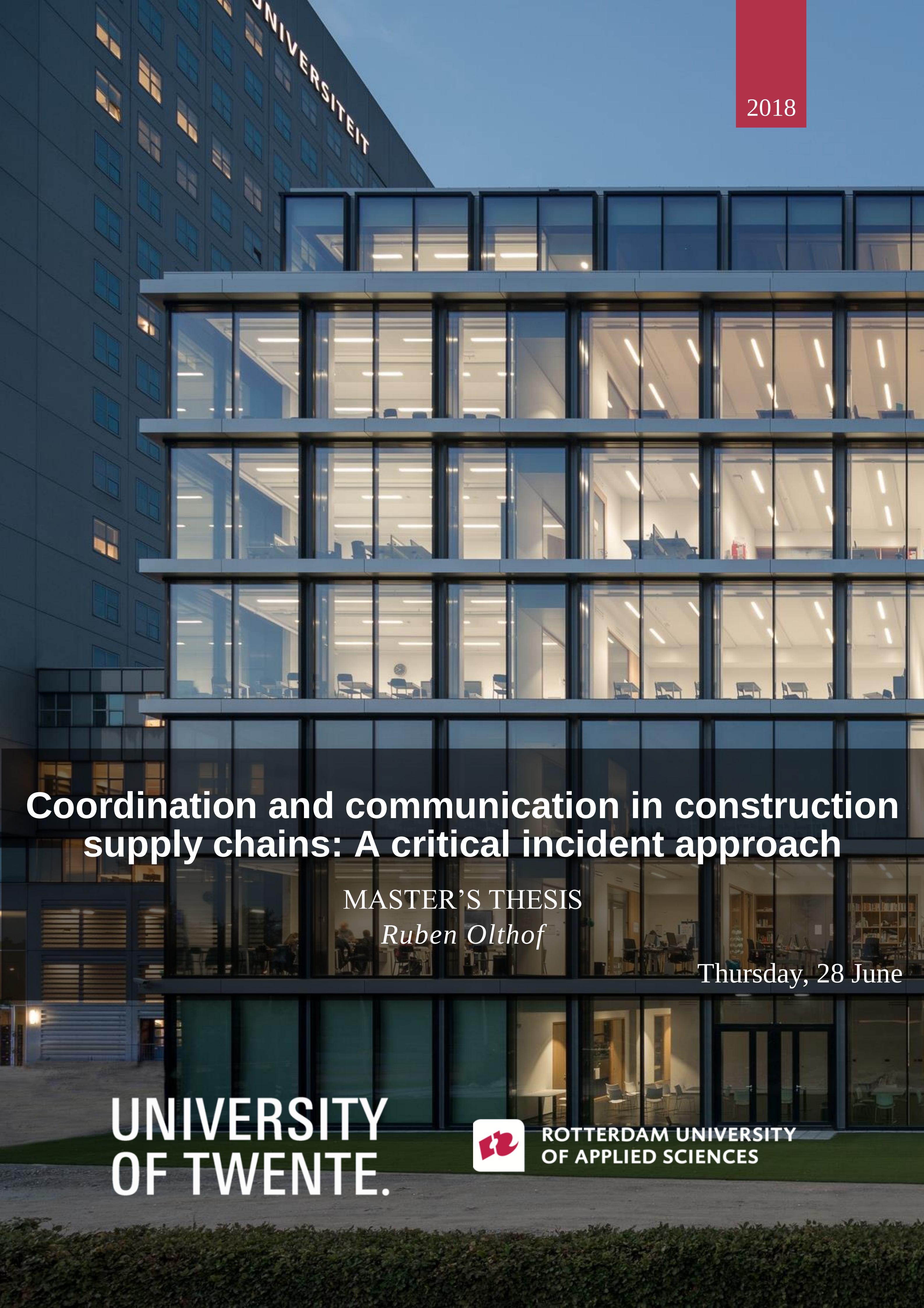

2018

Coordination and communication in construction supply chains: A critical incident approach

MASTER'S THESIS

Ruben Olthof

Thursday, 28 June

UNIVERSITY OF TWENTE.

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PREFACE

This document contains my master's thesis "*Coordination and communication in construction supply chains: A critical incident approach*". In the past year I have conducted this research as final assignment to obtain my master's degree at the University of Twente in the field of Construction Management and Engineering (CME). The research has been performed at the behest of the research centre for sustainable port cities, which is part of the Rotterdam University of Applied Sciences.

During the research process I have collaborated extensively with my fellow researcher and supervisor Alexander de Vries, who currently works on his PhD thesis concerning the same subject. Together we set out to study the application of coordination and communication in the context of a construction project. The research process proved to be a long road full of obstacles to overcome. However, thanks to the dedicated guidance of Alexander de Vries and my other supervisors Hans Voordijk and Arjen Adriaanse, I managed to complete this research with satisfying results.

I move towards the end of my thesis with mixed feelings. First of all, it has been an intense period of hard work and considerable amounts of frustration. On the other hand, it proved deeply satisfying when efforts paid off, which motivated me to keep making progress. Nevertheless, I am very pleased with the final result and look forward to move on to new challenges in my future career.

Many different people have supported me over the course of this research. I would like to thank family and friends for their support in this endeavour. More specifically I thank my supervisors for their excellent guidance. Alexander, I thank you for our many interesting discussions and your tremendous involvement in my research work. You have guided my observation efforts significantly and triggered my enthusiasm to examine on-site processes both critically and with great curiosity. Hans, you have been essential in keeping my efforts focussed and preventing me to drown in the extensive amount of case study data. Furthermore, your advice to deviate from the intended methodology towards a grounded approach proved to be a pivotal first step towards the final insights provided by this research. Also, I thank Arjen Adriaanse for his part in the expert meetings, wherein his refreshing remarks helped significantly in shaping the definitive conceptual model.

Lastly, I would like to thank Franske for her unconditional support, especially during the last few months of this research, which have not always been easy. You have managed to keep me focussed and committed towards finalising my research. I look forward to a well-deserved holiday with you and new things to do in the future.

Ede, June 26, 2018

Ruben Olthof

SUMMARY

The construction industry faces numerous problems, which hamper construction performance. A substantial part of these problems seems to be caused by the fragmented nature of the industry. To solve them, many authors acknowledge the need for improved coordination and communication practices. However, despite the apparent consensus about the importance of these practices, only little research is performed that clarifies how these concepts work in practice. Therefore, a lack of knowledge exists in regard to how coordination and communication are applied in practice and how they have an impact on construction performance.

Based on the identified research gap, this research aims to clarify how coordination and communication are applied over the course of critical incidents, which directly impact construction performance. Therefore, the primary objective is to develop a conceptual model, which provides an in-depth understanding of current practices during the course of critical construction incidents in order to contribute to future improvements. Consequently, the following central research question is formulated: "*How do coordination and communication take place during critical incidents within the examined construction supply chains and how do external factors influence this practice?*"

In order to provide an answer to the central research question this research adopts a grounded approach to explore a single case study through several embedded cases. Data is primarily gathered by observing construction processes on-site and is complemented with deepening interviews and document review. Subsequently, sensemaking strategies were applied to develop the intended conceptual model, which was used to generate comparable results for cross-case analysis. Based on this approach a dynamic coordination process is identified, which is influenced by several external factors. Firstly, based on numerous critical incidents a distinct course of coordination is determined based on three different levels of intervention. The applied level of intervention is determined by the mutual power and interest relations between the parties involved. Often, the party with a dominant interest attempts to enforce a favourable intervention. However, when a lack of power exists parties are required to negotiate in order to undertake interventions. Furthermore, several categories of uncertainty are established, which are considered the main cause of construction incidents. Lastly, it noticed that communication is primarily managed through shared information systems, despite the complexity of managing information processes.

The established insights provided by this research are broadly supported by existing theories, but also extend theory by focussing on critical incidents and reveal the dynamic process of coordination within these situations. Furthermore, the developed conceptual model provides a theoretical framework to analyse construction incidents in the future. Considering the practical implications, the gathered insights contribute to the understanding of power and interest relationships and their influence on coordination processes. This contribution might help to develop improved purchasing and relationship management strategies by main contractors. Additionally, the conceptual model might be used as a tool to analyse the risk of potential incidents affecting project performance due to a lack of power to control them. In the end, more research is suggested to further strengthen the findings established by this explorative study and extend this theory by identifying potential relationships between coordination and information exchange systems and the effectivity of interventions. Also, more research can be conducted to study the effect of different relationship management strategies on the effectivity of coordination in construction projects.

TABLE OF CONTENTS

1 INTRODUCTION

The construction industry experiences many problems and therefore often faces a negative reputation in terms of performance. In general, problems involve high failure costs, inadequate productivity growth; especially in comparison to other industries, and a lack of innovation (Adriaanse, 2014). Many of these deficiencies emanate from more specific problems, which are experienced on the construction site. These problems typically relate to either the construction process or supply chain (Olsson, 2010). Examples of frequently experienced on-site problems concerning the construction process are a lack of information sharing (Hong-Minh, Barker, & Naim, 2001; Laufer & Tucker, 1987; Love, Irani, & Edwards, 2004), poor communication between firms and project phases (Dainty, Moore, & Murray, 2006) and uncertainties (Bankvall, Bygballe, Dubois, & Jahre, 2010; Dubois & Gadde, 2002). In regard to the supply chain, firms experience problems concerning the reliability of deliveries (Agapiou, Clausen, Flanagan, Norman, & Notman, 1998; Akintoye, McIntosh, & Fitzgerald, 2000; Navon & Berkovich, 2006), planning of material flows (Bankvall et al., 2010) and the arrangement of communication and organisation (Briscoe, Dainty, & Millett, 2001; Titus & Bröchner, 2005). Conclusively, this variety of on-site problems is classified by Thunberg, Rudberg, and Gustavsson (2017) into four categories: (1) material flow issues, (2) internal communication, (3) external communication and (4) complexity.

Deriving from the background of the construction industry, fragmentation seems to be the essence of a substantial part of the problems experienced in the construction industry (App. I). Fragmentation and also low levels of repetition in the construction supply chains have caused particularly a lack of control and decreasing performance (Vrijhoef, 2011). Typically, the problems stemming from these two phenomena tend to progress through the supply chain, because of the causal relationships within the supply chain. In line with this view, Adriaanse (2014) approaches the construction industry as an archipelago of many islands, which are strongly divided in at least three ways (Figure 1). These divisions are classified as three types of fragmentation: (1) vertical fragmentation, (2) horizontal fragmentation and (3) longitudinal fragmentation. The first type of fragmentation is caused by a division of process phases during a construction project. After the completion of each phase, the information is passed on to the next phase, which is usually performed by other organisations or individuals. This approach is referred to by Adriaanse (2014) as the ‘relay’ approach. Mostly, information exchange between these phases is minimal due to a lack of alignment, which emphasises the existence of fragmented islands. Secondly, horizontal fragmentation emanates from the number of different firms working together within a particular construction phase. This particular type of fragmentation has mainly come about due to an increase in complexity (Gidado, 1996), which triggers the demand for additional specialist trade contractors (Eccles, 1981; Mitropoulos & Tatum, 2000). Subcontracted firms cover approximately 80 – 90% of the work within construction projects (Bemelmans, Voordijk, & Vos, 2012; Dubois & Gadde, 2000; Eccles, 1981; Hinze & Tracey, 1994). Correspondingly, complex networks of many autonomous firms have come into existence. Each firm, however, has particular interests, working methods and ICT systems (Adriaanse & Voordijk, 2005; Adriaanse, Voordijk, & Dewulf, 2004; Rahman & Kumaraswamy, 2004) and are linked together based on extensive contracts, which are procured based on price-selection (Bankvall et al., 2010; Dubois & Gadde, 2000, 2002). These conditions cause firms to sub-optimise their individual contributions without consideration of the project as a whole, which, in turn, induces a limited information exchange between firms (Adriaanse & Voordijk, 2005; Adriaanse et al., 2004; Dainty et al., 2006; Dorée, Holmen, & Caerteling, 2003). The success of a construction project, nevertheless, depends on the performance of the entire network across firm and process boundaries (Gann & Salter, 2000). The last type of fragmentation, identified by Adriaanse (2014), is the longitudinal kind. This type is mainly a consequence of the project-based nature of the industry, wherein buildings are one-of-a-kind and build in temporary organisations. After completion these organisations are dissolved, which hampers information dispersal among multiple projects (Dorée & Holmen, 2004; Gann & Salter, 2000; Winch, 1998). Another challenge in regard to longitudinal fragmentation is approaching simultaneous projects in coherence instead of individual entities (Dorée & Holmen, 2004; Dubois & Gadde, 2002).

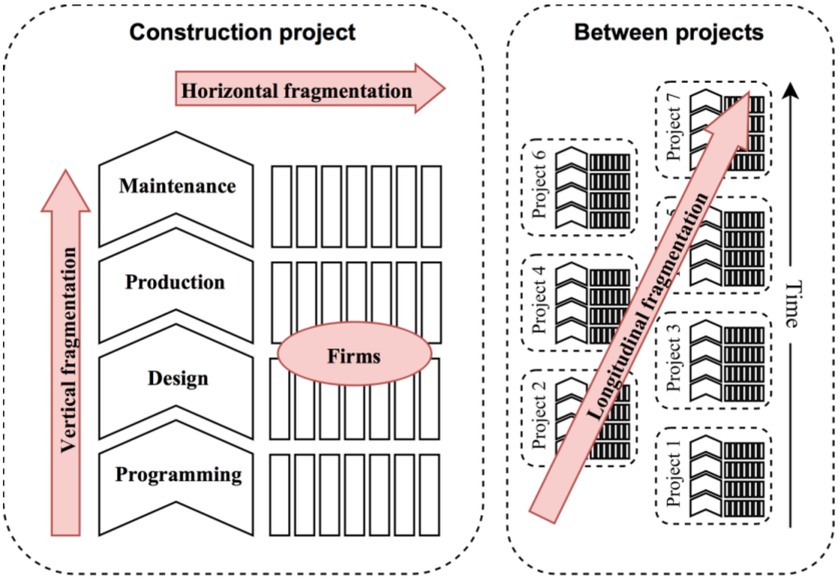

Figure 1: Multiple types of fragmentation in construction. Adapted from Adriaanse (2014).

In order to cope with the fragmented nature of the construction industry, many authors have come up with potential solutions. Integration of the supply chain is often mentioned as solution to improve the industry's performance, especially by decreasing horizontal fragmentation (Briscoe & Dainty, 2005; Vrijhoef, 2011). The concept aims to increase transparency and alignment of the supply chain in terms of coordination and configuration regardless of functional or organisational boundaries (Cooper & Ellram, 1993). However, Briscoe and Dainty (2005) argue that a lack of trust, vested interests and short-term perspectives still prohibit firms to commit to specific partnerships, which are required to integrate the supply chain. Especially small and medium-sized enterprises (SME) are sceptical of potential benefits, although they are crucial in attaining better integration (Dainty, Briscoe, & Millett, 2001). Another approach to inter-firm collaboration is suggested by Cox and Thompson (1997), who advocate 'fit-for-purpose' contractual relationships. They acknowledge that relationships are a means towards an end and partnerships are not "the panacea of all ills". Collaboration should be fostered by unequal power relationships or by incentivising suppliers because mutual trust cannot be enforced and should not be volunteered. Nonetheless, Dubois and Gadde (2000) suggest that the efficiency of the relationship may be enhanced by making adaptations within relationships. On the other hand, these adaptations may lead to interdependencies, which are undesirable in terms of a decreased flexibility, and require a considerable amount of commitment. Furthermore, Vrijhoef and Koskela (2005) discuss that resolving the problems experienced in the construction industry, requires fundamental change and restructuring on the production level. Accordingly, indirect methods, such as alternative financial and procurement methods will not suffice. However, in conclusion many authors seem to agree that improved coordination and communication practices are required to enhance construction performance and cope with the difficulties imposed by fragmentation.

1.1 PROBLEM DEFINITION

Among many authors the need for improved coordination and communication practices is shared in order to solve construction issues. To align the processes of interdependent organisations, coordination and communication are key aspects, which are essential for controlling the inter-organisational network (Kornelius & Wamelink, 1998). Tasks are often divided in multiple functional disciplines, which are executed independently by separate firms. The interfaces between these disciplines act as barriers for effective coordination and communication practices causing redrawing and rekeying of information, if not properly attended to (Love, Li, & Mandal, 1999). Ultimately, poor construction performance is therefore caused by an improper practice of multi-layer subcontracting, which requires improved interactions between those involved (Tam, Shen, & Kong, 2011). Furthermore, Thunberg et al. (2017) suggest that the construction process and the supply chain are interlinked. Mitigating on-site problems requires more effective planning, which would address the problems in both, process and supply chain, by means of more effective coordination and communication.

However, despite the apparent consensus about the importance to improve coordination and communication practices in construction supply chains, only little research is performed on how these mechanisms work in practice. Even though, it seems rather unknown how construction supply chains operate and how coordination should take place within these chains (Bemelmans et al., 2012). Such insights could bring about new ways to improve construction performance. Many authors, however, seem to propose solutions, which would, supposedly, enhance coordination and communication, without elaborating on the specifics of 'how' and 'why'. Understanding how coordination is conducted during construction projects and how this affects construction performance would allow research to work towards more significant improvements. Consequently, this research will focus on incident situations, which have a direct impact on the construction performance. In the end, the following problem statement, is addressed by this research:

A lack of knowledge exists on how coordination and communication is applied in construction, especially during the course of incidents, which have an impact on the construction performance.

1.2 RESEARCH MOTIVE

The Rotterdam University of Applied Sciences, in collaboration with the University of Twente, has commissioned this particular research. The motive for research is primarily based on the relevancy of the subject to the commissioning party, an external motive from an innovation consortium they are affiliated with, and the desire to perform research activities combined with an educational function.

As part of a research programme, named '4C control tower toepassingen voor bouwlogistiek', the Rotterdam University of Applied Sciences and University of Twente are occupied with performing research concerning the development of improved construction supply chain management practices. The programme is initiated by an innovation consortium, consisting of public and private parties involved in the construction industry. The main concern of the consortium is to mitigate problems like unnecessary transport operations, delays in the construction process, low productivity of operations on-site and unnecessary large amounts of waste (Navon & Berkovich, 2006). These problems are the result of difficulties to cope with the way construction supply chains operate. Solving these problems would potentially generate cost savings, as indicated in several studies, of approximately 5% (Navon & Berkovich, 2006).

According to firms operating in construction supply chains the inter-firm coordination can be improved significantly (Fulford & Standing, 2014). Coordination could potentially stimulate improvement of effectivity, efficiency and sustainability of construction processes. To trigger more collaboration, innovations in regard to construction supply chains are required. A previous research programme addressed this ambition by applying several logistical solutions on two construction projects, which were acquired as experimental research platforms. Based on the lessons learned from these platforms, it could be concluded that the implemented solutions paid off in terms of project lead times and logistical expenses. However, the implementation of information exchange systems for supply chain management purposes is still problematic. During sector-wide conferences, the need for better coordination was expressed as important point for improvement. The feedback of the market resulted in, among other things, a need for more research efforts in terms of the organisation of coordination within construction supply chains. Therefore, one of the themes incorporated in the current research programme is the development of cross-sector supply chain management concepts (van Merriënboer & Ludema, 2016).

