performed within a concise period	✓
Reluctance of the contractors' market	✓
Extensive translation of the requirements from the end-user and client to the contractor	✓

CHAPTER

5

CASE STUDY DESIGN

5 CASE STUDY DESIGN

A case study is defined as an intensive study about a person, group of people, or unit; the study is intended to generalise over several units (Gustafsson, 2017). Yin, Merriam, Stake are prominent methodologists who used the case study method in the field of educational research (Yazan, 2015). The case study in the current study is based on the methodological stages of Yin (2011), because this approach fits the 'how' or 'why' questions (Yazan, 2015). The first stage of composing study questions for the research is earlier described in section 2.2. The second and fourth stage of a proposition on how to approach these questions is not performed in the study. The units of analysis, which data needs the be collected is the third stage as described in this chapter. The interpretation of the findings of the study is described in section 6.5.

5.1 APPROACH OF THE CASE STUDY

The purpose of this case study was to identify the 'how' and 'why' factors in the underlying mechanisms that cause constructability not to be optimised in projects. The answers to such questions were likely to favour case studies, as described by Yin (2011). The determination of these 'how' and 'why' questions was accomplished by finding factual evidence of the underlying mechanisms. This evidence pertained to what happened in a project rather than the perceptions or opinions of a person.

The underlying mechanisms were derived from a limited sample of cases to enable in-depth research of specific projects. Generalisation from a large sample was not the aim of this research, and the misunderstanding of no generalisation on the basis of a single case is corrected by (Flyvbjerg, 2006). The data to be derived from the case study are described in Section 4.4. Multiple sources of evidence were included. The six main possible data sources are documentation, archival records, interviews, direct observation, participant observation, and psychical artefacts (Yin, 2011). In this research, the first three sources were applied (documentation, archival records, and interviews). These sources are used because of their availability and the opportunity to perform in executed projects.

The documentation source included administrative documents, minutes of meetings, and contract documents – such as announcements, contract changes, and other related documentation in the projects. The archival records consisted of the organisational records of the selected cases as well as client satisfaction reports, personal records of notes, and internal communication. The final source were the interviews, with an open-end nature. This allowed the respondent to express their opinions about the questions and to diverge from the questions.

The use of different sources of evidence is called triangulation. In this study, triangulation was also methodological due to the application of different methods, which is known to improve the construct validity (Yin, 2011). The application of a case study database as a procedure to organise and structure the data from the case study (Baxter & Jack, 2008), is a second principle to increase the case study reliability and validity. A case study database was organised in Microsoft Excel.

5.2 CASE STUDY PROTOCOL

The application of a case study protocol is an important way to increase reliability (Yin, 2011). It was essential for the multiple case study methodology of this research. This case study protocol includes the following sections: Overview of the case study project, field procedures, case study questions, and guidance for the case study report. These topics are described in detail in the following sections.

5.2.1 OVERVIEW OF THE CASE STUDY PROJECT

The overview of the case study project explains the background of the project and the project characteristics. These characteristics include what the project was about, who was involved, where the project was executed, and why it was executed. The available information was collected through different sources, as described above.

5.2.2 FIELD PROCEDURES

This section describes the field procedures for the sources of evidence, namely documentation, archival records, and interviews. These items were provided by WSP in cooperation with the clients and contractors. Changes are thus indicated as impressive within the projects; the changes could relate to design, method, scope, time, costs, personnel, or other areas. These changes could result in rework in a project.

The identification of rework was used as the basis for interviews, and the archival records indicated how and why this rework had occurred. These data sources were obtained through direct contact with the project manager from WSP, who was the lead person for the project. In addition to the rework indicators, the archival records provided insight into how and why. These elements also indicate indirect mechanisms due to personal or internal experiences and effects.

The most important source for the case study was the interviews (Yin, 2011). As described above, semi-structured interviews were held with the managerial staff of the projects. These managers were from the client, design and engineering firm, or contractor. The intention was to represent at least two of these three roles in the interviews. To provide multiple perspectives, a minimum of three respondents per project was required.

The interviews were planned to occur after the collection of documentation and archival records. The respondents were all managers, so their times were determined by agenda and availability. The overview of the project provided the basis for inviting specific participants.

All interviewees were invited within a one-week timeframe per project. The order of interviews was a bottom-up approach that would build confidence and knowledge about the project by the researcher. If a respondent was not available, a back-up respondent was requested from the key person of the project. The questions asked in the interviews are described in the next paragraph. After the interviews were completed, a summary of the main observations and findings were shared with the interviewees for approval.

5.2.3 CASE STUDY QUESTIONS

As was the case for the exploratory interviews, the case study interviews were again arranged according to the framework of Kallio et al. (2016). This framework includes a predefined interview guide being prepared and appear competent during the semi-structured interview (Cohen & Crabtree, 2006). The predetermined questions were used in the interviews to ask follow-up questions and to obtain in-depth answers.

The questions for the interviewees were prepared according to three categories: process and organisational issues, the project and specific changes, and general future-oriented issues. The questions are described in the following list.

1. General introduction:
    - Explanation of constructability and rework definitions.

2. Process and organisational issues:
    - How was constructability organised in the project?
        - Who was involved?
        - What was done (reports, meetings)?

   - What was then done after constructability was considered (i.e., monitoring)?
- How were risks, health, and safety included in the invitation to bid?
- How was the method statement available in the invitation to bid?
- How was the method statement further developed during the tender stage, prior to submission of the bid?
- How was the risk inventory and mitigation file developed during the tender stage, prior to submission of the bid?
- How did the constructability process in the execution stage compare with the prepared process in the tender stage?
- Did rework occur related to constructability?
   - If yes:
      - How did this rework occur?
      - Why did this rework occur?
- How did the organisation, persons, or the interviewee react to the apparent rework related to constructability?
- How did personal behaviour or expertise affect constructability?
- How could the constructability process and organisational aspects be improved in the project?

3. Project and changes specific to the design, tender, and construction phases:
   - What in your view are the critical points to highlight the project?
   - Project-specific questions related to changes in the project:
      - Why did these changes occur in the project?
      - What were the consequences of the changes?
      - How was constructability affected by the changes?
      - How did you overcome these problems and obstacles linked to changes?
      - How could constructability be improved in the project?
4. General future oriented:
   - If you were to do this project again, what would you do differently?
   - How could the rework related to constructability be minimised if you oversee the entire process from predesign until construction phase?
   - Which party is a critical player in minimising rework related to constructability?
      - Why is this party a critical player?

5.3 SELECTING CASES

This section describes the selection of cases and the number of cases. The selection criteria are described in Section 5.3.2. The results from the interviews and WSP network are presented as a list in Section 5.3.3. The preferred characteristics for the cases are provided in Section 5.3.4. The caces are also verified, leading to a shortlist in Section 5.3.5. The final case selection is described in Section 5.3.7.

5.3.1 NUMBER OF CASES

According to Yin (2011), a case study can be arranged based on two approaches, namely a single or a multiple case study. A common misunderstanding about case studies is that the researcher cannot generalise from a single case, according to Flyvbjerg (2006).

Both single and multiple case studies were applied in this study. As discussed in the methodology section (Section 2.4), the case study was intended to provide a cross-case analysis. A multiple case study was thus suitable for this research, as multiple cases provide an understanding of the similarities and differences between cases. This approach indicates important influences based on the differences and similarities (Gustafsson, 2017). The selection criteria and preferred characteristics of the cases are detailed in the following section.

5.3.2 SELECTING CASES: CRITERIA

The selection process must lead to feasible and suitable cases for the case study. These selection criteria were arranged in cooperation with members of the graduation committee. The criteria used to select the cases are presented in Table 6.

Table 6: Case selection criteria

No	Criteria
1	Executed within the Netherlands.
2	Contract type: Building contract.
3	Maritime infra project type (quay walls, jetties, dolphins, mooring structures).
4	Project execution costs between €2.000.000 and €25.000.000.
5	WSP is involved in the project for client or contractor services.
6	Client or contractor is willing to participate in the research.
7	Project contains changes.
8	Execution was finished between 2005 and 2020.
9	Free of legal procedures or lawsuits.
10	Key project members are available for interviews.

5.3.3 LONG LIST OF POSSIBLE CASES

The exploratory interviews with practitioners discussed examples of constructability problems within the project. These examples were all provided from their own perspective and were then examined more closely to define the related project. The relevant projects were listed as possible cases, labelled from A through J. The long list of possible cases is provided confidentially in Appendix B (excluded from the public version).

5.3.4 SELECTING CASES: PREFERRED CHARACTERISTICS

In addition to the above-described criteria, several preferred characteristics were defined for the selection of cases. These characteristics contributed to the selection and trade-off of the different cases that fulfilled the selection criteria. To select the ideal cases, the list of possible cases was discussed with senior project managers at WSP. In cooperation with these managers, the cases were examined according to the preferred characteristics, listed below.

- Project documents contain an administration of contract changes
- The project was not executed within budget
- The project was not executed within time
- The project was not executed within scope
- The project was not executed to safeguard the safety
- There was a variety of clients and contractors
- WSP was involved from predesign to construction phase.

5.3.5 SHORTLIST OF POSSIBLE CASES

The shortlisted cases were tested according to the above-described selection criteria. Table 7 represents the verification of the project according to the selection criteria. These itemised characteristics were used to select preferred cases for the shortlist. These cases were used to select the final cases for the study. The shortlist of projects included Projects A, B, E, F, G, and I.

Table 7: Verification of projects to selection criteria

		Selection Criteria									
		1	2	3	4	5	6	7	8	9	10
Projects	A	✓	✓	✓	✓	✓	X	✓	✓	✓	?
	B	✓	✓	✓	✓	✓	X	✓	✓	✓	✓
	E	✓	✓	✓	✓	✓	X	✓	✓	✓	?
	F	✓	✓	✓	✓	✓	X	✓	✓	✓	?
	G	✓	X	✓	✓	✓	X	✓	✓	✓	✓
	I	✓	✓	✓	✓	✓	X	✓	✓	✓	?

5.3.6 FINAL SELECTION

As shown in Table 7, no cases met selection criterion 6 (client and contractor both willing to participate in the research). This criterion seemed to be the most challenging for the selection of cases. The participation of either the client or contractor was ensured, but in no case were both parties willing to participate. In Projects B and G, one of the parties was willing to participate and matched the preferred characteristics. The names and characteristics are not shown in the public version of this thesis. The names in the remaining cases are anonymised as Project 1 and Project 2.

CHAPTER

6 CASE STUDY RESULTS

6 CASE STUDY RESULTS

This chapter presents the case study results. The characteristics of the studied projects are described in Section 6.1, and the overview of interviews are given in Section 6.2. The case study project findings and interpretations are described in Sections 6.3 and 6.4. Both case study projects were cross-analysed and compared with the previous findings from literature and exploratory interviews, as discussed in Section 6.5. This chapter concludes in Section 6.6.

6.1 CASE STUDY PROJECTS

The characteristics of the projects describe what the project was about, who was involved, where the project was executed, and why it was executed. These specifications are excluded from the public version of this thesis. The project descriptions and specifications are found in Confidential Appendix C (excluded from the public version).

6.1.1 GENERAL DESCRIPTION: PROJECT 1

Project 1 involved the replacement of a 400-m quay wall structure in a slope. The tasks included demolishing and removing the current quay structure, applying an anchorage combi wall with horizontal anchors to an anchorage screen and concrete prefab false walls, and applying impressed current cathodic protection. The quay wall structure was connected to two existing operational quay structures. The business operations on the quay wall needed to continue during execution.

The project was started in 2009 and completed in 2012. The contract type for this project was a traditional RAW contract. The principal cross-section of the quay wall structure is shown in Figure 8.

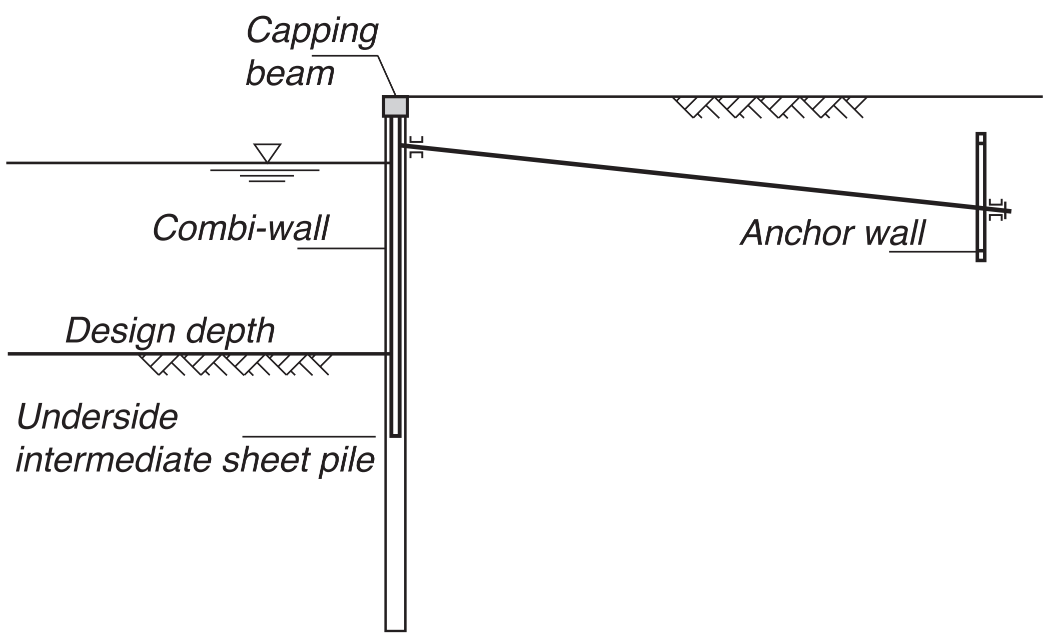

Figure 8: Main cross-section of quay wall in Project 1 (SBRCURnet, 2013)

6.1.2 GENERAL DESCRIPTION: PROJECT 2

Project 2 involved building a jetty, including an I-shaped 'finger' jetty, a quay wall, mooring and fender elements, the foundation of a vapour recovery unit, and dredging activities. These elements were all combined into one contract in an integrated form of design and construct. The jetty was the main element of the project, constructed from the substructure of tubular piles with prefab beams. On top of these beams, prefab plates were placed. An anchored combi wall supported the landfall of the jetty, while a leading jetty protected it.