Within the research programme, a subproject is the initiation of student research projects. This particular research is initiated in support of the doctoral research performed by Drs. Ing. A.M.R. de Vries, senior lecturer and researcher at the Rotterdam University of Applied Sciences. He currently performs his research, concerning coordination and communication in construction supply chains, at the University of Twente. Besides supporting this doctoral thesis, this research is also an independent research project, which is initiated to study inter-firm coordination and communication activities within construction supply chains.

1.3 RESEARCH OBJECTIVE

The objective of the research is determined based on the composed problem definition and research motive. Firstly, the external objective is described, which outlines the purpose of the study. The second part of the objective concerns the knowledge to be gained by performing the study (Verschuren & Doorewaard, 2010).

The defined research objective is formulated as:

To develop a conceptual model on coordination and communication in construction supply chains, which provides an in-depth understanding of current practices during the course of construction incidents in order to contribute to future improvements in regard to construction performance…

…by…

… delineating critical incidents, occurring within the construction supply chain, that affect construction performance and analyse how and why specific coordinative measures are applied to deal with these incidents.

1.4 RESEARCH QUESTIONS

To achieve the formulated research objective effectively, a structural multi-layer approach is employed. The approach comprises a central research question supported by several sub-questions. Each subjacent question represents a knowledge component required to answer the central research question and achieve the proposed research objective. The combined answers of all sub-questions constitute the final answer to the central question.

Central research question

How do coordination and communication take place during critical incidents within the examined construction supply chains and how do external factors influence this practice?

Sub-questions

Empirical basis *(Purpose: Gathering data on how coordination and communication practices are applied over the course of critical incident situations.)*

1. How is coordination applied over the course of the identified critical incidents?
2. What external factors affect the occurrence and course of these critical incidents?
3. How does communication facilitate the coordination process during critical incidents?

Synthesis *(Purpose: Unravelling a common dynamic of coordination among critical incidents and explaining why particular coordinative measures are applied.)*

4. How can the gathered insights, in regard to the course of coordination during critical incidents, be constituted into a conceptual model?
5. What patterns can be identified, using the developed conceptual model, which explain the course of critical incidents?

Validation *(Purpose: Relating the gathered insights to literature and explaining their importance for current practice in order to evaluate the external validity of the findings and draw final conclusions.)*

6. How do the insights concerning coordination and communication during critical incidents relate to existing theory?
7. What practical implications can be learned from the acquired insights concerning coordination and communication in construction supply chains?

2 METHODOLOGY

The objective of this particular research is to develop a conceptual model, which explains the course of coordination and communication during critical incidents in construction projects in order to contribute to future improvements in terms of construction performance. To achieve this objective, a systematic process of collecting analysing and interpreting data is required in order to increase the understanding of the studied phenomenon (Leedy & Ormrod, 2013). This chapter elaborates the applied research methodology in four subsequent sections. Firstly, the research approach is clarified elaborating the specific philosophy supporting the designed methodology. Secondly, the applied strategy is discussed. Thereafter the research structure is described including an overview of all steps undertaken to achieve the research objective. Lastly, a justification of the research methodology is provided to ascertain the validity and reliability of the study.

2.1 RESEARCH APPROACH

In previous studies the need for an enhanced insight in coordination and communication becomes evident. As pointed out in the problem definition, it is unclear how construction supply chains operate and how coordination should take place. To establish a better understanding of the dynamics in the cooperation between builders and suppliers and the development of this cooperation in time, a need for more longitudinal studies within the operational context of construction projects is required (Bemelmans et al., 2012). To comply with the articulated need, this research applies a grounded approach in order to come to new insights through an extensive case study. This type of research is selected to embed data into an organisational context and capture contextual complexities. Therefore, primarily qualitative answers are provided, which are context-bound, holistic and explanatory (Leedy & Ormrod, 2013). However, this approach will result in subjective outcomes, which are relatively soft, flexible and regulative due to the interpretations and guidance of the researcher during the research process (Silverman, 2013). For this reason, the research will present results drawn from multiple perspectives. The results are constructed through social interaction with various actors operating at multiple levels and by prolonged involvement in the field (Creswell, 2013). Furthermore, this research aims to explore how coordination and communication affect the performance of construction supply chains. Consequently, the main focus of the research is put on the dynamics of the studied phenomena during critical incident situations. These incidents are considered operational empirical observations, or “any observable human activity that is sufficiently complete in itself to permit inferences and predictions to be made about the person performing the act” (Flanagan, 1954, p. 327). This definition of incidents, however, originates from a sociology perspective to examine the behaviour of individuals. In the context of this particular research, incidents are concerned with organisational behaviour, rather than the behaviour of individuals. Additionally, only critical incidents are addressed because they are more accurately identified than more average incidents (Flanagan, 1954). To conclude, critical incidents provide a means to identify and analyse comparable occurrences relevant for pattern finding across multiple instances.

2.2 RESEARCH STRATEGY

In line with the research approach, the developed research strategy is primarily based on the guidelines provided by Eisenhardt (1989). This roadmap for building theory from case studies synthesises qualitative research methods, case study design (e.g. Yin, 1984) and grounded theory building (e.g. Glaser & Strauss, 1967). Using this overall framework, a single embedded case study design is performed, wherein a revelatory construction project is studied through multiple sub-units of analysis.

Case studies are a method of empirical research, which considers a contemporary phenomenon within its real-life context. Furthermore, it is particularly effective when 'how' or 'why' questions are being posed and the researcher has little control over events (Yin, 1984). Only a single embedded case is selected in order to be able to examine the course of coordination and communication in critical incidents over a prolonged period of time within a consistent organisational context. An embedded design is adopted to enhance and deepen insights in the selected case. Besides the case study method, the applied research strategy is also characterised by the grounded approach. By many this method is considered any form of inductive theorising (Langley, 1999). However, Glaser and Strauss (1967) have detailed a comparative method for developing grounded theory. It commences with data collection and relies on a continuous comparison of data and theory. Consequently, theoretical categories emerge from evidence by using an incremental approach to case selection and data gathering (Eisenhardt, 1989). Additionally, the method allows the researcher to descend to lower levels of analysis. This provides an opportunity to explore different perspectives of multiple parties experiencing the same process in order to understand the more macroscopic process (Langley, 1999).

The following table introduces the applied method in a series of subsequent steps (Table 1). Nevertheless, the actual strategy is not completely restricted by this methodological structure. Such rigidity diminishes the importance of alternative more imaginary theorising activities, which are important for developing theory (Weick, 1989). Instead, the process involves constant iteration between steps. In particular, sensemaking strategies, described by Langley (1999), are employed to theorise from the gathered process data.

Table 1: Process of building theory from case study research. Adapted from Eisenhardt (1989).

Step	**Activity**	**Reason**
Getting started	– Definition of research question	– Focuses efforts
	– Neither theory nor hypotheses	– Retains theoretical flexibility
Selecting cases	– Specified case population	– Constrains extraneous variation and sharpens external validity
	– Theoretical sampling	– Focuses efforts on theoretically useful cases
Crafting instruments and protocols	– Multiple data collection methods	– Strengthens grounding of theory by triangulation of evidence
	– Multiple sources and perspectives on multiple types of data	– Fosters divergent perspectives and strengthens grounding
Entering the field	– Overlap data collection and analysis, including field notes	– Speeds analyses and reveals helpful adjustments to data collection
	– Flexible and opportunistic data collection methods	– Allow investigator to take advantage of emergent themes and unique case features
Analysing data	– Within-case analysis	– Gains familiarity with data and preliminary theory generation
	– Cross-case pattern search using divergent techniques	– Forces investigators to look beyond initial impressions and see evidence through multiple lenses
Shaping hypotheses	– Iterative tabulation of evidence for each construct	– Sharpens construct definition, validity, and measurability
	– Search evidence for "why" behind relationships	– Builds internal validity
Enfolding literature	– Comparison with conflicting literature	– Builds internal validity, raises theoretical level, and sharpens construct definitions
	– Comparison with similar literature	– Sharpens generalisability, improves construct definition, and raises theoretical level
Reaching closure	– Theoretical saturation when possible	– Ends process when marginal improvement becomes small

In order to provide insight in the research strategy deduced from Eisenhardt (1989), a sequential diagram is presented to clarify the consecutive steps performed during the research process (Figure 2). Firstly, the preparation and preliminary actions are indicated as point of departure. This step includes the identification of the research problem, formulation of an objective and research questions to guide the process. Additionally, some background information on the issue is delineated to ensure relevancy. Secondly, a case is selected for data gathering and a data collection protocol is established to prepare for the case study. In correspondence with the grounded research approach, no prior literature study is performed to direct the research into a predetermined direction. Instead the studied phenomena are examined with a fresh perspective in order to arrive at new insights. Consecutively, the case study research commences, wherein data is collected and analysed about four embedded subcases. Furthermore, sensemaking strategies are adopted to translate the individual case study data into an integrated conceptual model on the course of coordination and communication during critical incidents in construction supply chains. Internal validation of the model is, successively, conducted by using the conceptual model as analytical framework to analyse the collected case study data. Hence, comparable case study results are established. Drawing upon these results a cross-case analysis is performed to explore patterns and insights concerning the investigated phenomena. Subsequently, the legitimacy of these insights is validated by confronting them to literature. Finally, conclusions are drawn and recommendations are made based on the, now embedded, insights established by this research.

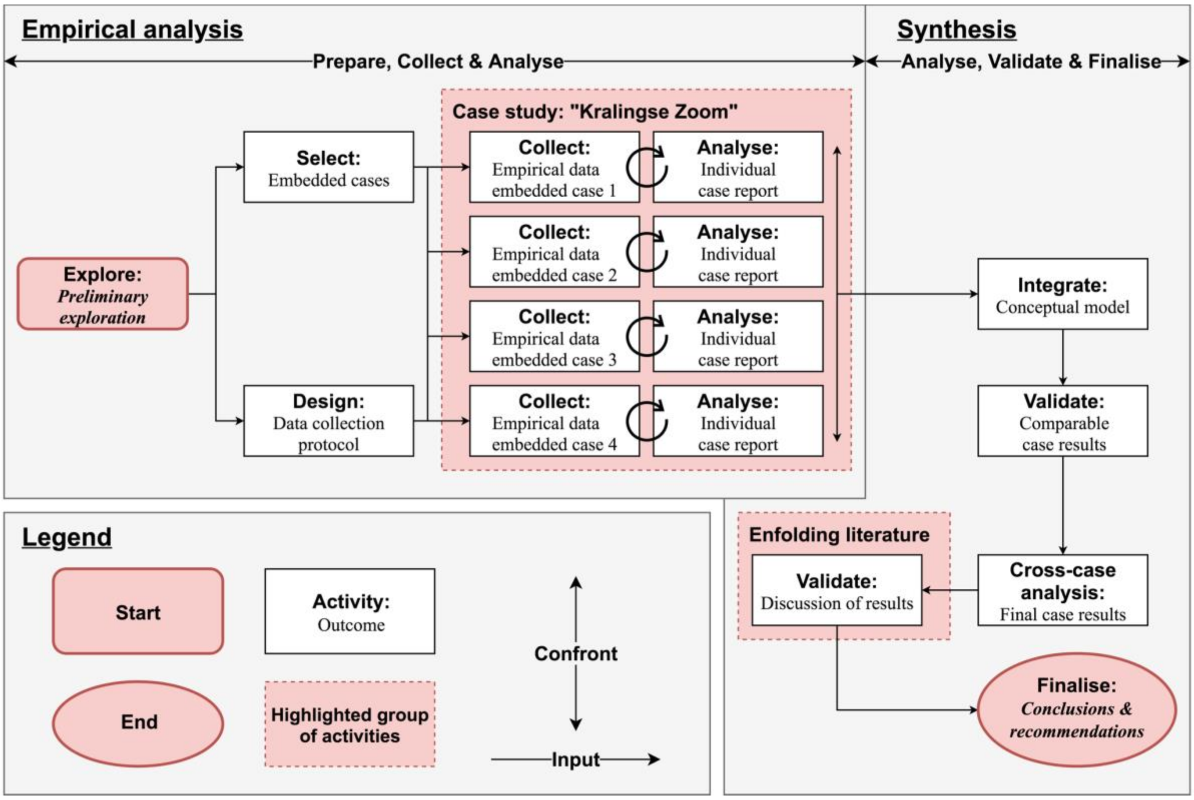

Figure 2: Sequential diagram of the consecutive steps performed within this research.

Case selection

The primary case in this research is selected based on theoretical sampling, which is selection deriving from theoretical reasons, instead of statistical reasons (Glaser & Strauss, 1967). Embedded sub-units comprise several examined construction supply chains, which are chosen by considering their likeliness to further help developing the emergent theory (Eisenhardt, 1989; Leedy & Ormrod, 2013). The selected case was chosen based on representative, revelatory and longitudinal arguments (Flyvbjerg, 2006; Yin, 1984). The construction project possesses characteristics, which are representative for non-residential buildings in terms of size and organisation. For example, a similar construction project was finished by the same contractor in 2015. Moreover, the unusual full access to project documentation and possibilities for longitudinal observations provided a substantial argument for selecting this particular case for in-depth study of coordination and communication in construction. Furthermore, in regard to the timeframe of this particular research project, only the finishing phase of the project was selected to be studied. It is assumed that more supply chains are employed concurrently during this phase and fragmentation issues are likely to be more evident.

The examined case concerns a non-residential construction project commissioned by a university of applied sciences established in one of the major cities in the Netherlands. It is located at the edge of the city and concerns the expansion of an existing location. It will accommodate several study programmes for approximately 10,000 students. The expansion replaces an existing part of the building, which is demolished, and connects to the remaining building sections. In total the new building provides a gross floor surface of 12,000 m^2 spread over six floors and costs roughly €18 million. More detailed, the construction project is tendered to a main contractor and all agreements are included in an engineer and construct (E&C) contract. However, the design was already elaborated quite extensively and required little additional technical development. The main challenges concerning the project, according to the main contractor, are considered the short project timeline and sustainability demands. These demands state that the final building has to comply with the demands established in the sustainability certificate BREEAM-NL Excellent. In regard to the project duration, the overall timeline comprises approximately seventeen months. An additional difficulty can be considered the other building sections, who remain operational during the project. Nevertheless, these sections are closed during the holiday periods. Provided are an impression of the final building (Figure 3) and its relation to the other building sections and surroundings (Figure 4).

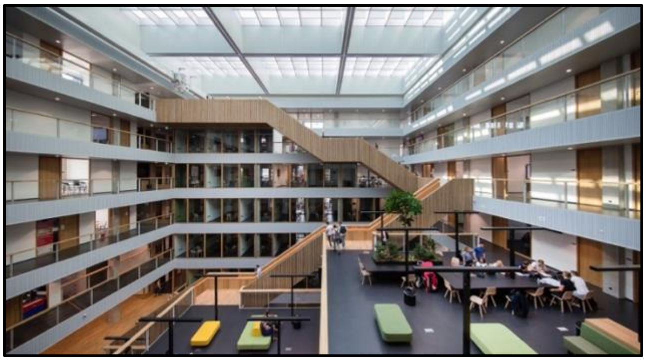

Figure 3: Impression of the finished project.

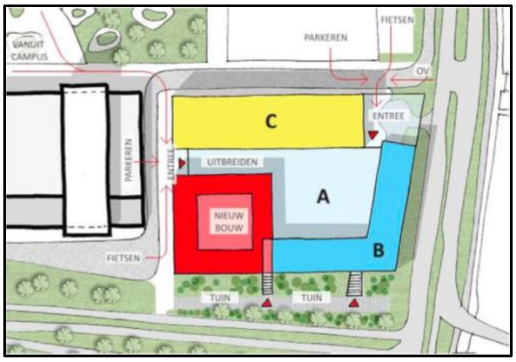

Figure 4: Schematic of the project (red square) in regard to the surrounding buildings.

Data collection

The main data collection procedure, employed within the grounded research strategy, is the critical incident technique (CIT). This method consists of a set of procedures to collect direct observations of human behaviour in order to utilise their potential value for solving practical issues and develop broader principles (Flanagan, 1954). Originally it was developed during the second world war as an outgrowth of studies in the Aviation Psychology Program of the United States Army Air Forces. The method was used to identify effective and ineffective behaviour in a variety of military activities. In essence, the procedure involved obtaining reports containing an objective record of satisfactory and unsatisfactory executions of assigned tasks. The cooperating individual described a particular situation, whereupon critical behaviour was identified. Critical behaviour was defined as behaviour vital for performing the assigned task effectively or ineffectively (Flanagan, 1954). Furthermore, the method does not contain a set of rigid rules for collecting and analysing the data. Moreover, the CIT is based on a set of flexible rules that should be adapted to a specific situation (Flanagan, 1954). Due to the flexibility of the method, it can be used to study a wide range of phenomena and fits within the definition of qualitative research (Butterfield, Borgen, Amundson, & Maglio, 2005). More specifically, the research takes place in a natural setting, wherein the researcher is the key instrument of data collection; data is collected through interviews, participant observation, and qualitative open-ended questions; data analysis is done inductively and the focus is on the perspective of participants (Creswell, 2012). Furthermore, it is described that the method is effective for descriptive, explorative and theory building purposes, and is applicable in an interpretative paradigm, which makes it a powerful method to perform research within organisational contexts (Woolsey, 1986).

Following the approach, elaborated by Flanagan (1954), the main aim of data gathering is uncovering how coordination and communication take place during critical incidents and why it takes place as such. Therefore, it is decided that the various construction processes, or events, of the selected embedded cases are observed on the construction site. Events are defined as abstract concepts of coded sets of incidents (van de Ven, 2007). During the observation of events, the researcher will identify and record critical incidents. Observation is performed on-site because it is presumed that the effects of coordination and communication practices will manifest at the point where enclosed supply chains meet. Also, multiple perspectives are delineated because various parties, working on the construction site, are engaged for informal talks. Nevertheless, the perspective of the main contractor is dominant as principal source of information. Based on the primary data, collected through observations, additional interviews and document review will provide secondary data in order to expand insight in the construction supply chain beyond the construction site. Moreover, the secondary data is used to reconstruct the arrangements within the several supply chains. Furthermore, the supplementary data results in an increased internal validity, because of a triangulation of data (Leedy & Ormrod, 2013).

In total more than 120 hours of observational data is recorded over 33 site visits during a period of 16 weeks. Each site visit is documented in an observational report containing photographs and textual elaborations of observed events and informal talks with employees and supervisors. Triangulation of data is achieved through interviews and document review. Altogether twelve interviews, including interviews recorded by collaborating researchers, are performed and a database of approximately 1000 documents was available for the purpose of document review.

Analytical procedure

The analysis of the acquired data is a complex iterative process. Eisenhardt (1989) describes the data analysis as the most difficult and least codified part of case study research. This point of view is shared by Leedy and Ormrod (2013), who state: “There are no magical formulas, no cookbook recipes for conducting a qualitative study” (p. 143). In regard to the CIT, it is important to acknowledge that data analysis is subjective and an interpretation of observed events (Woolsey, 1986). Although data analysis is not specifically codified, some guidance is provided by the generic sensemaking strategies for the analysis of process data addressed by Langley (1999). The variety of strategies can be used interchangeably and helps to overcome the overwhelming nature of process data by focussing on some anchor point that helps structuring the material.

The grounded sensemaking approach, applied in this research, commences with a narrative strategy to compose stories, based on observational data, in a chronological order. These stories establish specific events and help structure the detailed and varied information in all its subtlety and ambiguity existing in the observed situations. However, the method is ineffective to identify a plot and produce theory out of the extensive and complex stories. To single out individual critical incidents from the event stories a visual mapping strategy is performed. This strategy allows the researcher to visualise data with a large variety of inputs, but potential conclusions tend to stick to the surface and overlook forces driving activity sequences. Therefore, it serves as intermediate step between the raw data and a more abstract conceptualisation. Nevertheless, by comparing individual incidents a commonly shared dynamic process structure for coordination is identified. Consecutively, forces driving the dynamic process are required to establish causality to the emerging model. Accordingly, a grounded theory strategy is applied to determine external factors influencing the course of coordination in critical incidents. In order to establish a conceptual model, incidents are systematically compared, which results in a small number of categories that integrate into a theoretical concept (Strauss & Corbin, 1990). Lastly, cross-case analysis is performed to move towards a more predictive theory. For that reason, the synthetic sensemaking strategy is employed to find patterns and add predictive power to the established conceptual model. This strategy is made possible by the boundaries and level of abstraction created in the previous steps. Conclusively, final predictive conclusions are established by analysing each critical incident, using the developed conceptual model, and comparing the results. In the end, the gathered insights are compared to literature in order to embed the grounded theory into a general context, which makes it viable for further testing. When the proposed relationships are repeatedly tested and confirmed in future research this might eventually lead to the discovery of lawful relationships (Babbie, 2012).

2.3 RESEARCH STRUCTURE

This paragraph comments on the content of the upcoming chapters. The first two chapters discuss the introduction, methodological procedure and justification of this research, which comprises the preparation phase. Subsequent chapters introduce the developed conceptual model, the application of the model, analysis results and the final discussion of results and conclusions.

Chapter 3 discusses the development of the conceptual model, which is established based on the grounded case study data obtained from the observed events. Within the chapter a model is gradually introduced which reveals a common dynamic of coordination and communication among incidents and external factors of influence affecting the applied coordinative approach. The development process of this model can be described as an iterative learning procedure because the advancement of insights in the coordination process is accompanied by the refinement of more clearly delineated incident situations and vice versa. During the iterative process expert meetings were consulted to enhance the model and gain new insights (App. III). Ultimately, the aim of the conceptual model is to provide a means to establish a common structure to compare critical incidents and identify relevant patterns and insights among the analysed incidents.

Chapter 4 introduces the application of the conceptual model on critical incidents. By applying the conceptual model as an analytical framework, comparable results are achieved for cross-case analysis. Additionally, this chapter establishes internal validity of the model by demonstrating how the model functions in multiple contexts. In the end, a database of results is generated from all the examined results.

Chapter 5 analyses and compares the distinguished critical incidents from the case study in order to identify cross-case patterns. To accomplish this endeavour, this chapter will examine similarities and differences among the incidents and attempt to explain the course of coordination by means of interpretation. The aim of the chapter is to get insights in why coordination takes place in a particular fashion and how the contextual playing field determines what type of interventions are applied. Based on these insights it is conceivably possible to predict the course of coordination in construction supply chains arrangements. Understanding this dynamic is key for developing future improvements in coordination and communication in the construction industry.

Chapter 6 discusses the final results of this research and establishes the final conclusions drawn from the outcomes produced by the previous chapters. Firstly, the main conclusions are delineated based on the answers to the formulated research questions. Afterwards, the findings are related to existing literature to provide context and enhance the external validity. Finally, practical implications are discussed followed by the introduction of research limitations, whereupon several suggestions are considered for future studies.

3 CONCEPTUAL MODEL DEVELOPMENT

This chapter discusses the development of the conceptual model using the grounded strategy as discussed in the previous chapter. Although the analytical process has been an iterative learning procedure, it is presented as sequential arrangement of consecutive building steps. Accordingly, a more comprehensible and orderly structure is applied to present the developed conceptual model. Firstly, a process model is presented to demonstrate the course of coordination over multiple levels throughout the construction process. This structure provides a clear framework to break down event narratives into comparable incidents, or units of analysis. Secondly, external factors, which influence the course of coordination, are identified and added to the process model adding causality in order to constitute a conceptual model. Furthermore, the role of communication within the developed model is clarified. Finally, a definitive conceptual model is introduced, which can be used to perform incident analyses.

During the course of the chapter specific incidents are used as examples to clarify the development process. These incidents are further elucidated in the next chapter when the application of the conceptual model is demonstrated on several exemplary incidents (chapter 4). ***For the purpose of referencing the incidents are coded. These are based on the corresponding embedded case no. (x), observed event no. (y) and attributed incident no. (z); and results in a final three-digit code (IC x.y.z).***

3.1 A CYCLICAL PROCESS APPROACH TO COORDINATION

Through analysing the events, a clear progression of coordination can be distinguished. All events start off by establishing fundamental principles. These principles contain the nature of the agreement, recorded in a contract, and the demands to which the performed work has to comply. Subsequently, plans are developed, which contain time schedules, work procedures and additional arrangements to facilitate the construction activities. Basically, the planned arrangements are elaborations of the initial agreements, which are determined in the fundamental principles. After the plans are established, the prepared work procedure is performed on the construction site. Whenever problems occur, which cannot be solved practically, parties seem to revert to a previous level of coordination and progress down to the executional level again. This cyclical dynamic of coordinative measures is noticed to recur until the construction process is finalised.

An incident triggering coordination on a particular level is, for example, when the main contractor cancelled the prefabrication of ceiling panel recesses in order to mitigate the production delay incurred by the supplier (IC 2.3.1). Plans were changed to achieve a specific purpose in accordance with the fundamental objectives. Another example is the dispute between the client and MEP contractor about the fire safety demands (IC 1.1.1). A disagreement involving the contractual arrangements caused both parties to renegotiate the contractor responsibilities. Lastly, the incident wherein the steel girders did not fit between the columns and concrete floor was solved by the subcontractor himself (IC 1.2.1). The girders were returned to the factory to be remade and the solution did not involve the alteration of main contractor plans. These examples suggest that executional impediments trigger coordinative measures on three different levels of intervention.

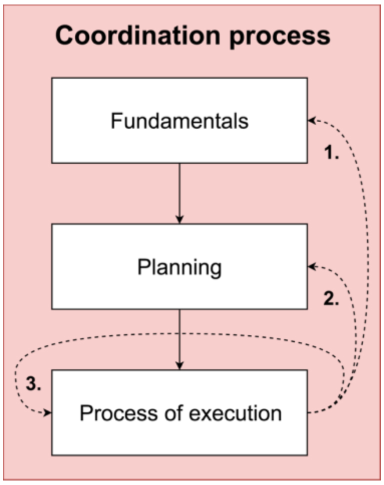

Figure 5: Comprehending the course of coordination in a cyclic process model.

The levels of intervention identified in the paragraph above are defined as:

1. (Re-)negotiate fundamental arrangements;
2. (Re-)adjust construction plans;
3. (Re-)do additional or altered work

Based on the insights, described above, a preliminary dynamic process model on coordination is drafted (Figure 5).

Applying a multi-level perspective

Coordination in construction involves multiple parties, who work together to achieve a finalised building structure. The addressed levels of intervention, accordingly, involve multiple parties at different levels in the project hierarchy. In a traditional construction project perspective, the different levels can be perceived as the client, main contractor and subcontractors. Translated to the preliminary model, presented in the figure above (Figure 5), the client formulates project demands, which are recorded in a contract with agreements signed by the main contractor. Based on these fundamental arrangements, the main contractor elaborates plans to achieve the complied demands and contracts parties for the proposed work. In a final stage, the devised plans are performed during the process of execution, usually by subcontracted parties (Figure 6). However, this perspective shifts when different levels in the construction supply chain are regarded. From the point of view of a subcontractor, the client might be considered the main contractor, who is customer of their business' services. In regard to this perspective, the demands are formulated by the main contractor and elaborated into plans by the indicated subcontractor. The subjacent process of execution, in some cases, can consist of a production process performed by a supplier, in other cases it entails the installation of a product outsourced to a lower tier subcontractor (Figure 7). Keeping this in mind, the identified dynamic of subsequent stages overlap over multiple levels in the construction supply chain. Hence, the expressions, as presented in the preliminary model, are volatile concepts of coordination activities. They indicate a process from generic arrangements between parties towards more detailed elaborations of final work processes and requirements. The exact contents of the expressions highly depend on the adopted perspective and incident situation within a larger system. To provide an unequivocal understanding of the coordination stages, clear definitions of the presented expressions are provided at the end of the chapter (Table 2).

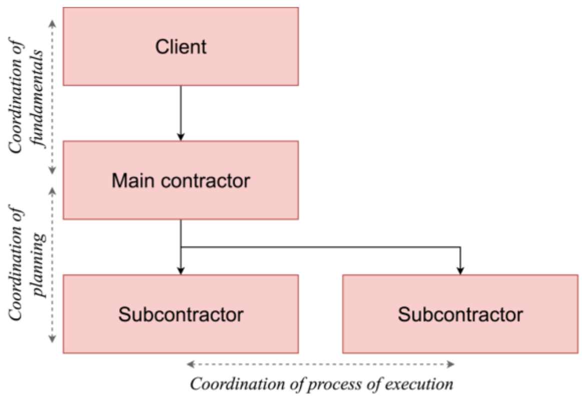

Figure 6: Traditional project perspective.

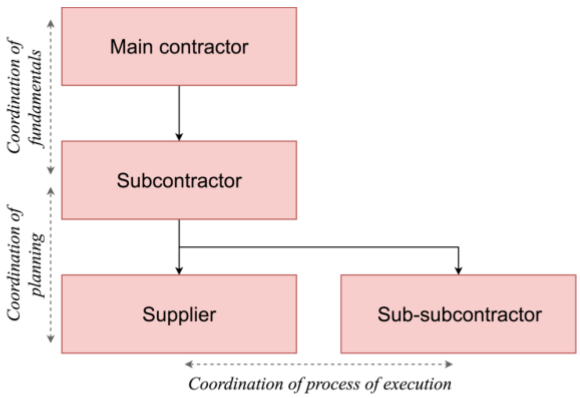

Figure 7: The subcontractor perspective.

In the context of this research, individual incidents consist of a reaction on a specific impediment, which requires an action in terms of coordination. Each incident cycle is approached from the perspective of a central actor. Ordinarily, the central actor is identified to be the main contractor because they are assigned to manage the construction project and thus influences all activities on site. However, the role of the central actor is more clearly defined as the party entitled to perform a coordinative measure in a particular situation. In regard to this definition, the central actor changes depending on the nature of the situation. Analysing the coordinative actions applied by the central actor, the developed process model contemplates the dynamic of coordination among all directly involved parties. When the central actor decides to change the plans, this affects the process of execution performed by lower tier parties. Renegotiating more fundamental arrangements, requires the central actor to negotiate with their client and potentially revise contractual demands. A final option is to leave the problem to be solved during the process of execution by the corresponding subcontractor.

As outlined in the previous paragraphs, incidents occur throughout the entire construction supply chain at multiple levels. Consequently, the position of the central actor can shift up- or downstream towards the client or subcontractors. Also, incidents can progress over time towards higher or lower levels in the supply chain. For example, when the MEP contractor ordered to revise the ceiling plan, because they provided the subcontractor with an outdated zoning plan. Consequently, the subcontractor was affected and had to process these changes. In turn the subcontractor needed to coordinate with the supplier to adjust the submitted production order (IC 2.2.1 & 2.2.2). Conceivably, the supplier, also, had to undertake some coordinative measures to align production with sub-suppliers. This case exemplifies that higher tier coordinative actions progress through the supply chain and trigger subsequent actions by lower tier parties. Similarly, lower tier impediments might progress upwards affecting higher tier parties when the central actor is unable to enforce a solution to a subjacent party. Such a situation was encountered when a glass pane from the roof construction of the study gallery broke, but the supplier factory just closed for the summer to carry out maintenance (IC 1.3.1 & 1.3.2). The incident threatened the deadline of the project and therefore lies beyond the sphere of influence of the roof subcontractor. Instead, it relates to the fundamental arrangements agreed upon between client and main contractor and has to be dealt with on the corresponding level. Furthermore, several other variations of coordination progressing through the supply chain are probable, for example when parties pre-adjust coordinative measures and take joint action. This situation is demonstrated when the main contractor and subcontractor devise a plan together to mitigate the incurred production delay of ceiling panels (IC 2.3.1). Both parties pursue the supplier as a single collective party to devise and impose an adapted solution. Lastly, in some situations only two parties are involved in an incident. For instance, when an incident occurs in the engineering phase the process of execution entails drafting plans, which will be executed by a subcontractor who is not yet acquired (IC 1.1.1). Another example of only two relevant parties is when the client acts as central actor and no higher-level party is involved within the scope of the project (IC 4.1.1).

Establish a process model

The developed process model on the course of the coordination in critical incidents provides a means to single out specific incidents from the several events examined during the case study. Theoretically, the demonstrated cyclical process model is a continuous procedure, which reiterates plans and fundamental arrangements until the process of execution is completed (Figure 5). However, incident sequences are not always arranged sequentially, because of the multi-level character of the identified process. A single coordinative measure might trigger reactions on several levels by multiple other parties. Apprehending this entire dynamic in a single model would create a cluttered and rather confusing sequence of events. With this in mind, distinct incidents can be singled out by addressing separate feedback cycles triggered by a specific impediment. Addressing individual instances results in a standardised format for incidents, which allows comparison between clearly delineated incidents. To clarify this added focus, the model is revised by adding a process and impediment output to the layout. When the process of execution runs according to plan a direct and final process output is generated. However, whenever impediments take place the model simulates a coordinative measure on a particular level of intervention. Subsequently, a definitive output is generated which potentially triggers succeeding coordinative actions. In short, only a single cycle is rendered over the course of a particular incident. Displaying entire events is achieved by linking multiple incidents with each other. The final dynamic process model for coordination is presented in the figure below (Figure 8):

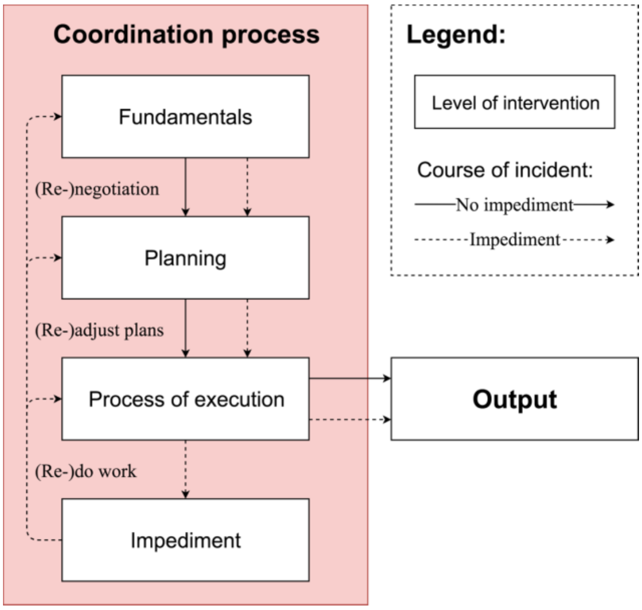

Figure 8: A dynamic process model for coordination during construction incidents.

3.2 EXTERNAL FACTORS OF INFLUENCE

In the previous section a process model is developed, which illustrates the course of coordination using narrative chronological events. This process model illustrates the course of coordination in incidents by analysing a cross-section based on time. However, the eventual purpose of this research is to uncover why particular coordination is applied within certain contexts. Therefore, the model should provide additional context and move from a configuration based on time towards causal relationships. A first step in the direction of such a model was produced in the last paragraph of the previous section (Figure 8). By focussing on single coordinative measures, a potential logic explaining coordinative actions can be explored and interpreted. Consequently, this section looks for context affecting the course of coordination in the form of external factors of influence.

Uncertainties

Understanding the context of incident situations starts with comprehending where incidents derive from. It establishes a particular history and reveals why coordinative intervention is required to manage construction processes. Also, potential insights in how coordination efforts might be improved beforehand is acquired. Within this research incidents are considered occurrences, which require adjustment and therefore coordination. These occurrences are not necessarily positive or negative deviations but establish impediments nonetheless. Because impediments emanate from unanticipated situations, they are closely related to uncertainty involved in the planning and executional process of projects. Plans and agreements are theoretical elaborations, which work towards the realisation of an implementation process and in the end a final product. However, in practice the envisioned plans tend to turn out differently due to uncertainty. Uncertainty exists in many different forms and surrounds all decisions concerning the construction process.

Examples of uncertainty during the examined construction process leading to incidents are, for example, the unclear contract specifications concerning the fire safety demands, which caused a dispute due to conflicting insights in task responsibilities (IC 1.1.1). Another example is the incident situation wherein the girders of the study gallery framework did not fit (IC 1.2.1). The margins for deviation of particular materials cause measurements to shift, which generates uncertainty about the established dimensions. By stacking multiple components without adjusting the measurements a misfit is likely to develop. Furthermore, uncertainty was experienced by the main contractor when the ceiling panel supplier could not fulfil the planned delivery lead times (IC 2.3.1). The estimated production schedule turned out to be unfeasible and disordered the intended construction process.

As described, uncertainty is experienced in many different ways originating from many different aspects. Coping with uncertainty is difficult and imposes a high level of complexity on construction efforts due to a constant need for adjustment through coordination, often within a network of many different collaborative parties. To prevent construction efforts to be paralysed by this level of complexity, construction processes are often abstracted through standardisation, or fundamental agreements complied by the participants. Over the course of the construction project these abstract arrangements are further refined into more detailed elaborations of component specifications and work processes. For example, during the design phase no specific ceiling panel was selected yet. Therefore, a standardised measurement was decided upon to allow parties to continue design activities, but also embed a margin of error to compensate for potential deviations during construction. Furthermore, the amount of permissible uncertainty is often engaged in terms of risk. Managers closely consider the trade-off between the extent of uncertainty; and the time and costs required by planning and negotiation to eliminate it. Consequently, construction processes are always, to some extent, uncertain, which leaves room for unplanned occurrences, or incidents, to occur.