The project was started in 2017 and delivered in 2019. The main freestanding flexible dolphin and tubular piles with prefab beams are shown in Figure 9. The principal cross-section jetty is shown in Figure 10.

Figure 9: Left: Main freestanding flexible dolphin (SBRCURnet, 2018a); right: tubular piles with prefab beams (SBRCURnet, 2018b)

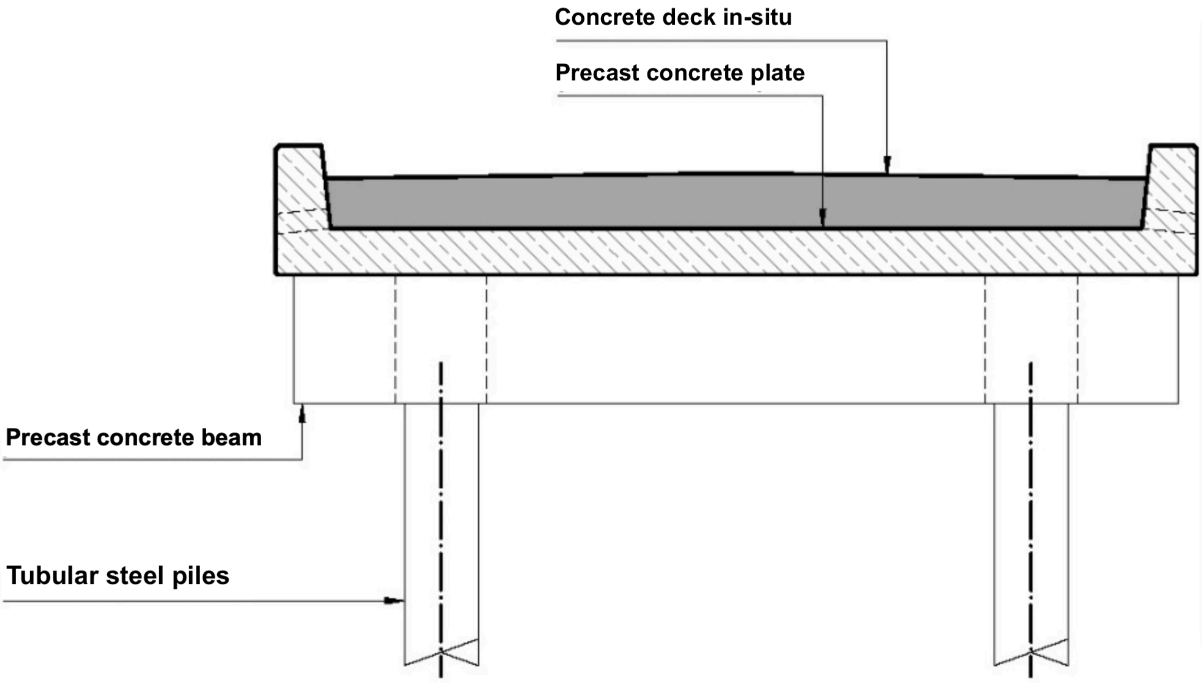

Figure 10: Main cross-section piles with prefab beams, changed to tubular steel piles (SBRCURnet, 2018b)

6.2 OVERVIEW OF INTERVIEWS

The interviews for the case study were performed according to the protocol described in the previous chapter. The interviews were conducted during the COVID-19 pandemic and there thus restricted to online meetings. The sessions were performed via Microsoft Teams.

An overview of the interview ID, company role, and role in the project is shown in Table 8. The interviewees' names are excluded in this public version but are provided in the confidential Appendix D (excluded from the public version). The interview IDs or roles are used in the next sections to identify the interviewees.

The interviewees were asked permission to record the interview for playback. All interviewees approved the recording, which enabled the researcher to obtain verbatim transcriptions. The transcripts are found in Confidential Appendix E (excluded from the public version). These transcriptions were detailed in an automatic speech recognition online application, Amberscript. The automatic transcripts were checked and improved by the researcher. Afterwards, the interview sessions were individually summarised in Excel and the interviewees approved the summaries. The approved summaries formed the basis for the analysis and interpretations in the case study. The interpreted results are described in the next subsections.

Table 8: Overview of interviewees' roles

Project	#	Role company	Individual role
Project 1	1.1	Design and Engineering firm	Project Engineer
	1.2	Design and Engineering firm	Contract Supervisor
	1.3	Design and Engineering firm	Site Supervisor
	1.4	Client	Project Manager
Project 2	2.1	Design and Engineering firm	Project Engineer 1
	2.2	Design and Engineering firm	Project Engineer 2
	2.3	Design and Engineering firm	Project Manager
	2.4a	Contractor	Superintendent
	2.4b	Contractor	Project Manager

6.3 FINDINGS AND INTERPRETATION: PROJECT 1

This section includes the findings and interpretations of Project 1, categorised into four themes. The themes are 1) organisation of constructability, 2) how and why rework and changes occurred, 3) quality level focus, and 4) the future orientation of constructability. The closing section summarises the applied and unapplied 'must-haves' for constructability inclusion in this project.

6.3.1 ORGANISATION OF CONSTRUCTABLITY

The method statement was noted in the tender phase and further developed in the execution phase by the contractor. In addition to this method statement, the health and safety plan was developed in the execution phase. The implication of constructability as a theme was implicitly included by the project engineer in the design phase. Its implicit inclusion in documents was also evident in the risk profile and mitigation file. The project engineer suggested that constructability should be included explicitly in projects.

The method statement, health and safety plan, and risk profile and mitigation file were derived from previous projects and experiences. Hence, developing these plans involved much copying and pasting. The perception of a common work method and experience with similar projects led to implicit implications in making the plans.

Meetings between the client, engineering and design firm, and contractor were held weekly, which was indicated as one of the success factors by the client. The alignment between all parties included knowing what parties were doing and defining and directly solving obstacles. At the beginning of the project, a teambuilding session was held to establish relationships within the project team. This session was held in a local museum. A project member from each party introduced themselves and shared work-related experiences. The weekly meetings and teambuilding session were must-have mechanisms to optimally include constructability in the project. These sessions are interpreted as must-have for enhanced communications, integration, coordination, and mutual respect among all project stakeholders.

The contract supervisor suggested that the missing constructability review was an aspect that indicated the difference between the execution-oriented and the theory-oriented staff. Execution-oriented staff wanted to focus on this review so not only theoretically conceived but also internally reviewed. The contract supervisor suggested that too much was still being devised that was not easily constructable. The ongoing lack of constructability reviews was interpreted that the constructability review is not performed or not performed by staff with constructability knowledge.

The lack of background information regarding the assumptions, drawings, requirements, or reports in the project documentation was another opportunity to improve proper handovers. This view was stated by project engineer. Thus, the substantiation of background information regarding assumptions, drawings, requirements, or reports in the project documentation and extensive handovers is another must-have to include in the project.

Improvement of the organisational and managerial process was also mentioned in the interviews. The process of feedback regarding practical performance and imperfections in the designs was insufficient or unstructured. These views were given by the client and contract supervisor. The contract supervisor suggested that the organisational process was not optimally organised. Experiences of the executional team or 'outside staff' were not reported to the designers or 'inside staff'. Young technical designers should visit the executional area more often, as site supervisors, to learn practical insights. The executional experience of these young engineers, technical designers, or modellers is often limited. Learning from mistakes and previous experiences and improving designs is limited due to the lack in feedback about the execution designs.

6.3.2 HOW AND WHY REWORK OR CHANGES OCCURRED

Rework and changes were identified from the project documentation and additional insights from the interviews. Rework and changes were combined with how and why they occurred, according to the interviewees. The descriptions of the rework and changes are kept vague to exclude any identifying information. Some of the described mechanisms were related to the rework or changes in the project, but other mechanisms were associated to the project by the interviewees.

The site supervisor indicated that the prescribed method statement was not strictly executed in the project. Changes were created in the final layout of the quay structure. In addition to this deviation, the executional method or phase was changed relative to the tender. That change was made by the contractor's executional team, as indicated by the site and contract supervisor. The intended executional method in the tender was not constructable on-site and was thus changed. The intended method had incorporated two parallel construction teams working towards each other. The change in working method led to a change in the finish date. Overall, the method statement was probably not checked by executional staff or the on-site team.

The underlying reasons for not checking the methods statement by executional staff can be related to the answers in the interviews. The contract supervisor suggested several reasons for changing the work method. These were the short tender period (due to the competitive market), the lack of constructability review by the executional team (in the tender phase), and individual preferences of the project staff. were reasons for the. These mechanisms can be translated to several must-have prerequisites, namely following the method statement ('stick to the plan'), using extended and valued tender designs and bids, reimbursing effort or ideas, and conducting a constructability review.

The immediate surroundings and continuous business operations at the construction site hindered the execution of the project. The site supervisor specified that a weekly meeting was held with direct stakeholders of the project. However, schedules and agreements were changed, which changed the work method or planning of the contractor. The end user of the project also did not meet the schedules and agreements.

Sometimes, the construction site was surrounded by unworkable air, according to the client and supervisors. Insufficient or incorrect coordination with the environment was thus a hindrance to the project. Overall, the must-haves were as follows: increased communication, integration, coordination, and mutual respect among all project stakeholders; improving trust between stakeholders; and identifying, visualising, and reviewing the project environment before construction.

One of the major changes in the project occurred because of a changing requirement from the client. Hence, a system was added to the structure late in the project as a last-minute change. Early in the design process, changing requirements from the client directly led to changes in time, scope, and cost. They also led to rework in the design or during execution. It appeared that the inclusion of the system was not fully checked because it became defective due to a normal weather event, according to the contract supervisor.

Another mechanisms described by the client was the separation of different construction elements. In this project, some elements were excluded from the project scope and executed by a different party. This was a challenge for execution, according to the client representative. This information can be interpreted as a must-have to integrate the construction elements where possible. The demands and requirements from the client were not analysed critically before being applied in the project.

The translation from the end user of the asset to functional or technical requirements was another mechanism that caused rework and changes. The design process was faced with diverse functional requirements, some of which were questioned by the end user when the execution was almost finished. This point was stated by the client. The translation of such requirements occurs through the relationships with the end-user client and the client. Therefore, another must-have is to ensure the extensive translation of requirements of the end user and client to the contractor. The commitment and participation of employers and understanding their needs another must-have.

An individual choice by the workers on site was a mechanism that emerged during the interviews. The drawings were good, but the interpretation or processing in practice was not correct, according to the site supervisor. Some construction elements were placed at the wrong level, for example. This element must be replaced in the correct layer or lever, which required rework. This was an unmanageable aspect because individuals made these decisions. The organisation could provide the personnel with insight regarding the effect of such individual choices.

Another individual aspect was the overestimation by a young design engineer about the dimensions on site. Similarly, there was over-optimisation of the design, using uncommon materials of unknown specifications, by the young design engineer. The contract supervisor stated these points. This individual overestimation or over-optimisation can be managed with sufficient checks and supervision during the design process and by reviewing plans and presenting feedback to designers. Sufficient supervision during the design process could include early checking and ongoing verification of assumptions, standards, calculation methods or other essential parts of the calculations. These mechanisms would thus be made manageable.

Execution drawings were not finished and checked on time, so the execution stated ahead of finishing engineering activities. The details of the design incurred constructability issues on-site. These constructability issues occurred because of the failure to apply new visualisation or control techniques and software such as 3D models and drawings, according to the contract supervisor.

The change of staff among the entire executional team during the holiday break led to limited work and a focus on administration instead of the project. This was according to the client and the site and contract supervisor. These problems could be described as a lack of quality focus, which was directly mentioned by the contract supervisor: ‘The project needs a contractor who focusses on the job and puts all the energy into the project.’ This missing quality focus can be associated with the competitive market, lowest price wins, and a 'try everything' attitude to gain additional work. The must-haves include a quality focus, minimising changes to the staff, and preparing executional drawings before the executional phase begins.

The 'how and why' of rework being prevented was also addressed by the interviewees. Equal collaboration and trust were indicated as must-haves in the project organisation between the client and the design and engineering firm. This point was seen in the division of roles and the use of expertise in the meetings. Additionally, the early involvement of an experienced staff member on the client side was a must-have to include constructability details early in the process.

The final valued aspect was the design with an hourly basis and not in a competitive market. Extended constructability analyses might not be included in a design if it is tendered competitively. The design in this project was extensive because there was no competitive market in the design phase. This project also included extensive ground and environmental research in the design phase. The client stated that investing in good research at the ground and environmental levels was possibly costly; however, but if pile driving was not working, the project would face a delay. Valuing the design and investing in a proper and extensive design process were the positive aspects of this project. These aspects can be interpreted as an appropriate consultant fee. These aspects were described by the client representative.

The following mechanisms could not be related to the rework and changes in this project; however, these obstacles had been encountered in practice by the interviewees. One such aspect was a poor ambience and working environment among the project execution team. Furthermore, familiarity and relationships with the project teams of the client, contractor, and design and engineering firm are important. During the COVID-19 pandemic, such relationships have been impaired and mutual respect may decrease, according to the contract supervisor. The mutual respect, working environment and relationships are interpreted as the human factors of well-being, respect, relation, ambience, and working environment are aspects to consider.