Relative bargaining position

Coordination comprises the act of making decisions to establish and manage project processes. However, from a project perspective it sometimes seems that incidents are settled impractically and would be better coordinated at different levels of intervention. It would, consequently, be probable that particular barriers exist, which prevent apparent decisions from being taken. Many coordinative measures tend to stick to the process of execution, while a revision of plans or fundamental arrangements appears to be more difficult to achieve. Analysing the context of mechanisms influencing the course of coordination should provide an explanation which clarifies the reason behind why particular coordinative measures are applied in favour of others.

Incidents in construction, to a greater or lesser extent, involve multiple parties. When a subcontractor stumbles, the main contractor and subsequent subcontractors are affected. Eventually, if the problem progresses also the client is involved, provided that the project demands are compromised. Deriving from this consideration, parties within the network of construction supply chains are interdependent due to their common share in the success of the final product. Nevertheless, parties have alternative objectives in regard to project activities and show different levels of commitment. Based on the data it is perceived that impediments often revolve around these conflicts of interests. Generally, a field of tension exists between client and contractor concerning the expected quality and the required expenses. Both sides attempt to obtain the best possible deal, wherein the client is concerned with value for money while the contractor pursues profit. Following this predicament, parties negotiate terms and agreements under which collaboration takes place. As a result of negotiation, arrangements are recorded in legal documents to substantiate and commit to the agreement. However, as indicated, incidents derive from unplanned situations, which require anticipation through coordination. Therefore, changing plans or fundamental arrangements is restricted based on the recorded arrangements and often require renegotiation of terms. Conclusively, coordination appears to be highly limited by the relative bargaining position of the central actor.

The concept of bargaining position can be broken down in two separate components. Both are roughly, but not explicitly, addressed in the previous paragraph. First of all, the interest of the involved parties is relevant to the bargaining position as it constitutes the potential for finding common ground between parties. Aligned interest allow parties to establish new agreements, while conflicting interests cause impasse situations. In these conflicting situations some kind of authority is required to compel parties into a similar direction. The position of power establishing authority is considered the second component of the bargaining position and constitutes a playing field to perform coordination. Relevant power structures are found to be set based on recorded contractual arrangements and market contexts. Often liability issues are recorded in the arranged legal contract, which provides a coherent chain of responsibilities among collaborative parties allowing potential impasses to be settled. Nevertheless, in other situations, market positions of parties or other external influences become decisive, as some resources prove to be scarce or project timelines do not provide legal matters to be settled.

To substantiate the line of reasoning presented in the previous paragraphs and illustrate how insights derive from case study data a couple of examples are illustrated. Firstly, the incident situation, wherein the delivery of ceiling panels is delayed, illustrates a supplier, who falls short in their obligation towards the main contractor to deliver the arranged product within time (IC 2.3.1). This incident illustrates a common situation, wherein the legal arrangements serve as power mechanism to enforce a change of plans. In order to settle the situation and minimise construction delay, the main contractor wishes to change the existing production plans. By revoking the preproduction of panel recesses they seek to simplify production in contemplation of the production speed. Within this situation the supplier seems inclined to accept the proposed coordinative measure, because the power position of the main contractor increased significantly due to the default by the supplier. Conclusively, a change of plans is implemented by the main contractor, which serves their interest and is compelled by power deriving from the legal arrangements. A second example exemplifies a situation when a power mechanism fails to accomplish to allocate power in an impasse situation. The dispute concerning the fire safety demands could not be settled by appealing to the established contractual arrangements, because both parties disagreed about the attributed responsibilities deriving from these arrangements (IC 1.1.1). Therefore, a negotiation process was set in motion to settle the dispute. Eventually, the impasse was settled by compromises, because the project timeline was put in jeopardy, which aligned the interests of both parties. Considering this example, the dominant interests of parties might change over time to resolve impasse situations. Lastly, an example of power acquired from market situations is provided. During the construction process of the study gallery several glass panes broke due to imprecise material handling (IC 1.3.2). Although the main contractor anticipated some material damages, the reordering of glazing proved problematic. Extending the glass order with additional panes was not possible, because glass factories, in general, close down for summer maintenance. Unable to arrange an alternative supplier, the main contractor is forced to seek alternative solutions at other levels of intervention and wait for supplier availability. Within this situation the supplier obtains bargaining power through the scarcity of alternatives and manages to prioritise their business operations above project demands.

Conclusively, the analysed coordination context seems to revolve around two central factors of influence, which were identified in the previous sections. Uncertainty revolving around construction processes seems to be the primary cause of incident occurrences, while the relative bargaining position exemplifies the range of possible interventions, which can be initiated by the central actor. Based on this context the process model can be complemented and transformed into a causal relationship model (Figure 9). It is suspected that the identified factors of influence correlate with the eventual coordinative measures undertaken by the central actor during the coordination process.

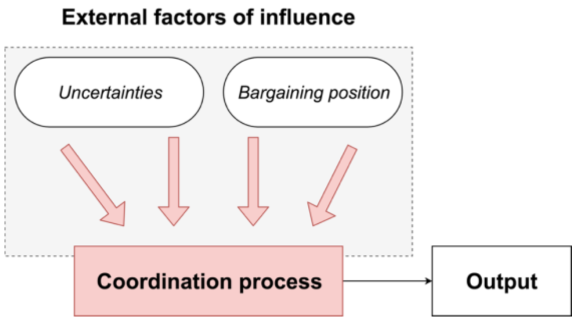

Figure 9: Establishing causality to the developed process model by adding external factors of influence.

3.3 INFORMATION EXCHANGE

Besides the role of coordination in construction, this research also set out to comment on the role of communication in supporting coordination efforts. In regard to information exchange methods the examined case study shows that especially shared information systems are used to convey information between project participants. More specifically, data is shared through mail and electronic documents, which contain contract arrangements, additional agreements, more specific technical elaborations of construction components and/or drawings in both 2D and 3D. Distributing information across the supply chain is primarily the task of the main contractor, who performs a pivotal role as primary channel for information. They have the main responsibility to translate client demands towards the supply chain in order to produce construction plans; and acquire information for verification by the client.

In regard to the developed conceptual model on coordinative behaviour within construction supply chains, the role of information is paramount. Each of the identified levels of coordination is succeeded by the transference of information between subsequent parties. Therefore coordination, in the sense of negotiating arrangements, takes place within the established process blocks, while the exchange of information is illustrated by the arrows, which establishes an integrated model. Following this process model, information progresses down the supply chain amplifying initial plans into finalised construction procedures. Consequently, the entire body of information grows when fundamental arrangements are elaborated into plans and further developed into implementation processes. Additionally, the occurrence of impediments adds to the advancement of information because the triggered recurrence to higher levels of intervention brings about an iterative improvement process. During this iteration process information is updated or added in order to support coordination efforts. As a result, the total body of information grows throughout the project timeline establishing an extensive amount of information to deal with (Figure 10). Ultimately, information management is inextricably related to performing coordination.

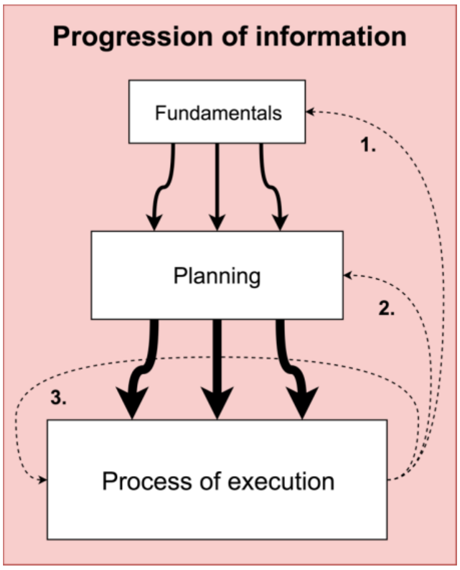

Figure 10: Visualising the composition of information within the developed process model.

Information, in its broadest sense, exists in many shapes and sizes. Within this research the focus is primarily aimed at information, which enables project processes. In this context, information is considered an important aspect to deal with uncertainty revolving around construction processes. Analysing how information is exchanged, but also what information is exchanged, is likely to help determining causes of construction incidents and the effectivity of coordination. However, in assessing the role of communication it seems that the quality of information is equally as important as the method for exchange. For example, the quality of the fire safety demands incorporated in the project requirements was considered unclear by the MEP contractor (IC 1.1.1). As a result, their interpretation of the demands differed from the intended outcome by the client. Conclusively, the quality of the distributed information induced uncertainty, which resulted in an incident. Nevertheless, the information exchange mechanisms remain an important aspect, as experienced in the incidents revolving around the ceiling plans (IC 2.2.1 & 2.2.2). Due to confusion about the latest version the ceiling subcontractor based their ceiling plans on outdated installation zoning plans, which resulted in an erroneous order towards the supplier. Proper exchange of information would have prevented such a situation. Furthermore, information seems to be constantly changing and should be managed constantly. Considering the misfit of the steel girders of the study gallery framework, the measurements changed over time, because component margins for error cause a gradual shift in the final dimensions (IC 1.2.1). Consequently, it is perceived that the required level of detail increases over time, which might be reason itself for iterative coordinative measures. Moreover, gathering information, through for example monitoring, might potentially be a proper detection mechanism for diagnosing potential impediments. Early detection of information deficits might result in incident prevention instead of resolving them. To conclude, the entire body of information, in regard to a construction project, grows exponentially and; acquiring and processing this information is of vital importance to manage these construction projects.

3.4 CONCLUSIVE CONCEPTUAL MODEL

Based on the previous sections, this chapter is concluded with the composition of a final conceptual model. The corresponding model displays how coordination is performed in construction supply chain incidents and what external factors influence this process. Additionally, the model introduces a framework to analyse the observed critical incidents and identify common patterns. The figure below introduces the conclusive model, which finalises the chapter (Figure 11).

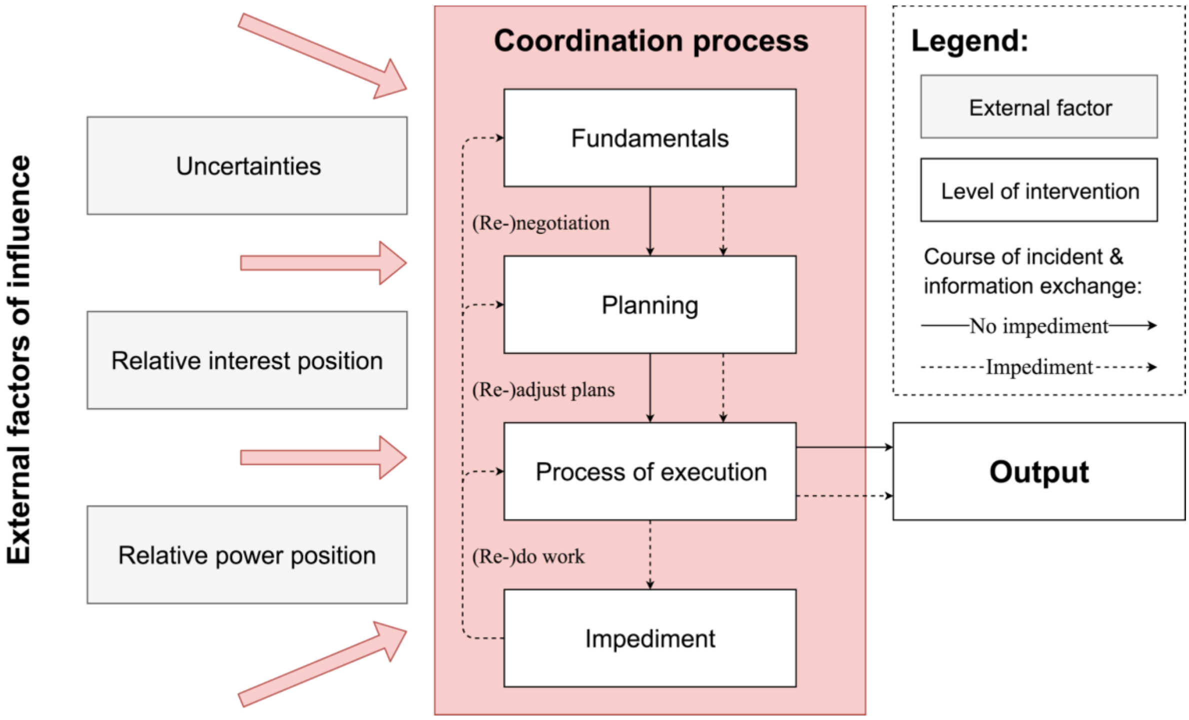

Figure 11: The conclusive conceptual model as developed and applied within this research.

Furthermore, each component of the conclusive model is provided with a definition (Table 2). These are primarily based on a common-sense approach and derive from ordinary language. Therefore, the Cambridge dictionary is used as general source to establish clear definitions for the used expressions.

Table 2: Definitions of the expressions used within the presented conceptual model.

Expressions	Definition
Central actor	The party entitled to perform a coordinative measure in an incident situation.
Fundamentals	The base, from which everything else develops. The considered base depends on the applied perspective and develops over time making it increasingly hard to change.
Impediment	Something that makes progress, movement, or achieving something difficult or impossible.
Output	The result of the process of execution.
Planning	The act of deciding how to do something.
Process of execution	The act of doing or performing something, especially in a planned way. The process transforms inputs into outputs.
Relative interest	A reason for supporting a particular action which will give the party an advantage.
Relative power	The ability to control people and events based on both a market and contractual relationship.
Uncertainty	A situation in which something is not known, or something that is not known.

4 CONCEPTUAL MODEL APPLICATION

In the following chapter multiple exemplary critical construction incidents are discussed to demonstrate the application of the developed model. Accordingly, the internal validation of the conceptual model is strengthened and by applying the model on all critical incidents a dataset of comparable results is generated, whereupon cross-case analysis is performed. The outcomes of this exercise are presented and summarised into an overview table (Table 16). For the purpose of internal validation, exemplary incidents are selected, mainly, based on their contribution to substantiate the developed conceptual model. Most incidents, referred to in the previous chapter, are discussed more extensively in the following critical incident descriptions. To provide additional context, the exemplary incidents are introduced by the corresponding embedded cases, from which they derive. Additional background, in relation to the observed cases is provided in the appendices (App. II). In the end, the objective of this chapter is to elucidate and validate the functioning of the conceptual model as analytical framework.

In the upcoming paragraphs twelve individual incidents are discussed in detail. Each incident is elaborated textually, which is followed by the interpretation of the incident through application of the developed model. In order to provide a clear overview of all exemplary incidents, discussed in this chapter, they are sorted per individual embedded case. Each embedded case regards incidents relating to a single construction component. Furthermore, a list is arranged including the discussed incidents and corresponding page numbers (Table 3).

Table 3: List of the discussed exemplary incidents in this chapter.

List of discussed exemplary incidents

4.1 EMBEDDED CASE NO. 1 – STUDY GALLERY

The following incidents are concerned with the study gallery constructed at the north side of the new building. At the entrance of the existing building a long hallway exists. During the construction of the new building this hallway is extended into a study gallery, which acts as connection between the new and existing building sections. The structure of the extended study gallery is attached to the floor of the new construction and consists of a steel framework, whereupon the façade, glass roof and installations are attached. For the construction process of the study gallery a rather stand-alone project approach is applied because there are minimal planning interdependencies between the study gallery and the rest of the construction project. As a result, the process is carried out as a rather self-contained sequence of activities, which has little relation to the finishing stages performed within the new building. Consequently, the planning for the construction of this gallery is flexible and contains slack for potential delays. Due to these characteristics the main contractor decides to allow a junior project supervisor to manage the construction of the study gallery. An impression of the structure is provided in the figures below (Figure 12 & Figure 13).

Figure 12: Study gallery before installing the glass roof construction.

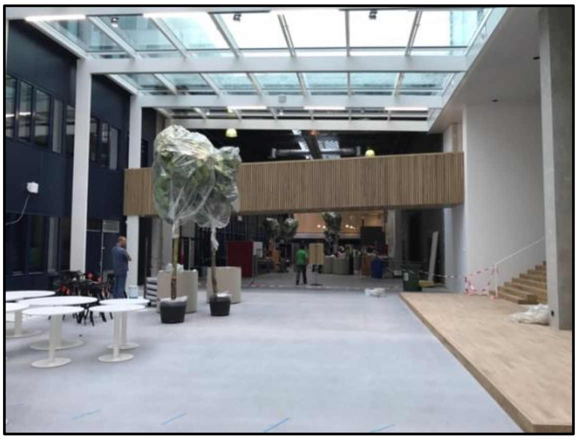

Figure 13: Study gallery during the installation of the interior.

IC 1.1.1 – Dispute concerning the fire safety demands

The first incident is the arisen dispute between the client and MEP contractor. Based on the elaborated fire safety demands, formulated by the client, the MEP contractor starts engineering the fire safety systems and sprinkler network. However, when presented to the client, both parties disagree about whether the engineered design fulfils the client demands. More specifically, the client claims that the MEP contractor did not engineer object monitoring for all requested areas. Furthermore, the MEP contractor proposed a more advanced sprinkler network and files for additional work costs. However, the client believes the proposed sprinkler network is in compliance with the demands and does not require additional payment. The MEP contractor disagrees with the client and as a result the parties have to renegotiate the conditions concerning the fire safety demands, because the current contract leaves room for interpretation. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 14).

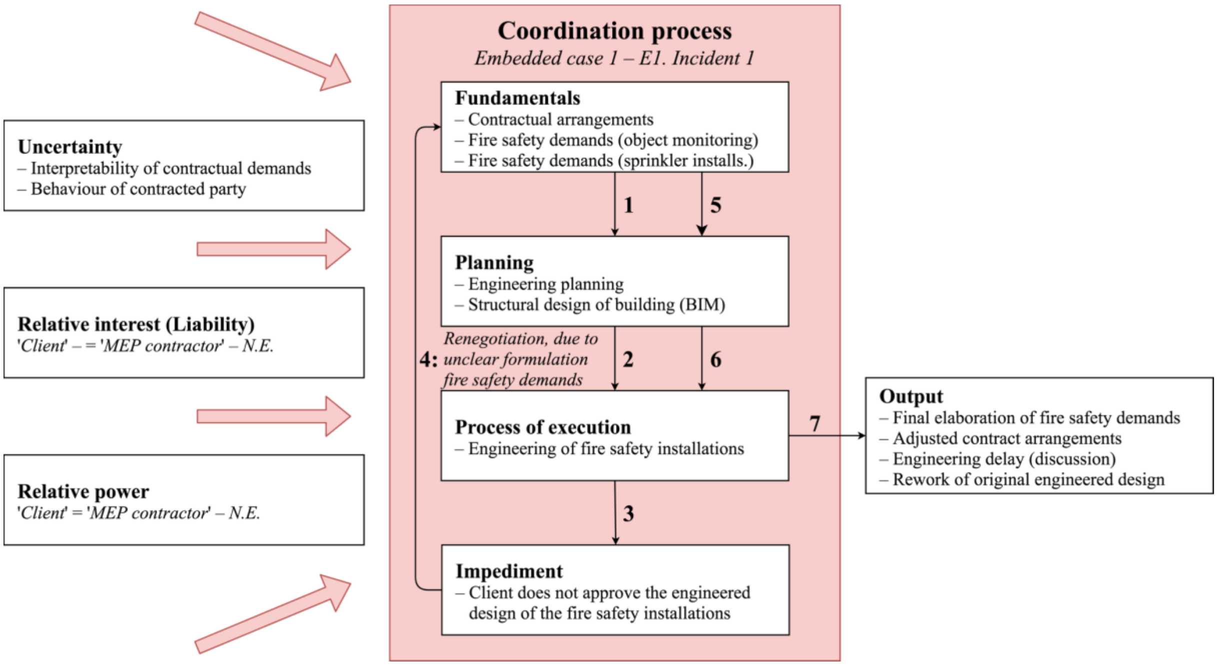

Figure 14: Visualisation of coordination process; "IC 1.1.1 – Dispute concerning the fire safety demand".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 4'.

Table 4: Textual elaboration of external factors and process steps depicted in 'Figure 14'.

Factor	***Interpretation***
Uncertainty	The contractual demands provided room for multiple interpretations and can therefore be considered unclear. This interpretability imposes uncertainty, in the sense that the client cannot rely on how the MEP contractor is going to elaborate the demands. Additionally, the unclarity provides an opportunity for the MEP contractor to act opportunistically and claim additional payment. Nevertheless, the behaviour can be considered uncertain because the attitude of the contracted party is unknown to the client.
Relative interest	Both parties have an equal relatively high interest in solving the dispute in their advantage. Process continuation is not yet crucial, which causes cost-saving measures to be favourable. Nevertheless, the client is reluctant to escalate, because they have sufficient funds left while the project deadline is crucial. Also, the MEP contractor will not escalate, keeping the project deadline in mind.
Relative power	The power position of both parties is balanced out because the problem is based on a different interpretation of contractually recorded demands. Therefore, no party can enforce cooperation, which brings about an impasse situation in regard to power.

	Process steps
1.	The project specifications and in particular the fire safety demands are incorporated into the contract, which is agreed upon by the involved parties.
2.	In the planning phase the engineering sequence is planned out. The MEP contractor is going to coordinate their engineering designs with the structural engineer, who engineers the structural design. During the process 3D BIM files are shared through a mutual accessible database and by mail. Additionally, design meetings are organised between project members and progress meetings are maintained to inform the client on progress of execution.
3.	The client evaluates the engineered fire safety systems and disapproves the elaboration of the fire safety demands.
4.	After a while the terms of the fire safety demands are renegotiated in a separate meeting. It is decided that the costs for the additional object monitoring is shared equally between both parties. The sprinkler network will be compensated for in full by the client because it is determined to be a full system upgrade compared to the demands.
5.	Based on the agreement the contract is extended by an additional amendment to settle the dispute.
6.	Conform the agreement, the additional engineering activities are planned similar to process step 2.
7.	As an output of the execution process the engineered object monitoring system and sprinkler network are finalised. However, the start of the subsequent activity is delayed.

IC 1.2.1 – Readjustment of the study gallery girder blocks

During the installation of the steel framework of the study gallery, the steel subcontractor experiences problems with the fit of the steel girders. Their dimensions are too large and do not fit between the concrete floor of the new building and the positioned steel columns. The misfit hampers construction and causes a delay because the workers cannot continue the installation activity. To solve the arisen problem the connection blocks, positioned between the girders and concrete floor, are returned to the factory and modified. Although, the production rework cost a day, the construction planning is not compromised, because the low level of interdependency between study gallery and main structure allowed a large amount of planning slack. As a result, the installation activity is finished late, but did not interfere with other tasks. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 14).

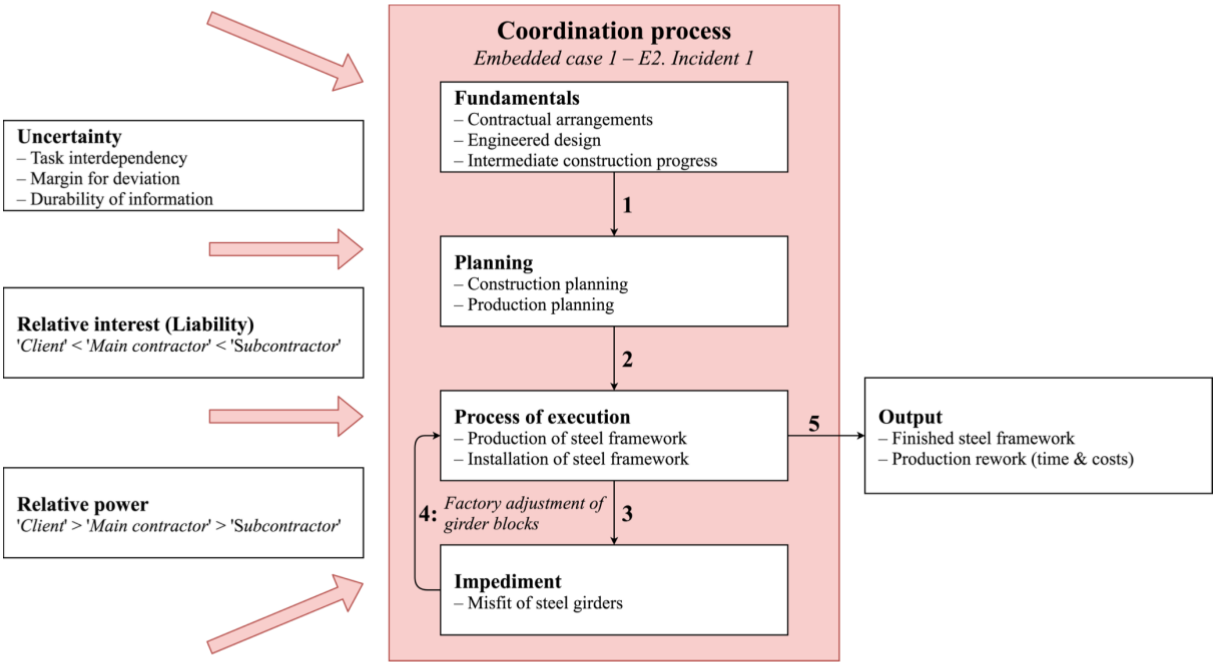

Figure 15: Visualisation of coordination process; "IC 1.2.1 – Readjustment of the study gallery girder blocks".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 5'.

Table 5: Textual elaboration of external factors and process steps depicted in 'Figure 15'.

Factor	Interpretation
Uncertainty	The steel framework subcontractor is dependent on the work performed in previous construction activities. This includes quality of the realised product and conformity with the design. During the production and installation of components a specific margin for deviation is allowed inherent to the product. However, the specific deviation is not known beforehand. When multiple products are stacked the deviations add-up causing shifts, in comparison to the original measurements. This uncertainty potentially causes misfits. Consistent with the relevant margin for deviation, the provided information, concerning the measurements is susceptible to change throughout the project. Therefore, the durability of information is uncertain in the course of time.
Relative interest	Because there is a large amount of planning slack on the steel framework installation activity, the main contractor is not very concerned by the misfit of the girders. Nevertheless, the steel subcontractor wants to proceed their activities and has a larger interest in the incident. Also, because they are contractually responsible for the additional costs incurred by the mistake. Differently, the client is not interested in the incident because they are not involved in daily operations and assigned the main contractor for operational management.
Relative power	The steel subcontractor is not responsible for managing the project and therefore has no power to demand a changed course due to their own mistake. Therefore, they have to fix the problem themselves. The main contractor is able to make changes, but is not interested in doing so, because they have no high interest in the problem.

Process steps	
1.	The fundamentals are primarily based on the contractual requirements in regard to the study gallery and its functions. Gradually, the engineered design and intermediate construction progress are added to the fundamentals, as they are approved by the client over the course of the project. The agreements are translated into a contract, whereupon the project team base their actions.
2.	In the planning phase an activity sequence for installing the study gallery is planned out. Based on this timeline a production planning is developed by the subcontractor. Specifications and requirements are exchanged by mail and through meetings. Shared work files are primarily 2D drawings and documents. Work meetings are arranged weekly to discuss progress among project members on the construction site.
3.	During construction the steel framework subcontractor notices that the steel girders do not fit between steel columns and concrete floor of the building shell.
4.	To solve the problem the steel connection blocks between the girders and concrete floor are returned to the factory and adjusted to the required measurements.
5.	After a day the steel connection blocks are returned to the construction site and the construction activities are continued. Consequently, the production rework cost the subcontractor additional time and costs, including transportation and handling costs.

IC 1.3.1 – Unable to reorder broken glass roof panels at the supplier

The installation of glass panes in the glass roof and façade of the study gallery is considered quite successful by the main contractor. Nevertheless, a few glass panes broke during the installation activity. Additionally, in a later stage some installed glazing broke due to inattention of construction workers. In order to finish the glass roof construction and make the structure weathertight the glass roof subcontractor plans to order new panes at the supplier. However, the supplier communicates that their factories are closed for the remainder of the summer in favour of maintenance. Apparently, this phenomenon is common in the glass industry in relation to construction holidays. This situation was not anticipated, because the construction project has been delayed with several weeks and now overlaps with the holiday period. Therefore, the glass subcontractor is faced with a problem due to their contract with the main contractor to install a glass roof. In addition, they cannot enforce the glass supplier to produce the glass panes because terms for substituting broken panes are not included in the contract. Finally, the glass roof subcontractor decides to install temporary plywood panels to fill up the remaining gap in anticipation of a more viable solution. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 16).

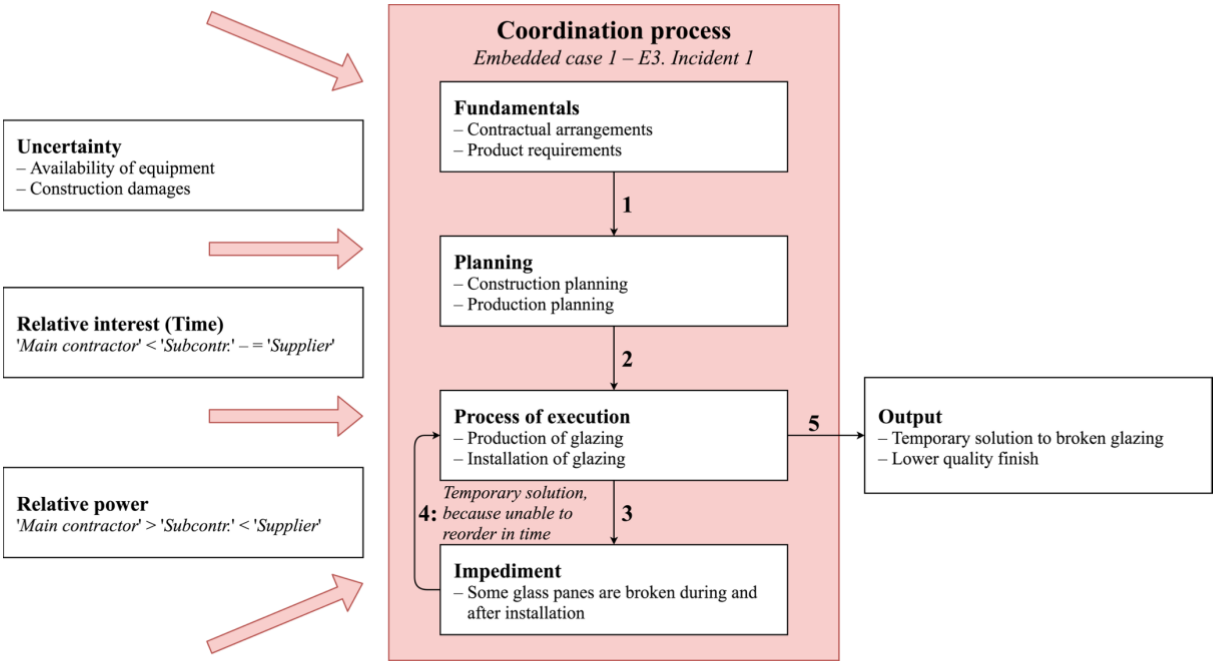

Figure 16: Visualisation of coordination process; "IC 1.3.1 – Unable to reorder broken glass roof panels at the supplier".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 6'.

Table 6: Textual elaboration of external factors and process steps depicted in 'Figure 16'.

Factor	Interpretation
Uncertainty	For the production of additional glass panes, to replace the broken glazing, the subcontractor is dependent on the availability of equipment at the supplier. However, the equipment has a particular capacity and the supplier decides how to deploy their assets. Consequently, the availability of equipment is an uncertainty for the glass roof subcontractor. When working with a fragile product like glass, the risk for damages is significant. Although, the aim is not to break any glass panes, often some do. However, anticipating potential damages, by ordering a surplus of panes, is costly and hampers profits. Therefore, damages remain an uncertainty.
Relative interest	The interests of the subcontractor and supplier are opposed due to their specific objectives. The subcontractor wishes to replace the broken glazing within the project timespan, but the supplier is occupied with maintenance and does not have an obligation towards the project. Within this incident situation the main contractor prefers the subcontractor to solve the problem, because they are liable to finish the glass roof. Therefore, their interest in the initial incident is low.
Relative power	In this case the supplier is in control because they fulfilled their initial delivery obligations. The replacement panels are an additional order and require the subcontractor to renegotiate terms with the supplier. Furthermore, the main contractor has contractual power over the subcontractor because they were contracted to arrange the glazing for the roof structure.

	Process steps
1.	In particular the product requirements and general agreements are translated into the contract, which has to be executed by the subcontractor. This is agreed upon by the involved parties.
2.	In the planning phase an activity sequence for installing the glazing is planned out. Based on this timeline a supplier is contracted and a production planning is developed. Specifications and requirements are exchanged by mail and through meetings. Shared work files are primarily 2D drawings and documents.
3.	While installing the glazing in the glass roof framework, two panes broke and have to be replaced in order to make the building weathertight.
4.	The subcontractor wishes to reorder some glass panes at the factory but is unable to because the factory is closed for maintenance. Also, switching suppliers is not possible due to similar issues. Therefore, the subcontractor installs plywood panels, as temporary solution, to make the building weathertight.
5.	The current state of the glass roof is undesirable because the work is not actually finished. However, the subcontractor is unable to arrange glass panes within the project deadline.

IC 1.3.2 – Postponing the replacement of broken glazing

The main contractor is approached by the glass roof subcontractor, who is in a deadlock situation. Therefore, they ask the main contractor to find an alternative solution. Unfortunately, also the main contractor has no power over the supplier and is committed to the project deadline. Alternatively, they are unable to switch to another supplier due to similar problems. Hence, they cannot break the deadlock and have to wait for the supplier to reopen. As a result, the only option is to approach the client with the problem and work out a solution. When the client is confronted with the arisen problem, they decide that the main contractor may postpone the order of glass panes till after project completion. When the building is finished the total amount of broken glazing will be recorded and ordered collectively afterwards. This solution anticipates future construction damages and allows the supplier to finish maintenance. However, the client imposes specific demands to the additional construction activities required to install the glazing, because the building will be operational by then. To conclude, the glazing problem is solved by negotiating a specific contract derogation for the replacement of broken glazing. However, this includes construction delay because operations are rearranged till after the official project completion. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 17).

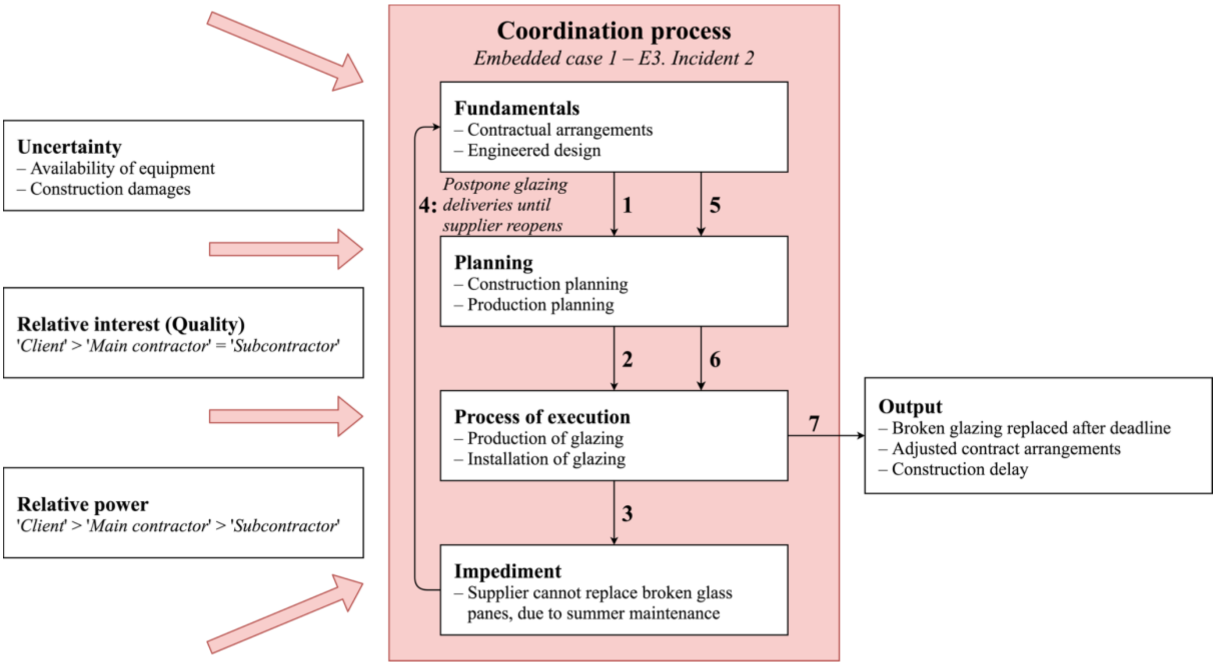

Figure 17: Visualisation of coordination process; "IC 1.3.2 – Postponing the replacement of broken glazing".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 7'.

Table 7: Textual elaboration of external factors and process steps depicted in 'Figure 17'.

Factor	Interpretation
Uncertainty	For the production of additional glass panes, to replace the broken glazing, the subcontractor is dependent on the availability of equipment at the supplier. However, the equipment has a particular capacity and the supplier decides how to deploy their assets. Consequently, the availability of equipment is an uncertainty for the glass roof subcontractor. When working with a fragile product like glass, the risk for damages is significant. Although, the aim is not to break any glass panes, often some do. However, anticipating potential damages, by ordering a surplus of panes, is costly and hampers profits. Therefore, damages remain an uncertainty.
Relative interest	In comparison to incident 1.3.1, the level of the incident ascends and now the main contractor is the central actor. All involved parties are now primarily invested in the quality of the product because the solution cannot be achieved within the project timeline. Also, it is clear that liability is with the main contractor and subjacent subcontractor due to their inability to finish the activity within the agreed time. Therefore, all parties look for an alternative solution, which guarantees quality without obstructing the building to be opened at the desired time. Still, the relative interest of the client is considered highest because the final quality is most important to them.
Relative power	The power structure is determined by the contractual responsibilities of the subsequent parties. Subjacent to the main contractor, the subcontractor was unable to fulfil their obligations and as a result the main contractor was unable to enforce its relative power over them.