Additionally, unstructured knowledge transfer is a hindrance for constructability improvements. Knowledge transfer is conducted from human to human. The knowledge transfer was not organised by the parties involved in the project, according to all interviewees. Thus, must-haves involve building trust between the stakeholders; increasing communication, integration, coordination, and mutual respect among all project stakeholders; and exchanging information through a database, documents of previous projects and lessons learned. Fast and easy access to this information is needed for all the team members.

Other mechanisms could not be linked to the project rework or changes but were related to the rework or changes by the interviewees. Limited checks of their own work or of personnel and the staff of subcontractors were mentioned by the contract supervisor as a reason for changes or rework. Furthermore, the subcontractors were even less supervised than the contractor's personnel. The contractor's personal has more motivation to supervise. Thus, must-haves include using the related checklists, reviewing the plans, and presenting feedback to designers, and changing work processes, policies, procedures, and behaviour.

Some sidesteps were taken in the interviews. Some aspects of these sidesteps were intangible, such as trust, culture, and the people involved in the project. The contract supervisor mentioned trust between the contractor, client, and supervisors. The honest handling of the contract and the dishonest request for additional payments was indicated as losing trust. The cultural aspect was mentioned by the client based on their personal experience with a professional commission for papers. Within these commissions, the culture between engineers with a client, design and engineering firm, and the contactor background was exposed. Individual attitudes to design calculation led to different outcomes, and the commercial perspectives of these engineers seemed to conflict. Thus, an awareness of differences in culture can increase the understanding of the design or design assumptions and calculations.

The last additional sidestep addressed the people involved in the project. These people can be staff members or executional employers on site. The contract supervisor suggested that the core of a project is the people; it is all about the team, not the individual. Educational level was observed to be relatively low, according to the contract supervisor. Additionally, quality control and responsibility were addressed by Interviewee 1.2. This interviewee explained that the personal control of their own work was missing. The contract supervisor implicated that the quality assurance mechanism is still not included in the daily work of an employee for both engineers and contractors.

6.3.3 FUTURE ORIENTATION OF CONSTRUCTABILITY

The interviewees were prompted to think about the future implications of constructability. The first topic addressed was what they would do differently in this project. This question overlapped with how and why rework or changes occurred. These suggested improvements or changes in the process or organisations are specific to the interviewees.

The project engineer would include constructability more explicitly in the process and reports. If these topics were explicitly included, the needed expertise could then be applied. Furthermore, more extensive reporting of the design considerations was indicated by the project engineer. These could include the underlying reasoning, assumptions, and steps taken in the design process to improve the handover between different parties.

The main future improvement for the site supervisor was getting clearer and fixed schedules and agreements with the surrounding businesses. Doing so would require stricter planning and fewer surprises during the execution. During the execution, the project teams met to agree on the planning for the next week and following weeks, together with the client and representatives from the end user, contractor, and port authorities. However, the arranged schedules and agreements regarding the meetings were not always met, according to Interviewee 1.3. Thus, there may be benefits from increasing the integration among all project stakeholders. This includes improving the communication, integration, coordination, and knowledge of project stakeholders about constructability and its advantages, and enhancing mutual respect among all project stakeholders.

The early involvement of executional experience or knowledge by the contractor, or executional supervision, were mentioned by the contract supervisor. The site supervisor and contract supervisor both shared the idea of reviewing the designs with experienced execution staff. This review was currently not optimally performed because of money trade-offs and the need to design with optimal constructability. Furthermore, the contractor should review the execution plans, and these plans need to be shared, checked, and adopted by the executional staff. These points were noted by the contract supervisor. Ensuring input remains constant is identified as improvement for constructability.

Another point addressed was the perceptions among designers and engineers during the design phase. The contact supervisor stated, 'What we should not do as a consultant is to step into the skin of a contractor and pretend that we also know how something should be executed. That is the expertise of a contractor, and we should leave that to him.'

The awareness of the lack of execution knowledge is interpreted as executional knowledge or expertise should be implemented in the design from the actual executional teams. The right person with authority and knowledge should be at the table.

The final suggestion by the contract supervisor was related to the daily procedures of their work. The result of the project must be highlighted in the contractual focus. 'Juridically is getting stronger, and that distracts the attention from what the client wants, a piece of infrastructure. We are constantly arguing about something that is actually not being done, so we must get rid of that juridically. This statement indicates the lack of focus on quality in the project and the juridically of the project over the years.

The client representative was clear about what would be done differently next time. The prevention of the separation of contracts or project parts was their main focus. The integration of the total project should provide more alignment between the elements. Another aspect was the prevention of changes to the scope or contract by the client. He stated that, 'The decision-makers should properly be informed what the impact is of their changes or additions to the project. The changes could lead to less quality because the process interferes.' Thus, the awareness of changes was present but not across the entire company or project stakeholders.

Future-oriented questions probed the interviewees' ideas of the ideal project and tender process. The interviewees were asked what they would do if they were in control of the entire project. The project engineer stated they would include the actual contractor and executional staff much earlier in the project. The executional staff must be involved personally, because the engineers would have a different approach than that of the responsible site superintendent or project manager. This implies another contract model to make early involvement possible.

The early specification and verification of design assumptions and designs with the end user were important, as mentioned by the site supervisor. This relates to the changing requirements of late changes by poorly interpreted demands during the process. The project had been executed with a traditional build contract, separating the design and execution phases. The predesign, design, tender documentation, and the site and contractual supervision were awarded to a single company. This scenario enabled the opportunity to provide feedback to the designer or to ask for the underlying ideas behind the designs, according to the project engineer.

The contract supervisor referred to a kind of teamwork among the involved parties, despite the complex contract forms. Teamwork between parties eliminates the competition between the contractors and the design and engineering firm, which could inflate project costs. The contract supervisor suggested that a RAW contract on the basis of UAV is common because the industry don't know better'. This contract supervisor suggested old-fashioned referential price lists in a national technical newspaper, such as the Cobouw in the building engineering sector. Such prices can be used to determine the project costs. Thereafter, the focus can be on specifying and detailing the project scope and specifications and the actual execution. The focus of the stakeholders should be the project and its results.

Another contractual point was about the complexity of procurement legislation. The client representative would like to include knowledge from the design and engineering as early as possible in the process, even in the initial project plans and business case study phase if possible. Practical implications are desirable in this phase – such as the delivery times of materials, updated unit prices, or constructability considerations. The current complexity of procurement legislation makes the early inclusion of execution knowledge impossible due to foreknowledge, as a level playing field is no longer guaranteed.

The site supervisor stated that reimbursement for additional work did not keep pace with the increase in work that must be performed. Another money-related topic was covered by the contractor representee, who commented on the extensive period and range of the project cost estimation. The cost estimation for this project was plus 40% and minus 10% of the estimated costs. The current observations were for a smaller period, even a one-day timeframe, for the project estimations, including the estimation margin. However, these margins were not considered in the business cases. The project risks, uncertainties, and specifications of the end user were not defined before the price estimation was compiled.

These implications for the ideals of tender or project processes were subordinate to the involved parties. The interviewees were asked which party was the most important for improving the constructability and decreasing the rework or changes. The identification of the crucial party was complex and not generalisable. Three of the four interviewees indicated that the client, contractor, and design and engineering firm were all important. The relations between all parties should be based on mutual respect among the stakeholders. However, the intangible relations also highlight the complexity of improving the constructability. The contractor should not interfere with the interaction between the supervisor and the contractor or client. The team's performance should lead to satisfaction in performing the project and decreasing the project costs, as suggested by the contract supervisor. The site supervisor identified the design and engineering firm as the key party to guide the client; the client is also important because all decisions cost them money. Hence, the decisions should be shared with and supported by the client, according to the site supervisor.

6.3.4 SUMMARISED MUST-HAVE CONSTRUCTABILITY INCLUSION

The must-have mechanisms to include constructability are summarised in Table 9. This table includes a traffic light system to classify the existence of a mechanism in the project. The green check mark indicates that the mechanism was applied in the project. The orange minus sign indicates that the mechanism was applied but not to its maximum potential. The red cross indicates that the mechanism was not recognised in the project. In total, six mechanisms were applied in the project, six were indicated as doubtfully applied, and 30 mechanisms were not applied in the project.

Table 9: Must-have mechanisms for constructability inclusion: Case Study 1

Must-have mechanism	Case Study 1
Appropriate consultant fee	✓
Existence of correct planning to achieve project objectives	✓
Enhancing teambuilding skills	✓
Awareness of the competitive market for contractor and design and engineering firms	✓
Sufficient spending of time and money early in the process (no fixed budget?)	✓
Method statement provided in tender and developed during the pre-execution phase;	✓
Using experts experienced in the field of designing	−
Substantiation of design assumptions	−
Building trust between the stakeholders	−
Reimbursed for effort or ideas	−
integrate the construction elements where possible (integral project approach)	−
Early checking and ongoing verification of assumptions, standards, calculation methods or other essential parts of the calculations	−
Learn from mistakes or previous experiences	✗
Understanding 'why' and 'how' errors are made at the individual, team, and organisational levels	✗
Stimulate quality focus	✗
Familiarity with and use of new and creative methods of construction or new technologies	✗
Identifying, visualizing, and reviewing the project environment before construction	✗
Increasing communication, integration, coordination, and mutual respect among all project stakeholders	✗
Preferring new contracts to traditional ones	✗
Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all the team members	✗
Using new methods of information and communication technology and development tools and equipment	✗
Prevention of owner changes and design error or omission	✗
Prevention of contract changes	✗
Management of cultural barriers due to traditional views and flexible vision	✗

Adequate supervision and inspections (off- and on-site)	✖
Understanding end user requirements	✖
Increasing integration among all project stakeholders	✖
Integrating knowledge and experience of all team members	✖
Reviewing plans and presenting feedback to designers	✖
Critical optimisation of elements by the designer of engineer, with constructability considerations	✖
Early involvement of the executing party or execution knowledge	✖
Ensuring the input remains constant (right person at the table)	✖
Extensive translation of the requirements from the end user and client to the contractor	✖
'Stick to the plan'	✖
Constructability review of the actual executional team on-site	✖
Being aware of human factor, such as human well-being, respect, relation, ambience and working environment are aspects	✖
Paying attention to handover of models, documentation, information, and knowledge	✖
Prevention of modifications in the project teams	✖
Being aware of cultural difference between different involved parties	✖
Explicit inclusion of contractability as theme in project documentation and designs	✖
Prevention of juridically	✖
Prevention of individual deviations in the plan	✖

6.4 FINDINGS AND INTERPRETATION: PROJECT 2

This section presents the findings and interpretations for Project 2. The findings and interpretations are categorised into five themes: 1) organisation of constructability, 2) how and why rework and changes occurred, 3) the personal effects of rework and changes, 4) quality focus, and 5) the future orientation of constructability. The closure of this section includes the summarised must-haves for constructability inclusion. The organisation of constructability is examined in the next section.

6.4.1 ORGANISATION OF CONSTRUCTABLITY

The method statement and risk and mitigation file were available and developed during the design and engineering phase. Examples of developed elements were provided by the contractor representatives, such as building phasing and work-order determination. However, these files and documents were not shared with all the engineers involved.

Project Engineers 1 and 2 were both unfamiliar with the method statement and risk and mitigation file. Hence, the engineers of the designs and calculations of the project elements were unaware of the project method statements and predetermined risks and mitigation. However, these files and documents were known to the contractor and project manager of the design and engineering firm. The interface between the different elements of the design was not managed from the beginning. The project manager added an overarching interface file to manage the interfaces, thus changing the interface of the various design aspects.

As would be expected in the contractual model of design and construct, the executional party was involved early in the project. The contractor was involved in the project during its design, and the involved staff were organised on a personal level. Hence, only the actual site superintendent and project manager were involved. Another organisation element of constructability was the weekly meetings between the contractor and the design and engineering firm. These meetings were supported by the executional team. This internal and external constructability check was included in the process, but some difficulties occurred during the execution.

The client designed some elements of the project at a different level, such as the preliminary design for the jetty and a final design for the quay wall. Furthermore, the different elements were designed by different design and engineering firms. This point was not indicated by the interviewees. The late inclusion of the interface management file by the project manager of the design and engineering firm indicated the absence of a well-integrated design.

Some improvement suggestions were provided by the interviewees. The contractor representatives indicated that they would integrate the project into a single integrated design. The verification process of the requirements was done at the final stage of the project. An improvement in ongoing verification of requirements was suggested by Project Engineer 1. In this project, some challenges occurred in the final stage because the verifier was not involved in assumptions and methodologies. The inclusion of the verifier could provide early insight into the requirements still to be met and those requirements already met through interfaces. This would prevent last-minute verification of the requirements as performed in this project.

Another improvement was suggested by Project Engineer 1. The contact moments in this project were organised with the contractor representatives and the project manager of the design and engineering firm. These contact moments could be more extensive, with larger numbers and more project members than only the project manager.

6.4.2 HOW AND WHY REWORK OR CHANGES OCCURRED

The rework and changes were defined in the project documentation and with associations during the interview sessions. Rework and changes were combined with how and why they occurred according to the interviewees. The rework and changes are vaguely described here to ensure the confidentiality of the studied projects. Some of the described mechanisms are related to rework or changes in the project, whereas others were linked to the project by the interviewees.

The first major request for change, according to the project manager of the contractor, was about changes in load combinations, dimensions, and the number of structural elements in the superstructure of the jetty. The separated design of the substructure and superstructure into different contracts, and at different levels of detail, led to this request for change. Another contractor was awarded the design and execution of the superstructure. Despite the changes in the final design, this superstructure is not realised on top of the finished substructure yet.