	Process steps
1.	In particular the engineered roof design and more general specifications are translated into the contract, which has to be executed by the project team. This is agreed upon by the involved parties.
2.	In the planning phase an activity sequence for installing the glazing is planned out. Based on the construction planning, the subcontractor plans their operations. Specifications and requirements are exchanged by mail and through meetings. Shared work files are primarily 2D drawings and documents. Work meetings are arranged weekly to discuss progress among project members on the construction site.
3.	While installing the glazing in the glass roof framework, two panes broke and have to be replaced in order to make the building weathertight. The subcontractor tried to order replacements but is unable to arrange new glass panes due to summer maintenance of glass factories.
4.	The main contractor contacts the client to discuss the issue and devise an alternative plan. It is decided to postpone the order of glass panes till after project completion in order to anticipate additional broken glazing. In this way the replacement of all broken glazing is combined and installation of the new panes can be performed at a single point in time to minimise hindrance because the building is operational then.
5.	Based on the agreement the contract is extended by an additional amendment to arrange the repairs.
6.	Conform the agreement, the repairs are performed after the construction deadline is expired. Therefore, the main contractor has to arrange that construction activities are planned around operational activities within the building. Communication is arranged similar to process step 2.
7.	The current state of the glass roof is undesirable because the work is not actually finished. However, the subcontractor is unable to arrange glass panes within the project deadline.

4.2 EMBEDDED CASE NO. 2 – SUSPENDED CEILING

The following exemplary incidents are concerned with the suspended ceilings and the mechanical, electrical and plumbing installations related to them. Throughout the building multiple types of ceilings are applied. However, only the suspended ceilings applied in the hallways and study platforms are studied. These ceilings consist of steel perforated panels, which conceal the installation components, such as cable ducts, conduits and air channels running through these open areas. Additionally, they provide room for embedded sensors, armatures, speakers, sprinklers and fire safety indicators. Besides the functions related to these installations, the suspended ceilings also provide acoustic comfort and fire safety resistance alongside their primary aesthetic function. The construction of the suspended ceiling is divided in several stages because it requires a particular interaction with the installation components. Consequently, the installation of the ceiling is a highly demanding task, which is intertwined with the entire construction planning of the finishing phase. A primary reason for this high interrelation is the degree of task interdependency and the location of the installation activities, which are the transit routes for all activity on site. An impression of the ceilings is provided in the following figures (Figure 18 & Figure 19).

Figure 18: Open ceiling with single technical panel.

Figure 19: Ceiling application in open space.

IC 2.2.1 – Redistributing the correct zoning plan

The following incident is concerned with the development of the ceiling plan, which is engineered in cooperation between the ceiling subcontractor and MEP contractor. The installation components, such as lighting and speakers, are integrated within the ceiling panels. Therefore, the MEP contractor develops a zoning plan to assign approximate positions to the installation components. Based on this zoning plan the ceiling subcontractor engineers the ceiling plan after which the MEP contractor determines the final positions of the installation components. Lastly, the final ceiling panels are ordered by the subcontractor. Nevertheless, information exchange between the MEP contractor and subcontractor was not successful, as multiple versions of the zoning plan were confused and used to determine the final ceiling plan. After the subcontractor ordered the ceiling panels, the mistake was identified by the MEP contractor. Hence, the correct zoning plan was distributed to match the required state of installation coverage. As a result, the subcontractor has to adjust their processes to match the new plans. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 20).

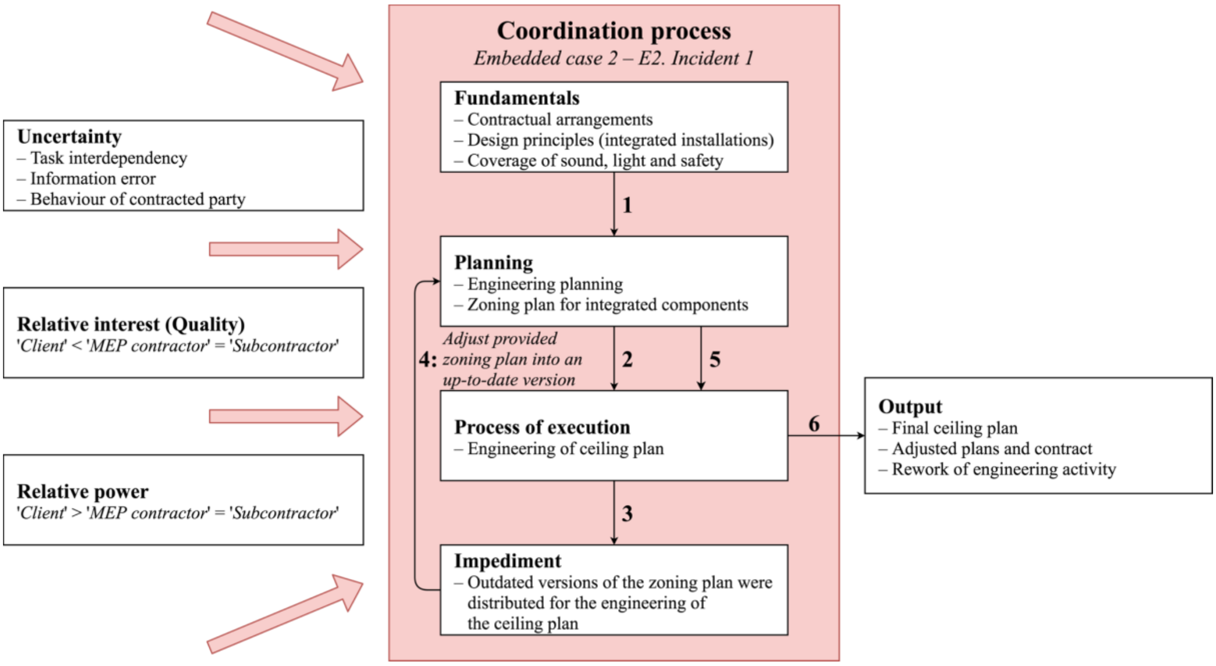

Figure 20: Visualisation of coordination process; "IC 2.2.1 – Redistributing the correct zoning plan".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 8'.

Table 8: Textual elaboration of external factors and process steps depicted in 'Figure 20'.

Factor	Interpretation
Uncertainty	The ceiling subcontractor is highly reliant on the performance of the MEP contractor, because both parties build upon each other's work in order to develop a final ceiling design. Nevertheless, the performance of the preceding party is always uncertain. When transferring information between parties a risk exists for errors. Mostly human errors or impractical information exchange systems cause a deficient exchange of information. To rectify the detected mistakes the MEP contractor requires cooperation from the ceiling subcontractor. However, their response to deviations from the agreed zoning plan is uncertain. In some cases, opportunistic strategies are employed to yield an additional profit.
Relative interest	The MEP contractor and ceiling subcontractor are highly reliant on each other during the process of execution. High levels of interdependency cause their interests to be aligned, because problems impeding the operations of one party affect the operations of the other. Consequently, a particular focus on quality is established. Differently, the client is not interested in the incident because they are not involved in daily operations and assigned the main contractor for operational management.
Relative power	Theoretically, the client is most powerful in this situation, as they expect the ceiling to be applied in accordance with the contractual arrangements. However, between the MEP contractor and subcontractor, an equilibrium exists because both parties have a particular amount of power. Reasonably, the MEP contractor is allowed to apply slight changes to rectify errors. However, the extent of these changes is limited by the principle of good faith. Therefore, both parties have to negotiate about what changes can be implemented and how this affects the initial agreement.

Process steps

1.	In particular the design principles, developed by the architect, and specific coverage requirements, in terms of light, sound and safety, are translated into the contract, which has to be executed by the project team. This is agreed upon by the involved parties.
2.	In the planning phase a work sequence of engineering is planned out. Also, the zoning plan for the required installations is produced by the MEP contractor, whereby the engineering of the ceiling plan commences. Coordination between the involved parties is primarily established through mail and meetings. Shared work files are primarily 2D drawings, which are later translated into the 3D BIM by the structural engineer. Work meetings are arranged weekly to discuss progress among project members on the construction site.
3.	The engineered ceiling plan, whereupon the production order is established, is incompatible with the installation positions. As a result, the installation coverage is at stake. This problem is the result of problematic information exchange causing the ceiling subcontractor to develop a ceiling plan based on an outdated version of the installation zoning plan.
4.	The zoning plan is checked and redistributed to the subcontractor in order to for them to adjust the developed ceiling plan.
5.	A re-engineered ceiling plan is produced by the ceiling subcontractor.
6.	As a result of the process a final revision of the ceiling plan is realised. However, the engineering activity is delayed and rework in the engineering caused additional costs. Furthermore, subsequent activities are affected by the applied changes.

IC 2.2.2 – Aligning the ceiling plan with the new zoning plan

The ceiling subcontractor developed a ceiling plan based on the received zoning plan from the MEP contractor. Deriving from the ceiling plan an order list is composed, which includes different types of ceiling panels. Subsequently, the order is placed at the supplier and terms for delivery are agreed upon. Later on, the employed zoning plan turns out to be outdated because something went wrong in the exchange of information. Accordingly, the ceiling subcontractor has to revise the ceiling plan and revoke the initial order of ceiling panels. The supplier is contacted by the subcontractor, who explains the arisen problem. Fortunately, the inaccuracy was noticed on time for the supplier to be able to apply changes. As a result, the required changes are implemented and the order is rectified. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 21).

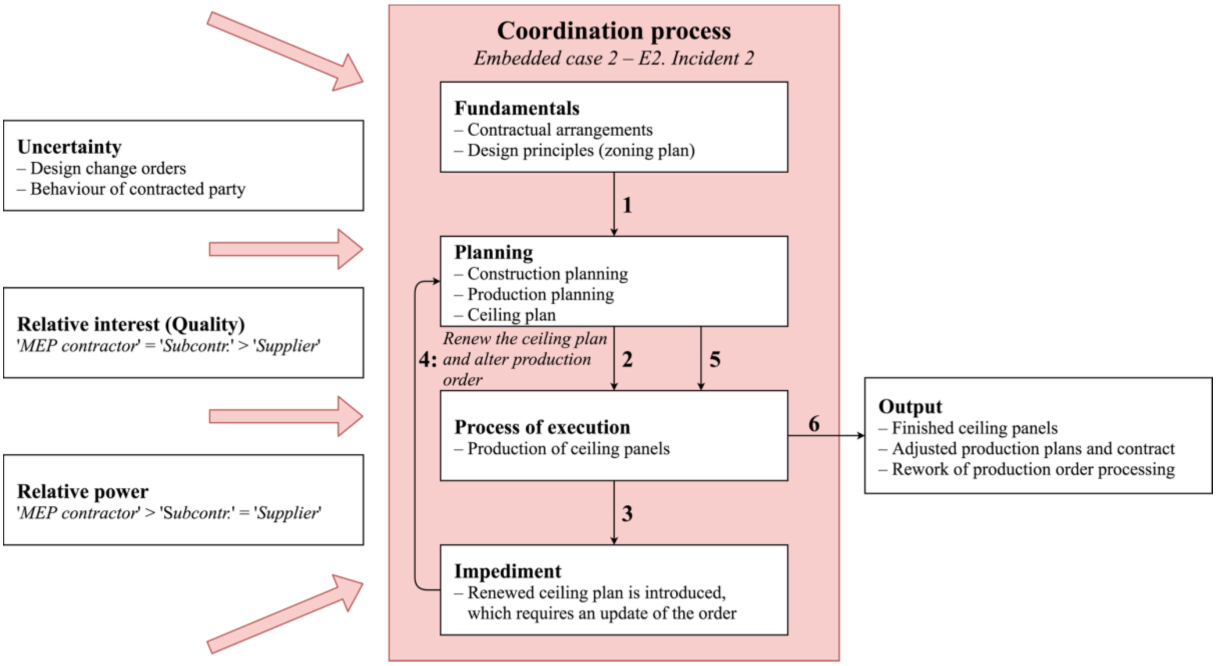

Figure 21: Visualisation of coordination process; "IC 2.2.2 – Aligning the ceiling plan with the new zoning plan".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 9'.

Table 9: Textual elaboration of external factors and process steps depicted in 'Figure 21'.

Factor	***Interpretation***
Uncertainty	In order to adjust to the altered zoning plan, the ceiling plan from the subcontractor is modified. However, these changes also affect the production order placed at the supplier. Conclusively the production order is subject to uncertainty as changes might be required over time. In some cases, opportunistic strategies are employed to yield an additional profit. The subcontractor is depending on the willingness and capabilities of the supplier to adjust their processes to the altered requirements.
Relative interest	The interests of the MEP contractor and subcontractor are aligned based on their concern for the quality of the process. When the affairs are in order the eventual construction process will proceed effectively, which benefits both parties. However, the supplier does not benefit from this advantage and is more concerned with the effectivity of production, which is potentially impeded by alterations.
Relative power	Basically, the MEP contractor is more powerful than the subcontractor in this situation because they already coordinated new arrangements between each other in an earlier incident situation. However, the subcontractor and supplier are relatively equally powerful. Reasonably, the subcontractor is allowed to apply slight changes to rectify errors. However, the extent of these changes is limited by the principle of good faith. Therefore, both parties have to negotiate about what changes can be implemented and how this affects the initial agreement.

	Process steps
1.	In particular the design principles, further elaborated by the MEP contractor into a zoning plan, are translated into the contract, which has to be executed by the project team. This is agreed upon by the involved parties.
2.	During the planning of the work sequence the engineering is planned out. Based on the zoning plan a ceiling plan is produced, whereupon a production order is composed. Coordination between the involved parties is primarily established through mail and meetings. Shared work files are primarily 2D drawings and documents containing requirements.
3.	The ceiling plan, whereupon the production order is established, is incompatible with the installation positions due to the revised zoning plan. Therefore, the ceiling plan and consequently the production order are outdated and require to be adjusted.
4.	Based on the new zoning plan the ceiling subcontractor develops a new ceiling plan and discusses the possibility to change the production order with the supplier.
5.	The production process is adjusted to the new purchase order and commences.
6.	Finally, the plans and contract are adjusted to the revised ceiling design. Nevertheless, the adjustments required additional work, which slightly delayed the overall process.

IC 2.3.1 – Postponement of ceiling panel deliveries

A third exemplary incident, in regard to the suspended ceiling, is the postponements of the ceiling panel deliveries by the supplier. The production process proved to be more demanding than was anticipated and requires more time, mainly because of the large variety of different ceiling panels. Because of the long production lead times, the construction activities, related to the ceiling panels, are delayed. Therefore, the ceiling subcontractor, in coordination with the main contractor, looks for a viable solution to diminish the delay. As a result, they discuss cancelling the prefabrication of specific panel recesses, wherein integrated installation components are installed. The consequence of this decision is that the ceiling subcontractor has to manually incise the recesses on site, which causes significant installation delays. However, mitigating the production delay also allowed other parties to continue construction sooner than expected. Nevertheless, at the end a significant activity delay, affecting the project timeline, is incurred due to the incident. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 22).

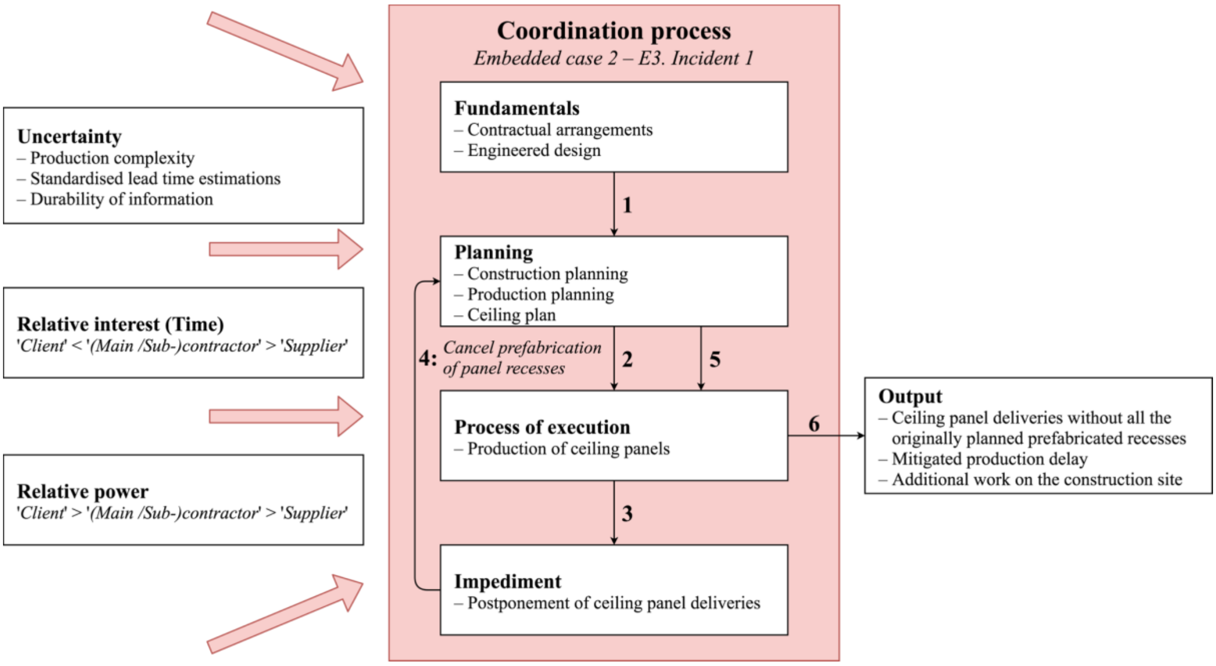

Figure 22: Visualisation of coordination process; "IC 2.3.1 – Postponement of ceiling panel deliveries".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 10'.

Table 10: Textual elaboration of external factors and process steps depicted in 'Figure 22'.

Factor	**Interpretation**
Uncertainty	The required product, which has to be produced, is considerably complex. Mainly, the prefabrication of many different panels amplifies this complexity, which induces a high level of uncertainty because many unexpected factors might disrupt the production process. Additionally, to product complexity, the parties are unfamiliar with the product, which causes them to make an unrealistic estimation of the production lead time. Therefore, the supplier runs into trouble when they learn that the production processes is more demanding than anticipated. Furthermore, the postponement of deliveries was communicated last-minute by the supplier. Therefore, an earlier intervention was not attainable, which would have required up-to-date information.
Relative interest	Relatively the ceiling subcontractor has a higher interest in the incident situation because the late deliveries threaten their performance and the project operation. However, the supplier also is invested in the incident because the contractual arrangements are violated. To protect their reputation and ensure payment for the services.
Relative power	In this case the ceiling subcontractor is most powerful because the supplier does not live up to the agreed contractual arrangement and is unable to deliver the product in time. However, the lack of time makes the subcontractor reluctant to enforce contractual sanctions, which also provides the supplier with a powerful position. Therefore, the main contractor and subcontractor look for a middle ground, which serves both interests.