In addition to the lack of integration in the design of the entire piece, the substructure was also not integrated when designed. The design of the foundation was separated from the precast beams, which were designed and fabricated by a subcontractor. The development of the beams from a preliminary design to the final or execution design resulted in a couple of changes, according to Project Engineer 2: 'We had to redo our calculations a number of times with different assumptions from the prefab supplier'. Project Engineer 2 added that they, as a design and engineering firm, could manage these changes. The redoing of calculations was not an unmanageable issue, but it could not be managed by the contractor of the design and engineering firm involved in the project.

Changes in the project occurred, such as the load combinations of the superstructure. These changes could be traced back to several events in the project. One reason for the change was an adjustment of the requirements by the client to add an extendable adjustment to the quay wall to make future extension possible. Another element was the coordination with the environment. The contractor was in contact with the surrounding stakeholders of the project during frequent coordination meetings. Although these meetings included an agreement to plan and schedule for the coming weeks, such plans and schedules were not adhered to by stakeholders. The project manager of the contractor indicated that they had aligned early with the stakeholders; however, certain stakeholders or the end user had changed the agreements and schedules ad hoc. This caused friction during the execution.

A special event in this project was the stop-and-go action of the client and end user of the project. The end user wanted to re-evaluate the investment, so the project was on hold for a short period. This period influenced the phasing of the project and created delays, according to the site superintendent of the contractor. The same issue influenced the composition of the design team. The composition of the team changed because some people were reassigned to other projects, according to the project manager of the design and engineering firm. The stop-and-go action of the client and end user of the project have led to a delay of the project and change in the project team. These events can be related to constructability challenges in the project.

Project engineer 2 indicated missing alignment by examples of the internal distribution of the work and responsibilities. Junior engineers performed the calculation under the supervision of senior engineers. The various engineers had personal preferences in their methods or assumptions, and could be stubborn, which could lead to rework due to divided responsibilities.

The delivery date of the project was set at the beginning of the tender process. Some obstacles then introduced new tender dates, so the starting date was moved. However, the delivery date did not change along with the starting date of a project. The contracting authorities entered the market late and with incomplete tender documents or with discussions in a tendering process, according to the project manager of the contractor. These events could not be managed by the awarded contractor. Nonetheless, the consequences of the delayed tender process were managed by the awarded contractor. This imbalance of responsibilities of unmanageable events for the contractor is interpreted as a mechanism of why or how changes could occur due to forced acceleration.

Both project engineers of the design and engineering firm suggested the same underlying mechanisms about why and how rework or changes occurred in the project. Both project engineers indicated that their interactions with the experienced expertise or knowledge of the designs. And receiving feedback was limited and rare. The constructability review process and feedback stage were not well integrated.

Project Engineer 1 added that feedback on the design would be appreciated because the design was still separated from the execution. Thus, learning from mistakes and previous experience, and in turn improving designs, were limited by the lack of feedback on the execution designs.

Within the organisation of the design team, there was a limited transfer of information and data. This information was fragmented when shared with the project engineers and technical designers by the project managers, according to Project Engineer 1. Within the project, rework occurred due to the incorrect interpretation of models, documents, or data between parties and subcontractors during handovers. These handovers were summarised in documents highlighting the stages.

Project Engineer 2 indicated that the transfer of complex computer models was done without the extensive underlying assumptions of the engineers or a solid handover. This missing assumptions and handover have led to wrong calculations and design, and thus, rework in the design phase. Project Engineer 2 stated that, ‘There is always a lack of substantiation for assumptions and elaborations’. The contractor representative indicated that the underlying requirements of the tender documents were unknown, this influenced the total project. The fragmented shared information, and the substantiation of assumptions and elaborations, are interpreted as underlying mechanisms for constructability not being optimally applied in this project.

Another transfer-related underlying mechanism was indicated by Project Engineer 1. This engineer discussed the lack of critical assessment during the handovers as follows: ‘It is easily assumed that the preliminary designs are complete and well designed in earlier stages’. The lack of critical assessment was also indicated by the project manager of the design and engineering firm. The executional team, superintendents, and subcontractor all viewed the designs of the project, but they did not identify complexities or mistakes in the designs. The constructability review was in place; however, the focus was not on the context but on the process.

The competitive market drives contractors to complete tender design and corresponding design choices in short periods. The site superintendent of the contractor indicated that following the tender design and intended process would have resulted in a 'debacle'. From a contractor's perspective, it is desirable to create the best tender design possible with the least costs, which results in easily determining the methods or assumptions. If, at a later stage, the requirements, norms, standards, and regulations are analysed in detail, it appeared that combinations would have led to other decisions. The project manager of the contractor indicated that the brief period given to the tender resulted in a continued design process until the final days of execution. The project manager indicated that the choices made early in the process were irreversible, but they led the project into non-constructable situations. The desired reversible choices also occurred at the end of this project. One of the construction elements was slim designed, as could be reasonably analysed, because the contractor wanted a cheap design. This slim-designed element appeared to be too slim to allow the implementation of the reinforcement.

As indicated in the previous paragraph, the design process continued until the end of the project. This parallel design process led to executional drawings that were not ready on time. These missing executional drawings were not present at the construction area, but the executional work was started. Rework occurred in the construction element through incorrect reinforcements, according to the site superintendent of the contractor. In line with the lack of executional drawings were the last-minute changes in calculations on drawings, which also appeared in this project. The last-minute changes were not themselves a problem, but Project Engineer 1 indicated that the consequences of those changes were not clearly verified or recalculated before execution.

The project manager of the design and engineering firm specified that modern software or techniques were unapplied to all the construction elements. The critical elements such as complex junctions were designed with 3D software, but the general cross-section was not. This was supported by the site superintendent of the contractor, who suggested that the reinforcement obstacles appeared during the executional works. Complex reinforcement can be drawn with simple lines, but with 3D drawing the can provide insight in the actual situation. This early 3D drawing, and checks could prevent some problems at the workplace.

Some sidesteps were taken in the interviews. The stubbornness or rigid attitude of the manager was indicated by Project Engineer 1 as a possible underlying mechanism. Such stubbornness is not related directly to the project but to the experiences of the project engineer. The project engineer had verified a design with the executional representative and had produced improvements to the design. However, the design representative did not accept the improvements. The rigid attitude of a manager is interpreted as a human factor that is hard to describe as an underlying mechanism.

Project Engineer 2 and the site superintendent of the contractor both indicated a related statement about the difference in the culture of the onsite versus offsite staff. This difference can also be described as the difference between theory and practice. The difference of culture among staff occurs not only within a company but also between the involved parties. Project engineer 2 stated that 'The contractor wants a robust design to mitigate margins and tolerances, the designer wants a clear and simple design, and the client wants it fast and cheap.'. Project Engineer 2 added that these conflicting interests would never totally mesh, but the optimum must be kept in mind.

6.4.3 PERSONAL TOUCH AND EFFECT OF REWORK AND CHANGES

The personal effects of rework and changes were probed in the interviews for the case study. These effects are what people added to the project related to constructability. They also involve the personal consequences of the rework or changes on people's feelings (affect) and their mental health.

The experiences of the project team were the main reason for including constructability in projects, according to the project manager of the contractor. The managerial staff with familiarity or experience from similar completed projects are preferred to be included in the projects. This could provide an advantage for choices about constructability and the determination of support structures, as suggested by the project manager of the contractor. This manager indicated that people's experience helped the project; however, some items are still missed in the process. Experience with the context of a project is essential, according to the project managers.

The frustration because of rework or changes was mentioned by four out of five interviewees. Project engineer 2 indicated that small changes of a specific element often led to recalculation of the entire structure because the elements are all connected. The project manager of the design and engineering firm indicated that the frustration was greatest among the modellers, technical designers, and specific drawers, who are at the end of the pipeline.

The time pressure in these projects also drives the frustration. This time pressure arises in earlier stages of the design but is intense at the end of the designs. The site superintendent indicated that frustration could be a bit exaggerated but not continuing in the final designs is unpleasant. Frustrations occurred onsite at the workplace regarding incorrect drawings or non-constructable working methods. These situations were solved onsite, but people needed time and energy to adjust and implement the plans.

6.4.4 FUTURE ORIENTATION FOR CONSTRUCTABILITY

What the interviewees would do differently overlaps with how and why rework or changes occurred. However, are these improvements of changes in the process or organisations specific characterised by the interviewees. Project Engineer 1 indicated two elements to improve the project. The first is the contact between design and execution. This contact could be more extensive and earlier in the process. Another addition could be personal contact between the design engineers and executional staff. Currently, this contact is organised by the project manager of the design and engineering firm.

A second element is better alignment with other parties, such as subcontractors or parties involved in previous phases or preliminary designs. The interviewees defined knowing the underlying reasoning behind the designs from previous phases or preliminary designs, and clear and extensive handover of documents, reasonings, and models to other parties as must-have to improve.

Project engineer 2 suggested improving the integration of design elements; this could be done by the design and engineering firm. The fragmented responsibility, verification, and alignment with subcontractors are obstacles to optimising the constructability. The risk and mitigations file should be completed by all involved parties, such as subcontractors, suppliers and client, contractors, and design and engineering firm, according to Project Engineer 2.

The project manager of the design and engineering firm would apply 3D design techniques to prevent reinforcement placement issues on site. The same manager stated that they would place greater pressure on the other parties to provide the data on time, to design with fixed requirements from other external designed construction elements. The preliminary design of these construction elements is used for the final or execution design of other construction elements. Therefore, 'The client needs to provide the opportunity to significantly improve the overall project process by finalising the separated construction elements into a final design' (Interview 2.3). This final design could be the starting point for the tender documents for the other construction elements.

The client representatives in Interviews 2.4a and 2.5b wanted to see the integrated design of all construction elements in the contract earlier during the organisation of constructability. In addition, improvements indicated what went well in the project. The clear handover from the design and engineering firm was appreciated by the client. The addition of a memo about construction requirements and aspects was pleasant to have, according to the contractor. It was helpful to know additional information such as execution tolerances. The extensive handover is interpreted as extensive underlying assumptions of the engineers or a solid handover to be included as must-have.

The interviewees were asked what they would do if they were in control of the entire project. Project Engineer 1 would stay connected with the person involved: 'These contacts should be started early in the process, but these contacts and meetings should really be implemented to make it valuable'. Furthermore, the right person at the table was indicated as an important condition to ensure the inclusion of the discussed aspects of the project.

Project Engineer 2 would organise the project differently to guarantee information flows to all involved project members. This engineer illustrated a situation where the project manager was in the meeting for the coordination with the client and end users. The obtained information was shared in fragments, and the fragmented information provided the basis for design by the project engineer. 'There was no possibility to ask questions directly to the end user or client and to discuss with the executional department,' as mentioned by Project Engineer 2. Sharing and exchanging information easily among all the team members could improve constructability.

The project managers of both the contractor and the design and engineering firm had the same views about the entire engineering phase being finished before the execution phase began. All executional drawings completed or even totally BIM or 3D integrated may result in an executional phase where the entire executional plan with details in known in front and the design in integrated.

An integrated design was also suggested by the project manager of the design and engineering firm. Instead of separated tenders, documentation, and responsibilities, the design-and-construct contract model could be changed to an integrated project with wider cooperation. This cooperation represents the integrated design and specifications of the sub- and superstructure of a jetty. It also occurs between the client, contractor, and design and engineering firm. The contract model of bouwteams was suggested by the same project manager. The definition of a bouwteam is adopted from Chao-Duivis (2012):

> A Bouwteam is a collaboration agreement in which the contractor is involved in the early phases of the project, and the client and contractor work together to translate the requirements of the client into a well constructable design and a matching construction agreement. A contractor is first selected through a tender. When the design and matching agreement is finished, the same contractor will be the first and only contractor to make a bid for the construction of the project.

The application of a bouwteam could be complemented with the expertise of a design and engineering firm. The application of a bouwteam is interpreted as preferring new contracts over traditional contract models.

The interviewees were asked which party is the most important to improve constructability and to decrease rework associated with changes. Project Engineer 2 indicated that all parties are important, because rework can occur in all phases of the project. However, the client was identified as the most important player to control the optimal constructability process.

6.4.5 SUMMARISED MUST-HAVES FOR CONSTRUCTABILITY INCLUSION

The must-have mechanisms to include constructability are summarised in Table 10. This table includes a traffic light system to classify the existence of a mechanism in the project. The green check mark indicates that the mechanisms was applied in the project. The orange minus sign indicates that the mechanism was applied, but not to its maximum potential. The red cross indicates that the mechanism was not recognised in the project. In total, three mechanisms were applied in the project; six were indicated as doubtfully applied, and 20 were not applied in the project.