	Process steps
1.	Based on the ceiling plan a production order is placed at the supplier. The plan contains a broad variety of different ceiling panels (± 280 types). Specific agreements are recorded in a contract and signed by both parties.
2.	Using a six-week production planning the deliveries of the ceiling panels are planned out for the project. Also, the ceiling subcontractor produces a list of all different ceiling panels and by using codes they assign panels to specific positions and floors in the building. Information is primarily shared using mail, because the supplier is a foreign trading and production company.
3.	The production of the ceiling panels proves to be demanding, especially due to the increased complexity cause by the large amount of different panel types. Therefore, the production is behind schedule and deliveries are postponed.
4.	To decrease the complexity and speed up the production process both parties agree to cancel particular prefabricated recesses, which diminished the amount of different ceiling panel types. The incision process is reallocated to the construction site, where the ceiling subcontractor will perform the incisions.
5.	Conform the agreement, the remaining ceiling panels are produced and planned similar to process step 2.
6.	Lastly, the ceiling panels are delivered with a delay and the construction process was stalled for quite some time.

IC 2.4.5 – Ignoring the contorted ceiling alignment

Near the end of the finishing phase, it is noticed that the alignment of the ceiling panels is contorted. Gaps of several centimetres and undulating lines are the result of an accumulation of various problems. Firstly, the seams between panels are not concealed and therefore panel installation is required to be very precise. Additionally, the panels are made of metal, which provides little room for deviation due to the rigidity of the material. Furthermore, the dimensions of the hallways, whereupon the ceiling plan is based, is susceptible to change over time due to margins for deviation. Therefore, measurements shift and cause little differences in the alignment of panels. Lastly, during the construction process many panels incurred little damages, which cause discrepancies in the ceiling surface, making it look contorted. At first glance the arisen problem seems to be the responsibility of the main contractor, but within the context of the hectic closing phase the situation is more nuanced. First of all, the main contractor claims that the contorted alignment was already foreseen in the engineering phase and communicated to the client. The client, however, claims that the issues were not conveyed through official channels and therefore unknown to them. This contradiction causes an impasse in terms of arranging repairs. Nevertheless, both parties agree that project continuation is most important in order to meet the project deadline and open the building in time. Therefore, the argument is put aside and it is decided to continue the construction activities without intermediate repair works. Nonetheless, the client intends to resolve the dispute when construction is finished. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 23).

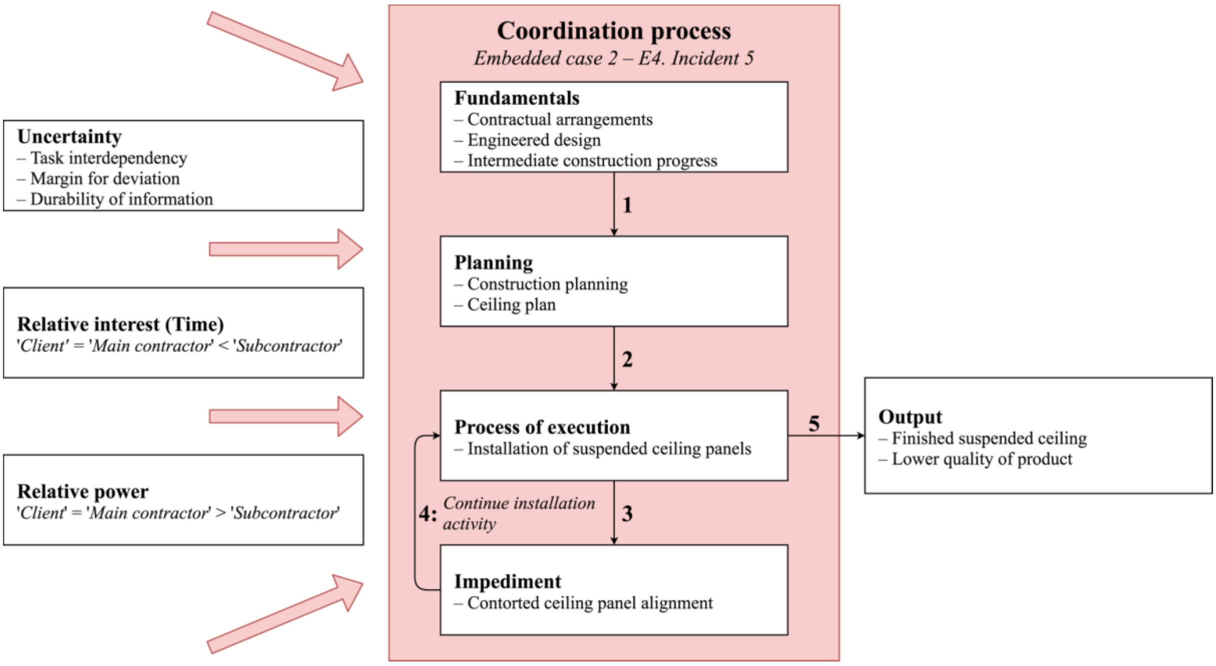

Figure 23: Visualisation of coordination process; "IC 2.4.5 – Ignoring the contorted ceiling alignment".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 11'.

Table 11: Textual elaboration of external factors and process steps depicted in 'Figure 23'.

Factor	***Interpretation***
Uncertainty	The ceiling subcontractor is dependent on the work performed in previous construction activities. This includes quality of the realised product and conformity with the design. During the production and installation of components a specific margin for deviation is allowed inherent to the product. However, the specific deviation is not known beforehand. When multiple products are stacked the deviations add-up causing shifts, in comparison to the original measurements. This uncertainty potentially causes misfits. Consistent with the relevant margin for deviation, the provided information, concerning the measurements is susceptible to change throughout the project. Therefore, the durability of information is uncertain in the course of time.
Relative interest	Interestingly, the interests of all parties are aligned in favour of project continuation. Nevertheless, the underlying reasons and urgency differs. The client wishes to open the building in time for the new academic year and therefore condones the contorted ceiling to stimulate the advancement of the project. The main contractor, on the other hand, has no intention to rectify the quality of the ceilings without additional payment because they argue that their actions comply with the contractual arrangements. Lastly, the subcontractor has the highest interest, because they are liable for potential rectifications.
Relative power	Because of the dispute between main contractor and client, considering the requirements in regard to the ceiling, the contract cannot be enforced to instigate particular actions. Therefore, they need to negotiate in order to devise a solution. Moreover, the main contractor has some power over the ceiling subcontractor because their mutual agreements is still enforceable. They can possibly demand, for example, little repairs of panel damages to improve the situation.

	Process steps
1.	The fundamentals are primarily based on the contractual arrangements in regard to the ceiling panels and its functions. Gradually, the engineered design and intermediate construction progress are added to these arrangements, as they are approved by the client over the course of the project. The agreements are translated into a contract, whereupon the project team base their actions.
2.	In the planning phase an activity sequence for installing the ceiling panels is planned out. Specifications and requirements are exchanged by mail and through meetings. Shared work files are primarily 2D drawings and documents. Work meetings are arranged weekly to discuss progress among project members on the construction site.
3.	When inspecting the suspended ceilings, it is noticed that the alignment of panels is contorted.
4.	It is decided by the involved parties to continue installation and finish the building. Nevertheless, the client intends to address the lack of quality at a later stage when the timely consignment of the building is secured.
5.	As a result, the suspended ceiling is finished, but with a low level of quality.

4.3 EMBEDDED CASE NO. 3 – BALUSTRADES

Another few incidents are described, which are related to the balustrades. Multiple types of balustrades are applied within the project, but in this particular case description the balustrades located at the study platforms and corridors are examined. They enclose the areas for fall protection and are made from glass and wood held together by a slender steel framework. The construction of the balustrades is organised sequentially and is arranged in several phases. Firstly, balusters are attached to the concrete floors and form the framework of the structure. Additionally, they support the cove construction concealing the installations attached to the ceilings. At floor level, a railing is attached to the balusters, wherein glazing is placed. On top of the glazing and balusters a laminated wooden banister is positioned. However, before the glazing is placed the steel balusters are submerged in a cement screed coat, which is poured on top of the structural floor. In terms of functionalities, the balustrades serve as fall protection and have fire resistant capacities. Additionally, the aesthetics are important for the overall look of the building. An impression of the constructed balustrades is provided in the figures below (Figure 24 & Figure 25).

Figure 24: Impression of balustrades before and after installation of glass elements.

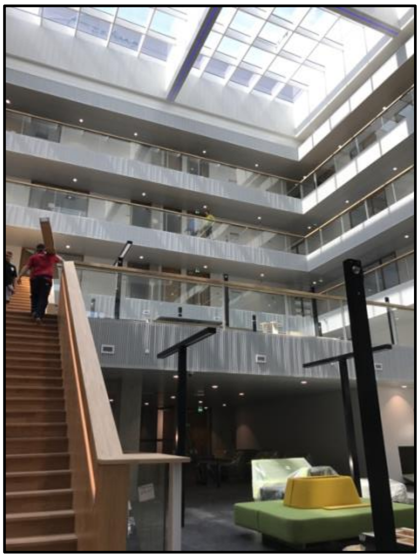

Figure 25: Impression of finished balustrades over multiple floors.

IC 3.1.2 – Cleaning the cluttered balustrade glazing rails

The balustrades are made of glass panes, which are secured in a framework of steel and wood. At the bottom of the framework a railing is positioned to secure the glazing of the balustrade. However, when a cement screed was poured, as base for the floor finishing, these glass railings filled up with the fluid cement. Although precautions were applied to block the cement, the railings were significantly tainted. When finally, the glazing arrived, the clogged railings required to be cleaned from cement residue. However, the subcontractor, assigned to arrange the glazing, is not responsible for cleaning the rails preceding their work activities. Therefore, the main contractor is compelled to assign a freelance worker to clean the rails manually. This time-consuming task caused the glazing subcontractor to postpone their activities and store the glass panes on the construction site. In a subsequent incident the glazing is damaged due to lack of proper storage. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 26).

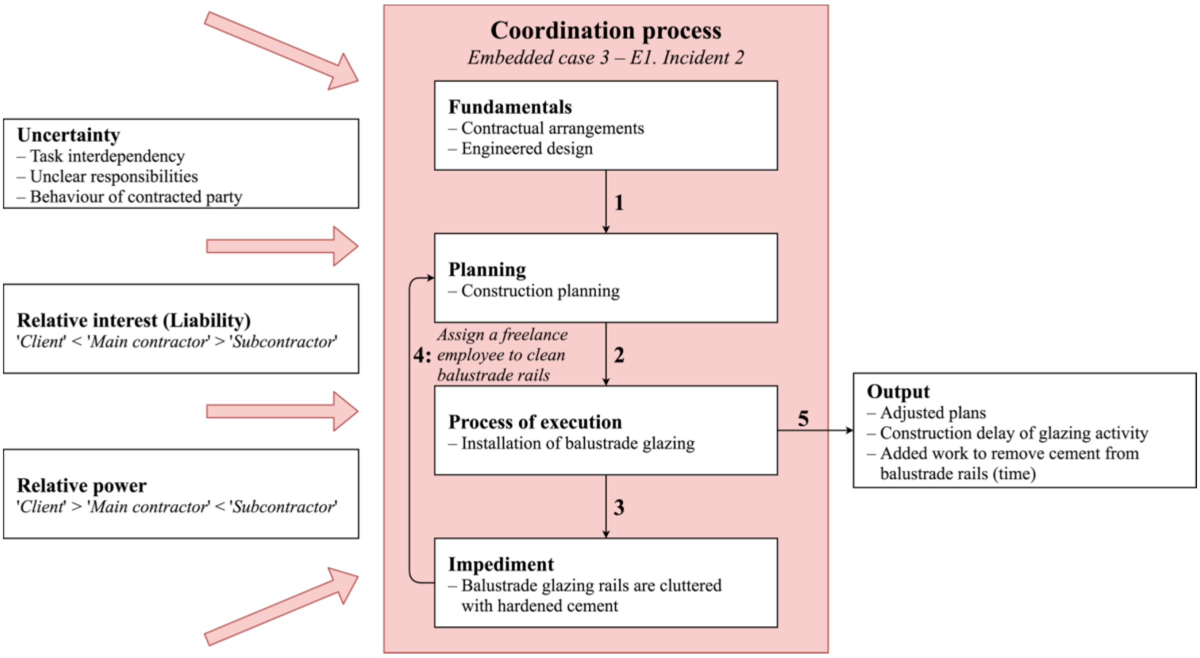

Figure 26: Visualisation of coordination process; "IC 3.1.2 – Cleaning the cluttered balustrade glazing rails".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 12'.

Table 12: Textual elaboration of external factors and process steps depicted in 'Figure 26'.

Factor	**Interpretation**
Uncertainty	The installation of the balustrade glazing is dependent on the performance of previous parties, who potentially affect the intended work process. In this case the floor subcontractor is not directly involved in the balustrade installation process, but still has a considerable effect on the course of the process of execution. Within the situation no clear arrangements are agreed upon in regard to the balustrade railings. The floor subcontractor is not responsible for keeping them clean, while the balustrade subcontractor is not assigned to clean the railings prior to installation. When responsibilities are unclear it provides an opportunity for the subcontracted party to act opportunistically and claim additional payment for more work. Nevertheless, the behaviour can be considered uncertain because the attitude of the contracted party is unknown to the main contractor. In this case the main contractor decides to resolve the issue themselves instead of attributing additional work to the subcontractor.
Relative interest	Primarily, the main contractor has an interest in the incident because they are liable for the arisen problem. Therefore, no obvious solution is available for the incident and a more cumbersome measure is required. The subcontractor has no interest in solving the issue and therefore remains passive. Furthermore, the client remains passive as well, as no impassable difficulties are encountered.
Relative power	The glazing subcontractor is in control because the main contractor falls short in their obligation to arrange the required starting conditions to commence construction activities. Therefore, they can decide to suspend operations until these conditions are achieved. Additionally, the client has contractual power over the main contractor because they were contracted to arrange the balustrades.

	Process steps
1.	In particular the engineered design for the balustrades is translated into the contract, which has to be executed by the project team. This is agreed upon by the involved parties.
2.	A construction planning is determined for installing the specific components of the balustrade. Specifications and requirements are exchanged by mail and through meetings. Shared work files are primarily 2D drawings and documents. Work meetings are arranged weekly to discuss progress among project members on the construction site.
3.	It is noticed that the glass railings are cluttered with cement, which impedes the installation of glazing and therefore require to be cleaned first.
4.	The main contractor assigns a freelance worker to clean the railings with a chisel and vacuum cleaner.
5.	Due to the scheduled cleaning activity the installation of the balustrade glazing can commence.
6.	Finally, the incident caused a construction delay because the glazing subcontractor could not start their activities right away. Furthermore, the adjusted plans contained work, which cost additional time and costs on top of the original project timeline and budget.

IC 3.2.1 – Imperfect finish of balustrade product interfaces

The balustrades are finished with an angled wooden banister, which corresponds with the banisters of the stairs. The installation of the banisters is performed by separate parties. However, the connections between the banisters applied by different parties are not accurately aligned. This leaves an awkward angle, which stick out and looks flawed. Nevertheless, the low-quality finish is not rectified because the operational parties cope with severe time pressure and are focussed on meeting the overall project. Generally, the time pressure causes parties to concentrate on work speed rather than quality. Even the client, who is ordinarily concerned with quality, seems prepared to make concessions in favour of project completion. As a final result, construction activities are carried on despite the lower quality finish of the banisters. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 27).

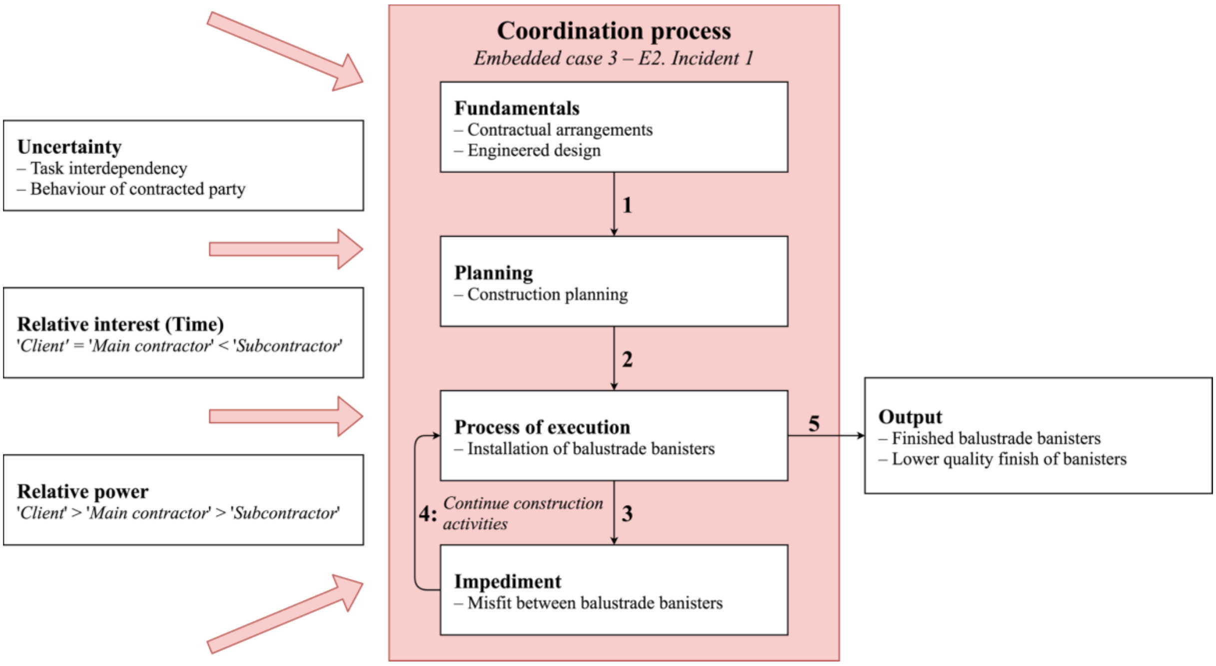

Figure 27: Visualisation of coordination process; "IC 3.2.1 – Imperfect finish of balustrade product interfaces".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 13'.

Table 13: Textual elaboration of external factors and process steps depicted in 'Figure 27'.

Factor	Interpretation
Uncertainty	Both subcontractors installing banisters are dependent on the performance of the concurrent party. When the alignment of one party is off, the final quality of both products is impaired. The behaviour of both subcontractors can be considered uncertain because the time pressure allows room for opportunistic behaviour. In this case, the main contractor is limited by time to correct imperfections, which might tempt subcontractor to cut some corners and be less focussed on quality. Nevertheless, the attitude of the contracted parties is unknown to the main contractor.
Relative interest	During the incident the client and main contractor are mainly concerned with the project deadline and therefore have an interest in continuation. Furthermore, the interest of the subcontractor lies with preventing rework. Rectifying the imperfections would require additional time and resources at their expense. Therefore, the interests of the subcontractor are considered highest.
Relative power	The quality of the banister finishes is arguably below the level of what can be expected. Therefore, the main contractor and subsequently the client can rely on the contract to enforce potential rectifications. Nevertheless, they do not wish to enforce this possibility and condone the lower quality in order to save time.