Table 10: Must-have mechanisms for constructability inclusion: Case Study 2

Must-have mechanism	Case Study 2
Using experts experienced in the field of designing	✓
Preferring new contracts to traditional ones	✓
Constructability review of the actual executional team on-site	✓
Existence of correct planning to achieve project objectives	–
Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management	–
Early involvement of the executing party or execution knowledge	–
Being aware of cultural difference between different involved parties	–
Participation and presence of contractors in the initial stages of the project to transfer construction knowledge and experience	–
Agreements about balanced responsibility distribution of unmanageable events and risks	–
Awareness of the competitive market for contractor and design and engineering firms	✗
Sufficient spending of time and money early in the process (possibly with no fixed budget)	✗
Substantiation of design assumptions	✗
Reimbursed for effort or ideas	✗
Integrate the construction elements where possible (integral project approach)	✗
Early checking and ongoing verification of assumptions, standards, calculation methods, or other essential parts of the calculations	✗

Learn from mistakes and previous experiences	❌
Familiarity with and use of new and creative methods of construction or new technologies	❌
Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all team members	❌
Using new methods of information and communication technology and development tools and equipment	❌
Prevention of owner changes and design error or omission	❌
Prevention of contract changes	❌
Reviewing plans and presenting feedback to designers	❌
Ensuring the input remains constant (right person at the table)	❌
Extensive translation of the requirements from the end user and client to the contractor	❌
'Stick to the plan'	❌
Being aware of human factors, such as human well-being, respect, relations, ambience and working environment	❌
Paying attention to handover of models, documentation, information, and knowledge	❌
Prevention of modifications in the project teams	❌
Information shared fully with the entire organisation	❌

6.5 CROSS-CASE COMPARISON

From the analysis of both cases, the researcher derived that 45 must-have mechanisms or prerequisites were present in one or both cases. An overview of must-have mechanisms, based on the literature as well as the exploratory and case-study interviews, is provided in Appendix B. These must-have mechanisms were distinguished into two types: applied and unapplied mechanisms. The applied mechanisms were observed to occur in the project, whereas the unapplied mechanisms were not present. Common themes were also derived from the data.

6.5.1 APPLIED MECHANISMS

The first type of mechanisms was characterised by being applied in one or both case study projects. An overview of these mechanisms, with a comparison between literature and exploratory interviews is presented in Table 11.

Table 11: Must-have mechanisms applied in one or both case study projects

Must-have mechanism	Literature	Exploratory Interviews prerequisite	Case Study 1	Case Study 2
Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management			✅	➖
Awareness of the competitive market for contractor and design and engineering firms		√	✅	❌
Sufficient spending of time and money early in the process (no fixed budget?)		√	✅	❌
Appropriate consultant fee	(Love & Edwards, 2004b)	√	✅	
Enhancing teambuilding skills	(Samimpey & Saghatforoush, 2020)		✅	
Existence of correct planning to achieve project objectives	(Samimpey & Saghatforoush, 2020)	√	➖	➖
Using experts experienced in the field of designing	(Samimpey & Saghatforoush, 2020)	√	➖	✅
Preferring new contracts to traditional ones	(Samimpey & Saghatforoush, 2020)	√	❌	✅
Constructability review of the actual executional team on-site			❌	✅
Substantiation of design assumptions		√	➖	❌
Reimbursed for effort or ideas		√	➖	❌
Integrate the construction elements where possible (integral project approach)			➖	❌
Early checking and ongoing verification of assumptions, standards, calculation methods or other essential parts of the calculations			➖	❌
Building trust between the stakeholders		√	➖	
Early involvement of the executing party or execution knowledge		√	❌	➖

Being aware of cultural difference between different involved parties			✗	–
Participation and presence of contractors in the initial stages of the project to transfer construction knowledge and experience	(Samimpey & Saghatforoush, 2020)	✓		–
Agreements about balanced responsibility distribution of unmanageable events and risks				–

The applied must-have mechanisms were analysed and grouped to highlight the common themes. The first derived theme was the inclusion of experience and expertise or knowledge early in the process. This early inclusion of expertise involves mechanisms known from the literature, namely the participation and presence of contractors in the initial stages of the project. They transfer their construction knowledge and expertise; in addition, experts in the field of designing are included.

The newly identified mechanisms are 1) the early involvement of the executing party or execution knowledge and 2) a constructability review of the actual executional team on-site. These mechanisms add a practical contribution to the existing mechanisms from literature. The inclusion of expertise early in the process was mainly observed in the second case study project. It was linked to the type of design and construct contract, which enhanced the inclusion of the contractor early in the process.

The second common theme was an awareness of the obstacles of the competitive market without reimbursement for additional effort or ideas. Preferring new contracts to traditional ones and paying appropriate consultant fees were also indicated in previous research. These mechanisms did not occur in both projects. The second project applied new contracts, whereas the first project applied an appropriate consultant fee without a competitive market.

New mechanisms were suggested in the exploratory interviews and the case study results. These mechanisms were all observed in the first case study. They included awareness of the competitive market for contractors and design and engineering firms; sufficient expenditure of time and money early in the process, without a fixed budget; reimbursement for effort or ideas; and the integration of construction elements where possible.

The identification of new must-have mechanisms related to the competitive market, contractor, and design and engineering firms indicates the need for greater awareness. The preliminary and final designs are drafted by the design and engineering firm in cooperation with the client. These designs are composed without competition from other design and engineering firms. This scenario results in appropriate consultant fees, sufficient expenditure of time and money early in the process (to investigate different alternatives), and reimbursement for effort or ideas. There was no fixed project budget; instead, a range was defined. The derived themes for the applied mechanisms are summarised in Figure 11.

Inclusion of experience, expertise or knowledge early in the process

- Presence of experienced expertise or knowledge in the initial stages of the project to transfer construction knowledge and experience
- Using experts experienced in the field of designing
- NEW: Early involvement of the executing party or execution knowledge
- NEW: Constructability review by the responsible execution team

Awareness of the obstacles of the competitive market without reimbursement for additional effort or ideas

- Preferring new contracts to traditional ones
- Appropriate consultant fee
- NEW: Awareness of the competitive market for contractor and design and engineering firms
- NEW: Sufficient spending of time and money early in the process (no fixed budget)
- NEW: Reimbursed for effort or ideas
- NEW: integrate the construction elements where possible (integral project approach)

Figure 11: Overview of the (partly) applied mechanisms, grouped in themes

6.5.2 UNAPPLIED MECHANISMS

The second type of mechanisms were characterised by being unapplied in one or both case study projects. An overview of these mechanisms, based on a comparison of literature and the exploratory interviews, is shown in Table 12.

Table 12: Must-have mechanisms observed as unapplied in one or both case study projects

Must-have mechanism	Literature	Exploratory Interviews prerequisite	Case Study 1	Case Study 2
Prevention of owner changes and design error/omission	(Habibi et al., 2019; Hwang et al., 2009; Love et al., 2013)	✓	✗	✗
Learn from mistakes or previous experiences	(Love et al., 2008)	✓	✗	✗
Familiarity with and using new and creative methods of construction and new technologies	(Samimpey & Saghatforoush, 2020)	✓	✗	✗
Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all the team members	(Samimpey & Saghatforoush, 2020)	✓	✗	✗
Using new methods of information and communication technology	(Samimpey & Saghatforoush, 2020)	✓	✗	✗
Reviewing plans and presenting feedback to designers	(Samimpey & Saghatforoush, 2020)	✓	✗	✗
Prevention of contract changes	(Verweij et al., 2015)	✓	✗	✗
Ensuring the input remains constant (right person at the table)		✓	✗	✗
Extensive translation of the requirements from the end-user and client to the contractor		✓	✗	✗
Stick to the plan			✗	✗
Being aware of human factor, such as human well-being, respect, relation, ambience and working environment are aspects			✗	✗
Paying attention to handover of models, documentation, information and knowledge			✗	✗
Prevention of modifications in the project teams			✗	✗
Information shared fully with the entire organisation				✗

Integrating knowledge and experience of all team members	(Samimpey & Saghatforoush, 2020)		✗	
Management of cultural barriers due to traditional views and flexible vision	(Jadidoleslami et al., 2018)		✗	
Stimulate quality focus	(Love & Edwards, 2004b)	✓	✗	
Understanding for end-user requirements	(Love & Edwards, 2004b)		✗	
Adequate supervision and inspections (off and on-site)	(Love & Edwards, 2004b)		✗	
Understanding 'why' and 'how' errors are made at the individual, team and organisational level	(Love, Teo, et al., 2018).	✓	✗	
Identifying, visualising, and reviewing the project environment before construction	(Samimpey & Saghatforoush, 2020)	✓	✗	
Increasing communications, integration, coordination, and mutual respect among all project stakeholders	(Samimpey & Saghatforoush, 2020)	✓	✗	
Increasing integration among all project stakeholders	(Samimpey & Saghatforoush, 2020)		✗	
Critical optimisation of elements by the designer of engineer, with constructability considerations.		✓	✗	
Explicit inclusion of contractability as theme in project documentation and designs			✗	
Prevention of juridically			✗	
Prevention of individual deviations of the plan			✗	

These unapplied must-have mechanisms were analysed and grouped into three themes. The first unapplied theme is the extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products. This theme is one of two that were unapplied in both cases. This theme was identified partly from known mechanisms but also from newly identified mechanisms.

The other major unapplied theme in both projects was 'stick to the plan and process by all stakeholders after awarding'. In literature, the prevention of contract changes and owner changes, design errors and omissions, and the stimulation of a quality focus were identified as mechanisms. However, both projects have exposed more mechanisms related to sticking to the plan.

Both projects have applied the method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management, ensuring the input remains constant (right person at the table), Stick to the plan and prevention of modifications in the project teams are the newly derived mechanisms. Creativity and optimisation during the design and tender phases are desired to execute optimally designed projects. However, changes after awarding the project to the contractor led to inadequate understanding and acknowledgement of the effects. These newly identified mechanisms were evidently unapplied in either project.

Awareness of the human contribution and a resistance to change, learn, improve, innovate, and perform in teams was the third theme of the unapplied mechanisms. This theme consists mainly of known mechanisms that were unapplied in the projects. The human contribution and obstruction contain most underlying mechanisms of all derived themes. This theme might be the most challenging area. Six known must-have mechanisms are applied in this theme. The majority of the mechanisms of the theme awareness of the human contribution and obstruction to change, learn, improve, innovate and perform in teams were unapplied. These known mechanisms are listed.

- Management of cultural barriers due to traditional views and flexible vision
- Familiarity with and use of new and creative methods of construction and new technologies
- Changing work processes, policies, procedures, and behaviour.
- Understanding 'why' and 'how' errors are made at the individual, team, and organisational levels
- Increasing communication, integration, coordination, and mutual respect among all project stakeholders
- Enhancing teambuilding skills

In addition to the known mechanisms, four new mechanisms were defined. Being aware of cultural difference between different involved parties and being aware of human factor, such as human well-being, respect, relation, ambience and working environment are aspects are awareness mechanisms. These mechanisms indicated that there was a difference between the parties. Parties can say the same thing but mean something different, such as the perception of constructability or design assumptions.

The awareness of the human factor such as human well-being, respect, relation, ambience and working environment are effect to a human in these projects. These individuals are the workers to building the projects assets, so these workers are more important than currently in place.

The final two new mechanisms were 1) the critical optimisation of elements by the designer or engineer, and 2) constructability considerations and building trust between the stakeholders. These two mechanisms were evidently unapplied in the first project. The derived themes from the unapplied mechanisms with the corresponding themes are summarised in Figure 12.

Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products

- Learn from mistakes or previous experiences
- Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all of the team members
- Using new methods of information and communication technology and development tools and equipment
- Reviewing plans and presenting feedback to designers
- NEW: Substantiation of design assumptions
- NEW: Extensive translation of the requirements from the end-user and client to the contractor
- NEW: Paying attention to handover of models, documentation, information and knowledge
- NEW: Early checking and on-going verification of assumptions, standards, calculation methods or other essential parts of the calculations
- NEW: Information shared fully with the entire organisation

Awareness of human contributions or obstruction to changing, learning, improving, innovating, and performing in teams

- Management of cultural barriers due to traditional views and flexible vision
- Familiarity with and using new and creative methods of construction and new technologies
- Changing work processes, policies, procedures and behaviour.
- Understanding 'why' and 'how' errors are made at the individual, team and organisational level
- Familiarity with and using new and creative methods of construction and new technologies
- Increasing communications, integration, coordination, and mutual respect among all project stakeholders
- Enhancing team-building skills
- NEW: Being aware of cultural difference between different involved parties.
- NEW: Being aware of human factor, such as human well-being, respect, relation, ambience and working environment are aspects
- NEW: Critical optimization of elements by the designer of engineer, with constructability considerations.
- NEW: building trust between the stakeholders

Stick to the initial plan and process by all stakeholders in every phase

- Prevention of contract changes
- Prevention of owner changes and design error/omission
- Stimulate quality focus
- NEW: Ensuring the input remains constant (right person at the table)
- NEW: Stick to the plan
- NEW:Prevention of modifications in the project teams
- NEW: Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management

Figure 12: Overview of the unapplied mechanisms from the case study, as grouped in themes

6.6 CONCLUSIONS OF THE CASE STUDY

This chapter provides the answer to the fourth sub-question: 'What variables are associated with cost of rework related to constructability in executed projects in the Dutch marine infrastructure sector?' The answer to this sub-question involved determining the common themes. These themes contain must-have mechanisms to include constructability in a project. In total, five themes were derived. These themes and the underlying mechanisms are shown in Figure 13.

Inclusion of experienced expertise (early) in the process

- Presence of experienced expertise or knowledge in the initial stages of the project to transfer construction knowledge and experience
- Using experts experienced in the field of designing
- NEW: Early involvement of the executing party or execution knowledge
- NEW: Constructability review by the responsible execution team

Awareness of the obstacles in the competitive market, without reimbursement for additional effort or ideas

- Preferring new contracts to traditional ones
- Appropriate consultant fee
- NEW: Awareness of the competitive market for contractor and design and engineering firms
- NEW: Sufficient spending of time and money early in the process (no fixed budget)
- NEW: Reimbursed for effort or ideas
- NEW: integrate the construction elements where possible (integral project approach)

Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products

- Learn from mistakes or previous experiences
- Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all of the team members
- Using new methods of information and communication technology
- Reviewing plans and presenting feedback to designers
- NEW: Substantiation of design assumptions
- NEW: Extensive translation of the requirements from the end-user and client to the contractor
- NEW: Paying attention to handover of models, documentation, information and knowledge
- NEW: Early checking and on-going verification of assumptions, standards, calculation methods or other essential parts of the calculations
- NEW: Information shared fully with the entire organisation

Awareness of human contributions or obstruction to changing, learning, improving, innovating, and performing in teams

- Management of cultural barriers due to traditional views and flexible vision
- Familiarity with and using new and creative methods of construction and new technologies
- Changing work processes, policies, procedures and behaviour.
- Understanding 'why' and 'how' errors are made at the individual, team and organisational level
- Familiarity with and using new and creative methods of construction and new technologies
- Increasing communications, integration, coordination, and mutual respect among all project stakeholders
- Enhancing team-building skills
- NEW: Being aware of cultural difference between different involved parties.
- NEW: Being aware of human factor, such as human well-being, respect, relation, ambience and working environment are aspects
- NEW: Critical optimization of elements by the designer of engineer, with constructability considerations.
- NEW: building trust between the stakeholders

Stick to the plan and process by all stakeholders after awarding

- Prevention of contract changes
- Prevention of owner changes and design error/omission
- Stimulate quality focus
- NEW: Ensuring the input remains constant (right person at the table)
- NEW: Stick to the plan
- NEW:Prevention of modifications in the project teams
- NEW: Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management

Figure 13: Must-have mechanisms to include constructability and potentially minimise cost of rework

CHAPTER

7

DISCUSSION

7 DISCUSSION

In this chapter, the research findings are discussed, and personal interpretations and suggestions are given. The findings reflect the research objective and the literature. The validity and limitations of this study are discussed in the last section of this chapter.

7.1 CONTRIBUTION OF THIS STUDY

The research objective was to identify the underlying mechanisms of the cost of rework related to constructability in Dutch marine infrastructure projects (Section 2.1). These underlying mechanisms were detailed to identify potential improvements in the projects, as indicated in the research design. The underlying mechanisms were identified, but quantification could not be performed. The mechanisms were derived from the literature as well as the exploratory semi-structured interviews and case studies (including further interviews). These three sources of data were repeatedly compared and aligned with each other (see Section 6.5).

The observations are grouped into three categories. The first category included mechanisms observed in the literature, the exploratory interviews, and case study projects. The second category included mechanisms that were evident only in literature. The third category included the mechanisms that were evident only in the exploratory interviews and case study. The three categories are presented in the following paragraphs.

Fifteen mechanisms were identified and confirmed through the literature review and exploratory interviews, and observations in one or both case studies. These mechanisms are spread over all identified themes (Section 6.5). Three themes included three or more confirmed mechanisms and can be regarded as already known must-have mechanisms. However, they were unapplied in the projects under study.

These unapplied but necessary themes were (1) the extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products; (2) awareness of human contributions or obstruction to changing, learning, improving, innovating, and performing in teams; and (3) 'sticking to the plan and process' by all stakeholders after awarding.

Most of the identified mechanisms across all sources were not yet being included in the projects. This exclusion was explained by Love et al. (2019), who indicated that rework is a 'known-unknown' phenomenon. Thus, rework is a risk that companies are aware of, but the size and effect of the risk is unknown. The personal attitudes of the project staff can also be an obstacle for improving constructability in a project. However, the identified mechanisms and themes can have strong potential for improvement because of their scientific substantiation.

Eleven mechanisms were found only in literature but not observed in the exploratory interviews or case studies. Such mechanisms could not easily be included in the derived themes. They were as follows:

1. Existence of systematic organising structure and reluctance of executive staff to offer pre-implementation consultation.
2. Promotion to change and the consent of the status quo.
3. Design consistency and reliance on IT application output.
4. Superior standard of workmanship.
5. Sufficient contract documentation.
6. Considering environmental factors (technological, economic, and social).
7. Allocating cost for constructability training and implementation.
8. Creating a strong support programme and its development.
9. Paying attention to design and construction standards.

10. Using computer models for better identification of the project situation.
11. Using related checklists.

These mechanisms seem to be far from practical implications and are not directly related to the context of the case study projects. These mechanisms are not perceived to be less important, but are not observed as applied or unapplied, which may indicate that these mechanisms are a useful direction, but the practical implication of translation should be extended. These 11 mechanisms should be further studied to determine a total set of mechanisms within Dutch marine infrastructure projects. Because these mechanisms were derived from the literature, their potential is scientifically substantiated.

The theory also needs modifications to be practically applicable. These modifications should operationalise the mechanisms evident in the literature. An example of an operationalised mechanism is the participation and presence of contractors in the initial stages of the project to transfer construction knowledge and experience (Samimpey & Saghatforoush, 2020). The current complexity of procurement legislation makes the early participation and presence of contractors with execution knowledge impossible. If the contractor is early involved, then a level playing field is no longer guaranteed, due to foreknowledge. This is reframed as the early involvement of the executing party or execution knowledge by the researcher. Executional expertise is crucial because it should not be present only within the contractor party.

Another mechanism that is not entirely accurate based on theory is the existence of systematic organising structure and reluctance of executive staff to offer pre-implementation consultation. The executive staff could not always be involved, but this could be operationalised with the inclusion of execution knowledge.

The final category of the research findings is mechanisms observed only in the exploratory interviews or case studies, but not in literature. Nineteen mechanisms were newly identified in this research and were included in all themes of the must-have mechanisms. However, four themes contain five of these observed mechanisms in this research. These themes are listed below.

1. Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products.
2. Awareness of human contributions or obstruction to changing, learning, improving, innovating, and performing in teams.
3. Stick to the plan and process by all stakeholders after awarding.
4. Awareness of the obstacles in the competitive market, without reimbursement for additional effort or ideas.

The newly identified mechanisms could also be regarded as operationalised must-have mechanisms, based on the known mechanisms. The abstract descriptions from the literature do not cover all the observations from the exploratory interview sessions and case studies. This operationalisation of known mechanisms contributes to the practice-oriented focus of the current study. Furthermore, the categorisation of mechanisms into themes can contribute to the practical implementation of the mechanisms in the projects. Interestingly, the theme stick to the plan contained more newly identified mechanisms than previously known mechanisms.

The derived theme of the inclusion of experience, expertise, and knowledge early in the process is not specifically addressed in this section. The different contract types in both projects influenced the relevance of this theme in the projects. The integrated contract of the second project did enable the inclusion of experienced expertise or knowledge, although it was not optimised in terms of manageable rework and changes at the construction site.

The inclusion of experience, expertise, or knowledge early in the process can be linked to Figure 2 of the level of influence in projects (Davis, 2016; Zolfagharian et al., 2012). Such influences in the project are stronger in the pre-construction phase than the construction phase. The inclusion of expertise early in the process provides essential knowledge in the high-influence phases.

7.2 PRIORITISING THE MECHANISMS

The previously described findings consist of an extensive list with must-have mechanisms to be included in the project. The researcher observed this comprehensive list to be too broad and not directly applicable in practice. The extensive list needs prioritisation to the underlying mechanisms, which causes rework in the case study projects. This prioritisation shortens the list with mechanisms to the most meaningful. The prioritisation is performed in two steps 1) logical causality analyses in section 7.2.1 and 2) classification of manageable or not manageable in section 7.2.2. The remaining mechanisms are discussed in section 7.2.3.

7.2.1 ASSOCATION, CORRELATION AND CAUSATION

The distinction between association, correlation and causation is not derived from determining the underlying mechanisms and related themes. This distinction is critical to prioritising the underlying mechanisms with a causal relationship to the cost of rework related to constructability. 'Association' and 'correlation' are often used interchangeably; however, association is a general relationship, whereas correlation means an increasing or decreasing relationship between variables (Altman & Krzywinski, 2015). In addition, Barrowman (2014) indicated that correlation is not causation. Hence, correlation is not enough for causation.

The observed mechanisms are all classified as associations because there was a lack of direction in the cause-effect relationship. The examination of causality is complex because of the interrelatedness of the variables and underlying mechanisms. However, logical reasoning about cause-and-effect relationships was derived from the case study to prioritise the extensive list of underlying mechanisms (Section 6.6).

The prioritisation was performed through the Pareto principle of 'vital few and trivial many'. This approach implies that relatively few causes account for most of the effect (Juran, 1975). The underlying mechanisms were analysed if causality with the cost of rework related to constructability was observed in the case study projects. The case studies and the interpretations of the researcher are the basis for the causality analysis. In total, 22 mechanisms were designated to have causality with costs of rework related to constructability. The researcher's line of reasoning about the determination of causality of no causality is demonstrated in four examples:

- Example 1: Early checking and on-going verification of assumptions, standards, calculation methods, or other essential parts of the calculations was identified as having a causal relationship with cost of rework related to constructability. In project 2, the calculations were not checked and constantly verified. This lapse led to constructability issues at the construction site, and these issues were passed back to the design and engineering firm to verify the applied solutions. In addition, some construction elements were constructed without proper calculations or verification.
- Example 2: 'Stick to the plan' was identified as a causal relationship with cost of rework related to constructability. In project 1, the tender design included two building streams to meet the desired planning. The responsible executional team changed this approach immediately at the start of the pre-construction phase although the method was constructable. They did not stick to the plan after awarding the tender. This indicates that a proper constructability review was not performed and led to a change by the executional team. These changes in the project plan could have been prevented if a constructability review had been performed in the tender design, and the initial plan could have been executed without changes. The team could only stick to the plan if the tender method statement was executable. This was the case in project 1, but the executional team preferred a different method.

- Example 3: Enhancing team-building skills was identified as having no direct causal relationship with cost of rework related to constructability. This was observed to have an indirect relationship with the cost of rework, because team building affects team performance and this performance can affect the cost of rework. However, direct relationships are possible with other underlying mechanisms, which would lead to further actions that may have causality. The human factor indicates the complexity of the solution space without knowing the directions of the causal relationships.
- Example 4: Appropriate consultant fee was indicated as no causal relationship with the cost of rework related to constructability. The appropriate consultant fee is desirable, but more budget does not directly lead to better designs.

The prioritisation highlighted three themes with mainly underlying mechanisms with causation identified as the vital few. These vital few themes are 1) extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products; (2) stick to the plan and process by all stakeholders after awarding; and (3) inclusion of experienced expertise early in the process. The remaining two themes only included one or two underlying causal mechanisms and were designated as less influential than the vital few. The vital themes and the 18 observed underlying causal mechanisms are shown in Figure 14.

Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products

- Learn from mistakes or previous experiences
- Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all of the team members
- Reviewing plans and presenting feedback to designers
- NEW: Substantiation of design assumptions
- NEW: Extensive translation of the requirements from the end-user and client to the contractor
- NEW: Paying attention to handover of models, documentation, information and knowledge
- NEW: Early checking and on-going verification of assumptions, standards, calculation methods or other essential parts of the calculations
- NEW: Information shared fully with the entire organisation

Stick to the plan and process by all stakeholders after awarding

- Prevention of contract changes
- Prevention of owner changes and design error/omission
- NEW: Ensuring the input remains constant (right person at the table)
- NEW: Stick to the plan
- NEW: Prevention of modifications in the project teams
- NEW: Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management

Inclusion of experienced expertise (early) in the process

- Presence of experienced expertise or knowledge in the initial stages of the project to transfer construction knowledge and experience
- Using experts experienced in the field of designing
- NEW: Early involvement of execution knowledge (or if possible the executing party)
- NEW: Constructability review by the responsible execution team

Figure 14: Vital few themes and underlying mechanisms with a causal relationship with costs of rework related to constructability

7.2.2 MANAGEABLE UNDERLYING MECHANISMS

The underlying causal mechanisms should be manageable by the design and engineering firm. The perspective of the design and engineering firm is applied because of the cooperation with graduation company WSP. This aspect of manageability was established in the problem statement. However, the classification of manageable or not manageable underlying mechanisms needs to be strengthened and is not explicitly addressed by the research findings.

All defined mechanisms were analysed and classified as either manageable or not manageable by the design and engineering firm. The classification of manageable mechanisms is based on the researcher's interpretation. The definition of manageable as 'Ability to be controlled and in the sphere of direct influence' was used to classify the mechanisms as manageable or unmanageable by the design and engineering firm. Four examples are provided here to demonstrate the reasoning.

- Example 1: Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all team members was identified as manageable. The reason is that these are an internal organisational aspect that can be included without others involved.
- Example 2: Presence of experienced expertise or knowledge in the initial stages of the project to transfer construction knowledge and experience is interpreted as manageable because experienced expertise or knowledge should be available within a design and engineering firm and need to be included in the project teams earlier. If this expertise is not sufficiently available, this mechanism is unmanageable.
- Example 3: Increasing the integration among project stakeholders was identified as unmanageable by the design and engineering firm. Only the client can steer the integration among project stakeholders. The design and engineering firm can integrate among stakeholders who have a direct relationship only if the contract type allows such integration. Therefore, the integration of stakeholders and top-level requirements should be clear and unambiguous at the start of the project. The design and engineering firm alone cannot affect this integration.
- Example 4: Prevention of owner changes and consequential design errors or omissions was identified as unmanageable. The design and engineering firm does not directly influence the decisions of the client or the owner to change. The client or owner can be made aware of the consequences, but the owner changes are still unmanageable.

The following underlying mechanisms with a causal relationship to costs of rework related to constructability and the overarching themes are identified to be manageable by the design and engineering firm. Figure 15 shows an overview of manageable mechanisms having a causal relationship with the costs of rework.

Inclusion of experienced expertise (early) in the process

- Presence of experienced expertise or knowledge in the initial stages of the project to transfer construction knowledge and experience
- Using experts experienced in the field of designing

Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products

- Learn from mistakes or previous experiences
- Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all of the team members
- Reviewing plans and presenting feedback to designers
- NEW: Substantiation of design assumptions
- NEW: Paying attention to handover of models, documentation, information and knowledge
- NEW: Early checking and on-going verification of assumptions, standards, calculation methods or other essential parts of the calculations
- NEW: Information shared fully with the entire organisation

Stick to the plan and process by all stakeholders after awarding

- NEW: Ensuring the input remains constant (right person at the table)
- NEW: Stick to the plan
- NEW: Prevention of modifications in the project teams
- NEW: Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management

Figure 15: Prioritised manageable must-have mechanisms to include constructability by a design and engineering firm

7.2.3 REMAINING UNDERLYING MECHANISMS

The extensive list is prioritised to manageable must-have mechanisms with a causal relationship with the costs of rework. The remaining themes and corresponding mechanisms are excluded in the prioritisation. These themes and mechanisms can be described as 'good to have' instead of must-haves. These earlier derived themes and mechanisms are still interesting but less relevant to be practically applicable. For example, the client and contractor could manage some of the derived themes and mechanisms, or a causal relationship could be observed in other projects. However, in the remaining sections are only the must-have themes and mechanisms used.

The remaining two themes are described as 'good to have' themes. These two themes are 1) create awareness of the human contribution and obstruction to change in behaviour and attitude, learn, improve, innovate, and perform in teams, and 2) Awareness of the obstacles of the competitive market without reimbursement for additional effort or ideas. These themes require adjustments to organisations, knowledge or the market because of observed interwovenness with other mechanisms. The researcher's augmentation is that the human is the centre of all activities and possibilities to improve. All earlier derived themes and mechanisms are related to personal choices and actions.

7.3 ADDITIONAL FINDINGS

The unwillingness to learn, improve, or share previous insights and experiences was a surprising observation for the researcher. This unwillingness could not easily be described in the previous chapters. In addition, the arrangement of the project for the case study was challenging. Exploratory calls with possible interviewees exposed that no project included all the involved parties who would cooperate in the research, as illustrated by a project that was to participate in the research. The contact person was willing to participate in the research but was unwilling to share everything about the project due to tension with other parties. The unwillingness to share everything was evident even for the project a decade old. This attitude is an obstacle for improving future projects. Business-related issues became personal issues between individuals.

The unwillingness to learn, improve, or share previous insights and experiences also indicates the complexity of the subject of constructability. This complexity is confirmed by the many indicated must-have mechanisms to be included. This study narrowed these down to provide a clear overview with overarching themes and corresponding underlying mechanisms. However, the number of mechanisms remains vast.

Another finding was the observation of the different perspectives. The interviewees all described the term 'constructability'; however, the client, design and engineering firm, and contractors all said something different. These descriptions by the interviewees resulted in a variety of perceptions.

Another perception related issue is observed in the case study projects, where it was indicated that the interpretation of needs, requirements, design assumptions, and calculations are vulnerable to other misunderstandings or imagination. The specified theme of extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products should contribute to the awareness of the transfer and handovers in projects.

Rework is described in this research as 'the total direct costs of re-doing work in the field regardless of the initiating cause'. This definition includes change orders and errors caused by off-side manufacture. Causes associated with rework appeared in the exploratory interviews and the case study related to client's or end-user's changes. Additionally, causes associated with rework are linked to organisational or personal errors. These observations are also suggested as causes of rework by Love and Li (2000) and Love et al. (2010). The broad applied definition of rework enables the range of underlying mechanisms for managing cost of rework related to constructability. Cost of rework is directly linked to cost of quality in this research. However, the research finding reveals rework is not only related to quality. The costs of rework are an integral part of the cost of quality, but intangible costs need to be considered to identify the total cost of quality.

Human contribution and obstruction in a project have been indicated in previous literature. However, the actual impact on a project is seldom elaborated. Enhancing teambuilding can be linked to Ryan's self-determination theory, which can increase the relatedness of people in projects. Self-determination theory includes competence, relatedness, and autonomy. These appear to be essential for optimal functioning and for natural growth and integration, as well as for constructive social development and personal well-being (Ryan & Deci, 2017).

Lencioni (2012) similarly indicated that the absence of trust is a critical dysfunction in a team. Two articles were found to support the awareness of the human contribution and obstruction to changing, learning, improving, innovating, and performing in teams. The mindsets of individuals and organisations are an essential aspect of moving from error prevention to error management as well as authentic leadership, psychological safety, and psychological contract (Love, 2020; Love et al., 2020). This shift from error prevention to error management is indicated in Figure 16. The change from a fixed mindset to a growth mindset, and the human factor and soft skills in a project, are areas for future research regarding Dutch marine infrastructure projects.

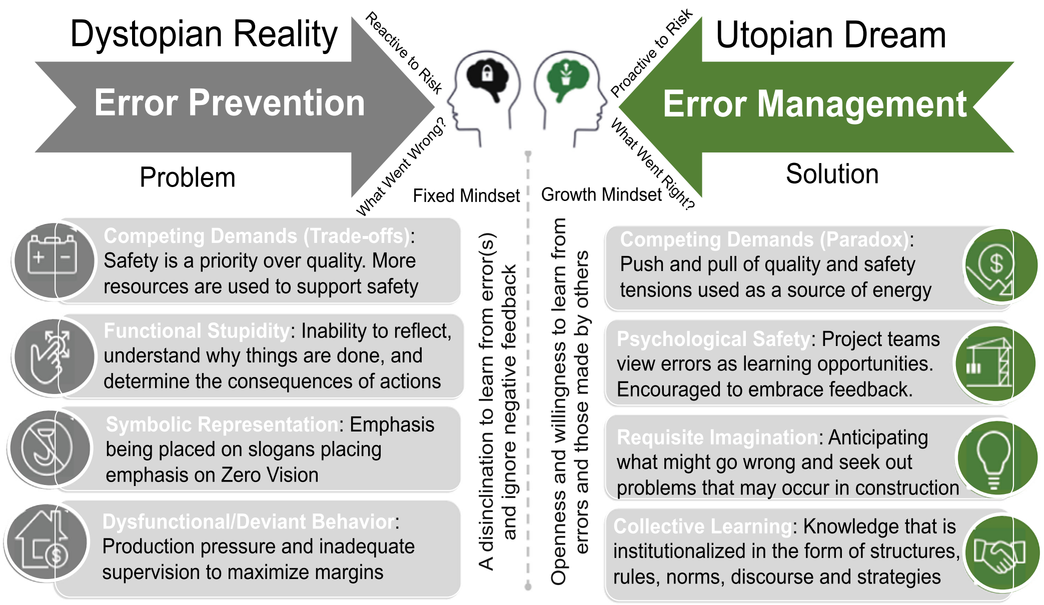

Figure 16: From error prevention to error management (Love et al., 2020)

Rijkswaterstaat investigated the future perspective of challenges and improvement opportunities in the grond-, weg- en waterbouw (GWW) sector in the Netherlands (Rijkswaterstaat, 2019). This report is known as the McKinsey report in the industry, because the research was performed by McKinsey. Some of the identified mechanisms are intended to be included in future infrastructure projects.

One such measure is the two-phase contract (Rijkswaterstaat, 2020). It separates the price determination of the design and execution into two phases but with the same contractor. This development supports the need for new contract models, appropriate consultant fees, sufficient allocation of time and money early in the process, reimbursement for effort or ideas, and the integration of construction elements where possible. These elements are combined in this research as the awareness of the obstacles of the competitive market without reimbursement for additional effort or ideas. Rijkswaterstaat's work could lead to the inclusion of the indicated must-have mechanisms in future projects.

7.4 VALIDITY AND LIMITATIONS OF THE RESEARCH

Qualitative research methods were applied in this research because they were suitable to determine the underlying mechanisms to include constructability. The literature review was extensive and resulted in a large sample of mechanisms. The exploratory interviews were semi-structured and were held confidentially because of possible commercial considerations. Yin (2011) suggested four requirements for case studies: construct validity, internal validity, external validity, and reliability. These four tests are examined in this section.

Pandey and Patnaik (2014) summarised construct validity as correct operational measures being used for the concepts being studied. The interviews were transcribed and summarised to be verified by the interviewees before inclusion in the thesis, to support construct validity. In addition to the reviewed summaries, multiple sources of evidence were applied to strengthen the construct validity.

The case study observations were analysed based on pattern-matching, which resulted in the derived themes in Section 6.5. Pattern-matching was implemented to compare the applied and unapplied mechanisms in the case studies. The common denominators were developed into themes to strengthen the internal validity.

The external validity is specified as defining the domain to which the study's findings can be generalized (Pandey & Patnaik, 2014). This generalisability can be questioned due to only two case studies and an engineering and design firm's perspective. However, interview sessions were held with representatives of the engineering and design firm, client and contractor. These diverse roles include all points of view to the case study projects. Extensive research is need to examining the broad generalisability of the derived must-have themes and underlying mechanisms.

Golafshani (2003) identified reliability as a result that can be replicated. The reliability was increased by arranging the case study protocol to include semi-structured interview questions. The interview questions were shared with the graduation committee and improved with their feedback to ensure reliability. Furthermore, Noble and Smith (2015) stated that trustworthiness is critical in qualitative research. Trustworthiness was fulfilled by applying the case study protocol, semi-structured interviews, verbatim transcripts, and respondent validation.

The research contained different interview sessions held via digital meetings due to the COVID-19 pandemic. The digital form of interviewing is more limited than direct interaction, and deeper exploration could not easily be done. Another element related to interviews is bias among the interviewees and interviewer. Interviewee bias was prevented to anonymize the project and interviewees in the reporting. However, unwillingness to share insights could have led to socially desirable answers, which may have influenced the results. Interviewer bias was prevented by the structure of the interview sessions, with interview guidelines and predetermined questions.

The case study interviews included only one design and consultancy firm, one contractor, and one client. The difficulty in finding participants for the cases led to the decision to include different contract models instead of one. The number of cases was also a limitation of this research. Furthermore, quantification of the impact of underlying mechanisms was not possible in this research.

Finally, the point at which no new information or themes are observed in the data (Guest, Bunce, & Johnson, 2006) was not obtained. Thus, there is a need for further research about the must-have mechanisms to minimise the cost of rework related to constructability within Dutch marine infrastructure projects.

This research contributes to the link between theory and practice. The concepts cost of rework and constructability are combined to define the occurring mechanisms in two case study projects. Derived mechanisms from the literature are also observed in the case study project and so confirmed. The research also indicated new mechanisms to be included, despite the limited cases. These newly derived mechanisms could contribute to the literature's extension about underlying mechanisms of cost of rework related to constructability. The mechanisms derived in theory are not all integrated in practice, which indicates an opportunity to improve.

CHAPTER

8 CONCLUSION AND RECOMMENDATIONS

8 CONCLUSION AND RECOMMENDATIONS

This chapter answers the research sub-questions as well as the main question: What are underlying mechanisms for managing cost of rework related to constructability in Dutch marine infrastructure projects?' These answers are described in Section 8.1. In addition, recommendations from this research are provided in Section 8.2. They are separated into two sections: recommendations for practice (Section 8.2.1) and recommendations for further research (Section 8.2.2).

8.1 ANSWERING THE SUB-QUESTIONS

The sub-questions are answered in this section.

SQ 1 Which underlying mechanisms for managing the cost of rework related to constructability are known?

The known underlying mechanisms were derived from the literature review, consisting of a list of 38 prerequisites or must-have mechanisms to include constructability in a project (see Section 3.7). These mechanisms were then used to identify whether they were included in Dutch marine infrastructure projects.

SQ 2 What are the perspectives of clients, contractors, and design and engineering firms regarding constructability, in the context of traditional contracts?

The interviewees struggled to describe their perceptions and offered diverse views. The client representatives described the definition of constructability as diverse but limited. From their perspective, constructability means a constructable design, safety inclusion, constructability by various contractors; in addition, current and prevailing rules, directives, standards, and legislation must be applied.

Design and engineering firm representatives characterised constructability more extensively. Several aspects were included, such as buildability, executability, and feasibility of a design in geometric challenges and limitations. Other aspects mentioned were safety, impact on the environment, awareness of execution obstacles, design responsibility, equipment, delivery time, and availability of materials.

The contractor interviewees had broader views than the client and design and engineering firm perspectives. The characteristics were defined as safety, the feasibility of the design, executability with current equipment, delivery time and availability of materials, the need for auxiliary structures, effect on the environment, design responsibility, equipment, lead time, and interface management. This expanded list by the contractor indicates a different view on constructability inclusion. Alignment of the perceptions of constructability could contribute to increased constructability in Dutch marine infrastructure projects.

SQ 3 Which underlying mechanisms regarding managing the cost of rework related to constructability are observed in exploratory interview?

In the exploratory interviews, 32 mechanisms were indicated by the interviewees. Most (21) were already known from the literature. Eleven additional mechanisms were suggested in the interview sessions, but they were unapplied in the current project approach. The newly suggested but unapplied must-have mechanisms were as follows:

- Awareness of the competitive market for contractor and design and engineering firms.
- Critical optimisation of elements by the designer or engineer with constructability considerations.
- Substantiation of design assumptions.
- Building trust between the stakeholders.
- Early involvement of the executing party or execution knowledge.
- Sufficient spending of time and money early in the process (no fixed budget).
- Reimbursed for effort or ideas.
- Ensuring the input remains constant (right person at the table).
- Realistic estimation of parts that can be performed within a brief period.
- Reluctance of the contractors' market.
- Extensive translation of the requirements from the end user and client to the contractor.

SQ 4 What variables are associated with cost of rework related to constructability in executed projects in the Dutch marine infrastructure sector?

Two projects were investigated with two different contract types, the 'build and design' and 'build' forms. In total, 26 mechanisms were indicated as applied or unapplied mechanisms in both projects. Among these mechanisms, 10 were also evident in the literature and interviews. Seven unapplied mechanisms from the exploratory interviews were confirmed, and nine new mechanisms were discovered. These confirmed and newly discovered mechanisms provide additional mechanisms to include in future projects.

The cross-case analysis resulted in a broader view, which introduced themes regarding the mechanisms for constructability inclusion. These themes combine a group of mechanisms and indicate the group's core. These themes, listed below, are must-haves to include in a project.

- Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products.
- Inclusion of experienced expertise or knowledge (early) in the process.
- Awareness of human contributions or obstruction to changing, learning, improving, innovating, and performing in teams.
- Stick to the plan and process by all stakeholders after awarding.
- Awareness of the obstacles in the competitive market, without reimbursement for additional effort or ideas.

8.2 ANSWERING THE MAIN RESEARCH QUESTIONS

The answer to the main research question – What are underlying mechanisms for managing cost of rework related to constructability in Dutch marine infrastructure projects? – was informed by the answers to the sub-questions. The cost of rework related to constructability can be minimised by including the must-have mechanisms and themes in a project.

These mechanisms were narrowed down by examining causation with cost of rework related to constructability and manageability by the design and engineering firm. The defined and prioritised must-have mechanisms are listed below, with the themes in Figure 17. The newly derived or operationalised must-have mechanisms are identified as 'New'.

Inclusion of experienced expertise or knowlegde (early) in the process.

- Presence of experienced expertise or knowledge in the initial stages of the project to transfer construction knowledge and experience
- Using experts experienced in the field of designing

Extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products

- Learn from mistakes or previous experiences
- Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all of the team members
- Reviewing plans and presenting feedback to designers
- NEW: Substantiation of design assumptions
- NEW: Paying attention to handover of models, documentation, information and knowledge
- NEW: Early checking and on-going verification of assumptions, standards, calculation methods or other essential parts of the calculations
- NEW: Information shared fully with the entire organisation

Stick to the plan and process by all stakeholders after awarding

- NEW: Ensuring the input remains constant (right person at the table)
- NEW: Stick to the plan
- NEW: Prevention of modifications in the project teams
- NEW: Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management

Figure 17: Prioritised manageable must-have mechanisms to include constructability in a design and engineering firm

8.3 RECOMMENDATIONS FOR PRACTICE

This research identified underlying mechanisms for managing the cost of rework related to constructability, which could influence future projects. Several recommendations for practice can be adapted from this work. The most relevant recommendation for practice is the application of the manageable must-have themes including the underlying mechanisms. These are divided according to their role in the projects of the client, design and engineering firm, and contractor.

Recommendations for clients:

- Ensuring the input remains constant after awarding the contract. The client should stick to the plan, which includes prevention of contract and owner changes as well as design error/omissions.
- Apply the good to have theme being aware of the obstacles within a competitive market. This includes spending money early in the process, establishing an appropriate consultant fee, integrate the contract where possible and reimbursement for effort or ideas. This reimbursement could incentivise design and engineering firms or contractors to perform better or with better quality.

Recommendations for design and engineering firms:

- Implementation of extensive transfer, verification, handover, and control of knowledge, documents, models, requirements, needs, and products. This can be applied in the handover between parties, such as handover meetings at the engineering level and not solely at higher levels. Practical implications are derived from the obtained mechanisms: pay more attention to handover and verify if the information is interpreted in the same way, fully share information and documents, describe or explain the substantiation of design assumptions, and provide constructive feedback to the engineers.
- Include more experienced expertise or knowledge earlier in the project teams. This could be applied by including a contract supervisor (directievoerder) or site supervisor (opzichter) in the project teams.

Recommendations for contractors:

- Create awareness about deviations from the initial plan during the final design and execution phase. All stakeholders should thus stick to the plan and process after awarding. This includes remaining the same project teams, follow the initial plan, and paying attention to the development of the methods statement and risk analysis and risk management.

Recommendation for all:

- Apply the good to have theme Awareness of human contributions or obstruction to changing, learning, improving, innovating, and performing in teams. This recommendation is observed to be interwoven with many other mechanisms and requires an adjustment in the organisations, knowledge or the market. This can be implemented by enhancing teambuilding activities, increasing communication between project members, and creating a mental safe working environment.

8.4 RECOMMENDATIONS FOR FURTHER RESEARCH

This research has highlighted new opportunities for further research. Some ideas are listed below.

- Due to the time frame of the research and the complexity of constructability, the validity and causation of the newly defined mechanisms have not been tested or validated in a large sample of Dutch maritime infrastructure projects. It is recommended to validate the mechanisms in other executed projects or for a planned project. This research could contribute to a checklist for mechanisms to minimise the cost of rework related to constructability.
- Another interesting area for research is the human aspect in the project. Human contributions and obstructions to the project were identified in this research as possible obstacles for optimising constructability. Human involvement is an elusive phenomenon that highlights the social science, psychology, mindset, and teambuilding themes. These can inform additional research objectives.
- This study did not quantify the impact of the themes and underlying mechanisms on scope, time, cost, quality, personal health, and safety. It also did not examine causality. Quantifying the impact of the various mechanisms could help prioritise the mechanisms with the most significant impact. These effects are best analysed in an ongoing project. Intangible costs need to be considered to identify the total quantification, such as unwritten and undocumented effects.

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APPENDICES

APPENDICES

Appendix **A**

- Guidance semi-structured exploratory interviews

Appendix **B**

- Constructability mechanisms from literature, exploratory interviews and case studies

APPENDIX

A

GUIDANCE SEMI-STRUCTURED EXPLORATORY INTERVIEWS

GUIDANCE SEMI-STRUCTURED EXPLORATORY INTERVIEWS

SEMIGESTRUCTUREERDE INTERVIEW

Dit leidraad is opgesteld op basis van het framework van Kallio, Pietilä, Johnson, and Kangasniemi (2016).

De doelen van het interview zijn: explore perceptions on constructability in practice

Onderwerpen die besproken dienen te worden:

Welkom en toestemming tot opnemen van het interview

Algemene introductie Jordy plus introductie van afstudeeronderwerp:
Maakbaarheid en uitvoerbaarheid worden ingepast als het concept constructability
Binnen de maritieme infra projecten

Details interviewee

- Relevante werkervaring in de maritieme infra sector
- Rol van de organisatie in projecten
- Eigen rol in projecten

Hoe definieert u het begrip "Constructability"?
Perceptie: Hoe kijkt u aan tegen constructability, wat houdt het voor u in?

Welke voorbeelden kunt u geven m.b.t. problemen rondom constructability in projecten?

- Wat was het probleem?
- Waardoor werd het veroorzaakt?
- Welke repressieve maatregelen werden er genomen om Constructability te waarborgen binnen projecten?
- Welke preventieve maatregelen worden genomen om Constructability te waarborgen binnen projecten? Alternatieven vinden.
- Hoe had dat beter gekund?

Welke mechanisme zijn er die zorgen dat er niet wordt geoptimaliseerd op constructability?

Hoe ziet u de ideale omstandigheid tijdens de tenderfase met betrekking tot constructability?

Wat wilt u nog kwijt over "Constructability"?

Afsluiting bedanken voor interview

Kallio, H., Pietilä, A. M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of advanced nursing, 72*(12), 2954-2965.

APPENDIX

B

CONSTRUCTABILITY MECHANISMS FROM LITERATURE, EXPLORATORY INTERVIEWS AND CASE STUDIES

CONSTRUCTABILITY MECHANISM FROM LITERATURE, EXPLORATORY INTERVIEW AND CASE STUDIES

Table 13: constructability must-have mechanism from literature, exploratory interview and case studies

#	Must-have mechanism	Literature	Exploratory Interviews prerequisite	Case study 1	Case study 2
1	Learn from mistakes or previous experiences	(Love et al., 2008)	✓	❌	❌
2	Understanding 'why' and 'how' errors are made at the individual, team and organisational level	(Love, Teo, et al., 2018).	✓	❌	
3	Stimulate quality focus	(Love & Edwards, 2004b)	✓	❌	
4	Sufficient knowledge	(Jadidoleslami et al., 2018)	✓		
5	Appropriate consultant fee	(Love & Edwards, 2004b)	✓	✅	
6	Commitment and participation of employers and understanding their needs	(Samimpey & Saghatforoush, 2020)	✓		
7	Existence of correct planning to achieve project objectives	(Samimpey & Saghatforoush, 2020)	✓	✅	➖
8	Familiarity with and using new and creative methods of construction and new technologies	(Samimpey & Saghatforoush, 2020)	✓	❌	❌
9	Knowledge of project stakeholders about constructability and its advantage	(Samimpey & Saghatforoush, 2020)	✓		
10	Changing work processes, policies, procedures and behaviour.	(Love, Edwards, et al., 2016)	✓		
11	Identifying, visualizing, and reviewing the project environment before construction	(Samimpey & Saghatforoush, 2020)	✓	❌	
12	Increasing communications, integration, coordination, and mutual respect among all project stakeholders	(Samimpey & Saghatforoush, 2020)	✓	❌	

#	Must-have mechanism	Literature	Exploratory Interviews prerequisite	Case study 1	Case study 2
13	Preferring new contracts to traditional ones	(Samimpey & Saghatforoush, 2020)	✓	❌	✅
14	Sharing and exchanging information through a database, documenting previous projects and lessons learned, and fast and easy access to them by all of the team members	(Samimpey & Saghatforoush, 2020)	✓	❌	❌
15	Using experts experienced in the field of designing	(Samimpey & Saghatforoush, 2020)	✓	➖	✅
16	Using new methods of information and communication technology and development tools and equipment	(Samimpey & Saghatforoush, 2020)	✓	❌	❌
17	Prevention of owner changes and design error/omission	(Habibi et al., 2019; Hwang et al., 2009; Love et al., 2013)	✓	❌	❌
18	Willingness to innovation and creativity	(Jadidoleslami et al., 2018)	✓		
19	Prevention of contract changes	Verweij et al. (2015)	✓	❌	❌
20	Participation and presence of contractors in the initial stages of the project to transfer construction knowledge and experience	(Samimpey & Saghatforoush, 2020)	✓		➖
21	Management of cultural barriers due to traditional views and flexible vision	(Jadidoleslami et al., 2018)		❌	
22	Design consistency and reliance on IT application output	(Lam & Wong, 2009)			
23	Adequate supervision and inspections (off and on-site)	(Love & Edwards, 2004b).		❌	
24	Existence of systematic organising structure and reluctance of executive staff to offer pre-implementation consultation	(Jadidoleslami et al., 2018)			
25	Understanding for end-user requirements	(Love & Edwards, 2004b)		❌	

#	Must-have mechanism	Literature	Exploratory Interviews prerequisite	Case study 1	Case study 2
26	Allocating cost for constructability training and implementation	(Samimpey & Saghatforoush, 2020)			
27	Considering environmental factors (technology, economic, and social)	(Samimpey & Saghatforoush, 2020)			
28	Creating a strong support program and its development	(Samimpey & Saghatforoush, 2020)			
29	Enhancing team-building skills	(Samimpey & Saghatforoush, 2020)		✅	
30	Increasing integration among all project stakeholders	(Samimpey & Saghatforoush, 2020)		❌	
31	Integrating knowledge and experience of all team members	(Samimpey & Saghatforoush, 2020)		❌	
32	Paying attention to design and construction standards	(Samimpey & Saghatforoush, 2020)			
33	Reviewing plans and presenting feedback to designers	(Samimpey & Saghatforoush, 2020)	✓	❌	❌
34	Using computer models for better identification of project situation	(Samimpey & Saghatforoush, 2020)		✅	
35	Using related checklists	(Samimpey & Saghatforoush, 2020)			
36	Sufficient contract documentation	(Love & Edwards, 2004b)			
37	Superior standard of workmanship	(Love & Edwards, 2004b)			
38	Promotion to change and the consent of the status quo	(Jadidoleslami et al., 2018)			
39	Awareness of the competitive market for contractor and design and engineering firms		✓	✅	❌
40	Critical optimization of elements by the designer of engineer, with constructability considerations.		✓	❌	

#	Must-have mechanism	Literature	Exploratory Interviews prerequisite	Case study 1	Case study 2
41	Substantiation of design assumptions		√	–	✗
42	Building trust between the stakeholders		√	–	
43	Early involvement of the executing party or execution knowledge		√	✗	–
44	Sufficient spending of time and money early in the process (no fixed budget?)		√	✓	✗
45	Reimbursed for effort or ideas		√	–	✗
46	Ensuring the input remains constant (right person at the table)		√	✗	✗
47	Realistic estimation of parts that can be performed within a concise period of time		√		
48	Reluctant of the contractors' market		√		
49	Extensive translation of the requirements from the end-user and client to the contractor		√	✗	✗
50	Stick to the plan			✗	✗
51	Constructability review of the actual executional team on-site			✗	✓
52	integrate the construction elements where possible (integral project approach)			–	✗
53	Being aware of human factor, such as human well-being, respect, relation, ambience and working environment are aspects			✗	✗
54	Paying attention to handover of models, documentation, information and knowledge			✗	✗
55	Early checking and on-going verification of assumptions, standards, calculation methods or other essential parts of the calculations			–	✗
56	Prevention of modifications in the project teams			✗	✗

#	Must-have mechanism	Literature	Exploratory Interviews prerequisite	Case study 1	Case study 2
57	Method statement provided in tender and developed during the pre-execution phase, including risk analysis and risk management			✓	−
58	Being aware of cultural difference between different involved parties.			✗	−
59	Explicit inclusion of contractability as theme in project documentation and designs			✗	
60	Prevention of juridically			✗	
61	Information shared fully with the entire organisation				✗
62	Agreements about balanced responsibility distribution of unmanageable events and risks				−
64	Prevention of individual deviations of the plan.			✗	