	Process steps
1.	The fundamentals are primarily based on the contractual arrangements in regard to the balustrades and its functions. Later, the engineered design is added to the fundamentals when it is approved by the client. The agreements are translated into a contract, whereupon the project team base their actions.
2.	In the planning phase an activity sequence for installing the balustrade components is planned out. Specifications and requirements are exchanged by mail and through meetings. Shared work files are primarily 2D drawings and documents. Work meetings are arranged weekly to discuss progress among project members on the construction site.
3.	When inspecting the banisters, it is noticed that the alignment between balustrades and stairs is contorted.
4.	It is decided by the involved parties to continue installation and finish the building in order to attain the project deadline.
5.	As a result, the banisters are finished, but with a lower level of quality.

4.4 EMBEDDED CASE NO. 4 – FURNISHINGS

The last incidents are related to the furnishings, which are applied inside the building. These are arranged separately by the client, but installation is performed concurrently with construction activities. Furnishings inside the building are split in different types, which are executed by separate parties. Firstly, standardised furniture from a catalogue is installed by a contracted furniture supplier. This category contains for example desks, chairs and bookcases. Furthermore, a category contains customised furniture such as custom sofa's, study benches, kitchenettes and whiteboards. Other categories are electronics and relocation of belongings from the temporary building. The process of installing furniture has to be completed before the start of the new academic year. An impression of the constructed balustrades is provided in the figures below (Figure 28 & Figure 29).

Figure 28: Installation of furnishings on study platform on third floor.

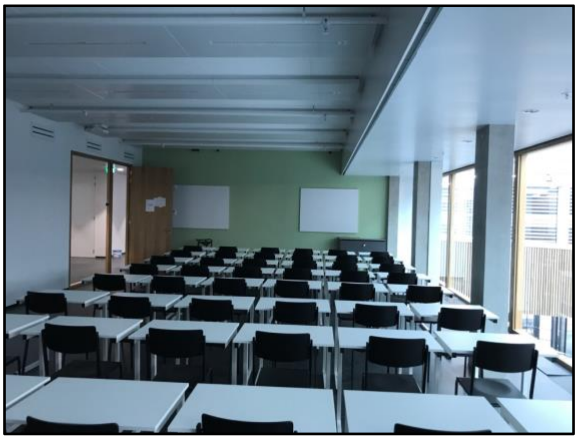

Figure 29: Layout of lecture room after furnishing

IC 4.1.1 – Change of management on the construction site

After the project is delayed multiple times, the utmost construction deadline is compromised. The client wishes to open the building before the start of the upcoming academic year. However, the process of moving into the building and furnishing it requires additional weeks as well. Therefore, the client is worried their main objective will not be achieved. In response to the problem the client contacts the main contractor to negotiate arrangements to advance the process of moving in. The client wishes to take control of the construction site before construction is officially finished and start off the furnishing process alongside construction activities. In exchange for the authority on site, the main contractor is allowed some more time to finish their activities. As a final result time is saved by performing activities concurrently. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 30).

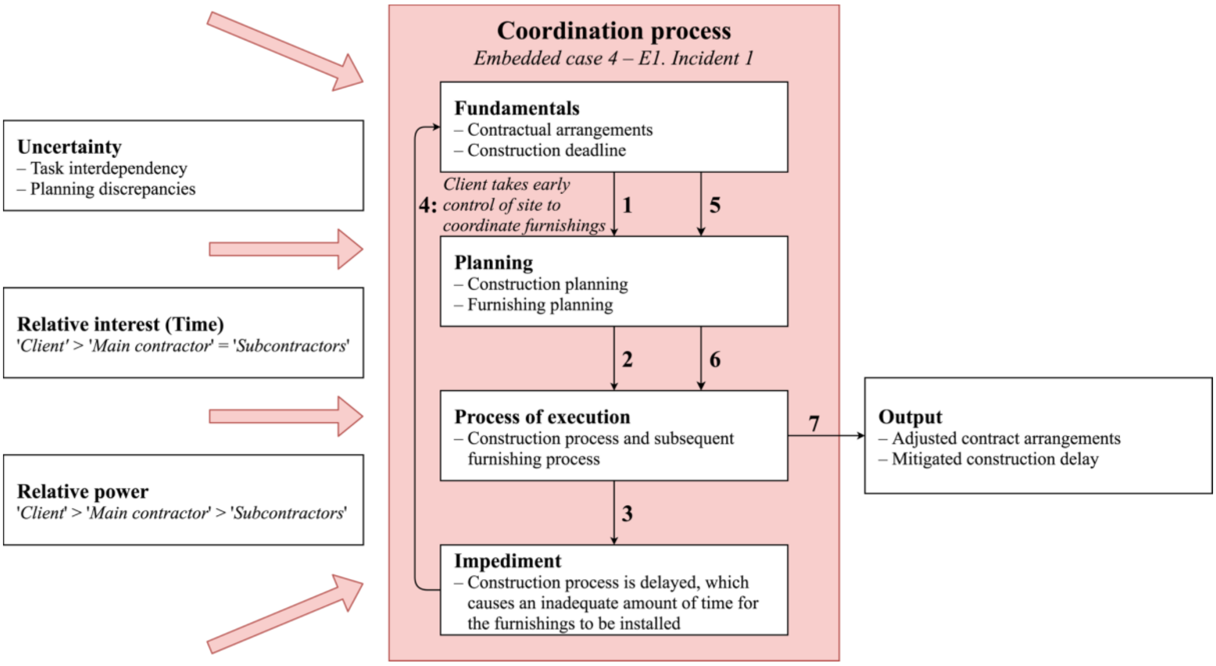

Figure 30: Visualisation of coordination process; "IC 4.1.1 – Change of management on the construction site".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 14'.

Table 14: Textual elaboration of external factors and process steps depicted in 'Figure 30'.

Factor	**Interpretation**
Uncertainty	First of all, the client is dependent on the construction activities coordinated by the main contractor in order to finish the new building in time for the upcoming academic year. Also, the furnishings are often the last operation in the sequence depending on the performance of the preceding parties. Besides task interdependency another uncertainty is the planning. When adapting to construction discrepancies, the planning of a project changes over the course of time. Therefore, the planning copes with uncertainty.
Relative interest	The client has a dominant interest in this situation because they want to have an operational building by the start of the new academic year. If this deadline is not achieved they have to extend a lease contract for a temporary location. The main contractor and subcontractor are willing to cooperate due to the delays they have incurred earlier in the process. Therefore, they have an interest in finishing the project in time and avoid potential fines.
Relative power	To cover some of the risk the client included a contractual clause, which allows them to impose a fine to the main contractor and construction partners when the building is not finished in time. Based on this clause, the main contractor is particularly willing to cooperate and look for solutions to achieve the intended deadline.

	Process steps
1.	The project specifications, especially in regard to construction deadlines, are incorporated in the contract, which is agreed upon by the involved parties.
2.	In the planning phase the work sequence is planned out to achieve the required project deadline. During the process files are shared through a mutual accessible database and by mail. Additionally, design meetings are organised between project members and progress meetings are maintained to inform the client of progress of execution.
3.	The client notices that the intended deadline will not be achieved by the main contractor due to incurred setbacks during the construction process. Therefore, they predict they have insufficient time after completion to furnish the entire building.
4.	Based on the noticed impediment the client contacts the main contractor to make arrangements to realise an operational building by the start of the academic year. It is conferred that the main contractor hands over control of the building site at the original completion date but is enabled to finish the remaining tasks. Meanwhile the client can start the furnishing process and finish the building in time.
5.	Based on the agreement the contract is extended by an additional amendment to settle the new deadline arrangements.
6.	Conform the agreement, the renewed work sequence is re-planned similar to process step 2.
7.	As an output the contractual arrangements are adjusted slightly in regard to the construction deadline. Consequently, the construction incurred construction delay is mitigated by planning work of the client and main contractor concurrently.

IC 4.2.2 – Installation of lecture furniture interface plugs

During the finishing phase the MEP contractor is behind on schedule for installing the required installation interfaces. For example, the wall plugs and connectors are not installed everywhere yet. Nevertheless, the client instructed their subcontractor to install all lecture furniture, wherein equipment is installed to operate the interactive whiteboards in the classrooms. However, this equipment must be plugged into the wall plugs and connectors, which are not present yet at all locations. Moreover, the installed lecture furniture hinders the installation of wall installations and needs to be removed again when the MEP contractor wants to perform their remaining activities. The miscommunication between client and MEP contractor mainly originates from a lack of overview of remaining installation activities. In comparison to the other construction activities, the MEP contractor is unable to keep up and therefore overview is lost. In order to solve the problem, the lecture furniture is removed by the MEP contractor after which the wall installations are installed. Subsequently, the lecture furniture is repositioned. The additional result of this ineffective procedure is that the lecture furniture is damaged due to mounting and dismounting of the product. The cause-effect diagram below represents the process of coordination and the external factors of influence affecting the coordination process, which results in a particular output (Figure 31).

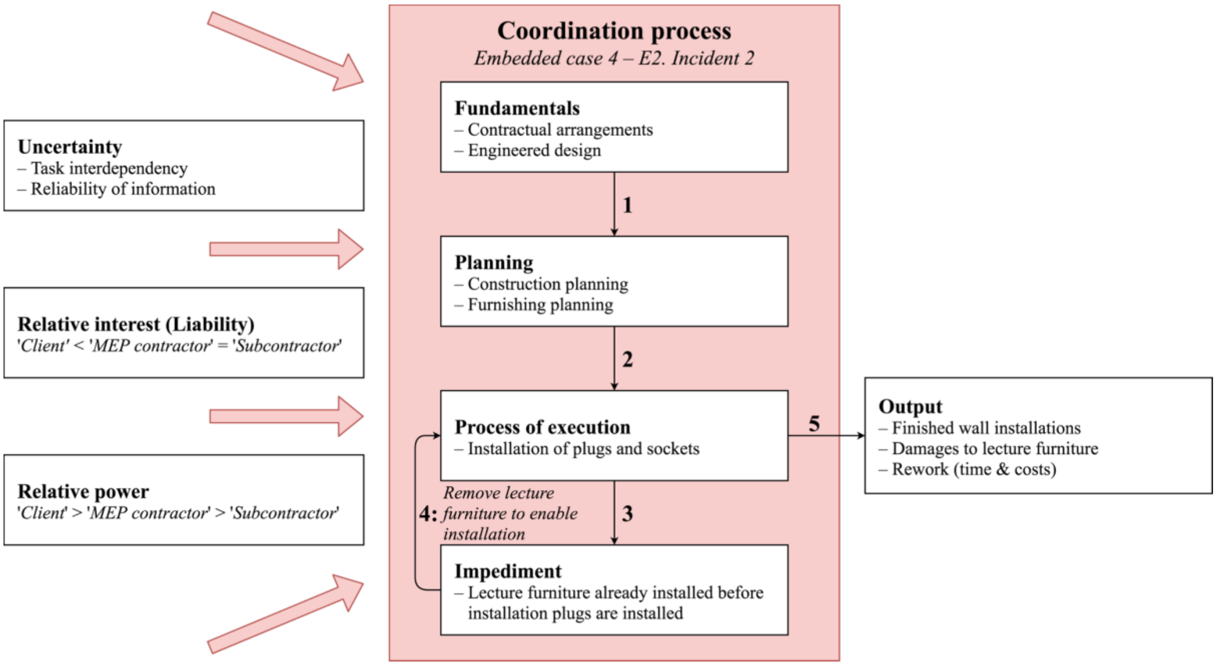

Figure 31: Visualisation of coordination process; "IC 4.2.2 – Installation of lecture furniture interface plugs".

To provide a more comprehensive context in regard to the diagram, the external factors of influence and the distinct process steps are further elaborated textually. These are presented in 'Table 15'.

Table 15: Textual elaboration of external factors and process steps depicted in 'Figure 31'.

Factor	Interpretation
Uncertainty	The subcontractor responsible for the furniture, who is acquired separately by the client, is dependent on the work performed by the MEP subcontractor installing the wall plugs and connectors. When the work sequence is not performed in the required order, problems arise and rework is incurred. Information about the finished tasks proved to be unreliable. The client was under the impression that all wall plugs and connectors were installed, while in reality some needed to be installed. Consequently, defective assumptions based on defective information caused the client to start-off their activities too early.
Relative interest	Primarily the MEP contractor and subcontractor have a dominant interest in this situation because due to the early instalment of lecture furniture they are unable to perform their work. The client, however, has less of an interest in solving the situation and favours the subcontractors to solve the solution by mutual adjustment.
Relative power	In this situation the client has most power because the MEP contractor should have already finished the wall plugs and connectors but lost the overview of remaining work activities. Therefore, subcontractors are assigned to solve the problem themselves, also because of the pressure involved to finish the project in time.

	Process steps
1.	The fundamental arrangements are primarily based on contractual agreements concerning the requirements of installation interfaces within lecture rooms. Later, the engineered design is added to the fundamentals when it is approved by the client. The agreements are translated into a contract, whereupon the project team base their actions.
2.	In the planning phase an activity sequence and plan for installing the walls and plugs and subsequent lecture furniture is planned out. Specifications and requirements are exchanged by mail and through meetings. Shared work files are primarily 2D drawings and documents. Work meetings are arranged weekly to discuss progress among the client and MEP contractor.
3.	When the equipment a subcontractor wants to plug in the equipment installed in the lecture furniture it is noticed that no wall plugs and connectors are installed yet.
4.	The MEP contractor is contacted to resolve the situation and let their subcontractors dismount the lecture furniture in order to install the wall installations. Subsequently, the lecture furniture is mounted again.
5.	Finally, the wall installations are finished and the lecture furniture, including the equipment, functions properly. Nevertheless, rework is incurred and some furniture was damaged during the dismounting process performed by the MEP subcontractor.

4.5 TABLE OF RESULTS

Based on the results gathered from all the incidents, a database is generated, whereupon cross-case analysis can be performed in the next chapter. The data produced by applying the model on all examined incidents is presented in the table below (Table 16). All incidents are numbered in correspondence with the matching case and event. Also, they are provided with a shortened name to provide some clarity in regard to the subject of the incident. Furthermore, the involved parties and the perceived uncertainties, which have induced the incident, are indicated. Subsequently, the relative interest (I) and power (P) positions are presented alongside the distinguished motive for intervention. The relative interest and power situations consist of two indicators. The first indicator (I_1 / P_1) specifies the interest and power relation between the higher tier parties, typically the client and main contractor, while the second indicator (I_2 / P_2) specifies the same relation between the lower tier parties, typically the main contractor and a subcontractor. Next, the applied coordinative intervention is displayed and finally the produced output of the coordinated incident is specified. As an additional note, the exemplary incidents are highlighted within the overall table.

Table 16: Overview table consisting of the data produced by analysing all examined incidents using the developed conceptual model as analytical framework.

Incident	Parties	Uncertainty	Motive	I_1	I_2	P_1	P_2	Coord.	Output
1.1.1 – Unclear fire safety demands	Cl. – MEP – N.E.	– Interpretable contract – Behaviour of contracted party	Liability	– =	*n.a.*	=	*n.a.*	Fundamentals	– Adjusted contract arrangements – Engineering delay – Rework (time & costs)
1.1.2 – Engineering the steel framework	Cl. – MEP – SubC.	– Task interdependency – Design change orders – Behaviour of contracted party	Time	<	=	>	=	Planning	– Adjusted plans and contract – Mitigated engineering delay
1.2.1 – Misfit of steel girders	Cl. – MC – SubC.	– Task interdependency – Margin for deviation – Durability of information	Liability	<	<	>	>	Execution	– Rework (time & costs)
1.2.2 – Poor fit of steel framework	Cl. – MC – SubC.	– Margin for deviation – Production error	Liability	<	<	>	>	Execution	– Construction delay – Lower quality finish
1.2.3 – Difficult fit aluminium framework	Cl. – MC – SubC.	– Task interdependency – Margin for deviation – Durability of information	Liability	<	<	>	>	Execution	– Construction delay – Lower quality finish
1.3.1 – Unable to reorder glazing	MC – SubC. – Sup.	– Availability of equipment – Construction damages	Time	<	– =	>	<	Execution	– Intermediate solution – Lower quality finish
1.3.2 – Postpone glazing deadline	Cl. – MC – SubC.	– Availability of equipment – Construction damages	Quality	>	=	>	>	Fundamentals	– Adjusted contract arrangements – Construction delay
2.1.1 – W-subcontractor work pace	Cl. – MEP – SubC.	– Planning estimations	Time	<	>	>	>	Planning	– Adjusted plans and contract – Mitigated construction delay – Lower quality finish
2.1.2 – Too low W-installations	Cl. – MEP – SubC.	– Task interdependency – Margin for deviation – Durability of information	Time	<	<	>	>	Execution	– Added work (time) – Lower quality finish
2.2.1 – Adjust the ceiling plan	Cl. – MEP – SubC.	– Task interdependency – Information error – Behaviour of contracted party	Quality	<	=	>	=	Planning	– Adjusted plans and contract – Rework (time & costs)
2.2.2 – Amend ceiling panel order	MEP – SubC. – Sup.	– Design change orders – Behaviour of contracted party	Quality	=	>	>	=	Planning	– Adjusted plans and contract – Rework (time & costs)
2.2.3 – Wrong positions armatures	Cl. – MEP – SubC.	– Reliability of information	Quality	<	>	>	>	Planning	– Adjusted plans and contract – Rework (time & costs)
2.3.1 – Postponed ceiling panel delivery	Cl. – M/SubC. – Sup.	– Production complexity – Planning estimations – Durability of information	Time	<	>	>	>	Planning	– Adjusted plans and contract – Mitigated production delay – Added work (time)
2.3.2a – Postpone armature delivery	Cl. – MEP – Sup.	– Delivery change orders – Behaviour of contracted party – Safe material storage	Quality	<	>	>	<	Planning	– Adjusted plans – Construction delay
2.3.2b – Unsolicited armature delivery	Cl. – MEP – Sup.	– Delivery change orders – Behaviour of contracted party – Safe material storage	Quality	<	– =	>	<	Execution	– Stolen armatures – Reorder (time & costs)
2.3.3 – Adjust plans to ceiling hold ups	Cl. – MC – SubCs.	– Task interdependency – Planning discrepancies	Time	<	>	>	>	Planning	– Adjusted plans – Rework (time & costs)

Incident	*Parties*	*Uncertainty*	*Motive*	I_1	I_2	P_1	P_2	*Coord.*	*Output*
2.4.1 – Early closing of suspended ceiling	Cl. – MC – SubC.	– Task interdependency – Planning discrepancies	Time	<	=	>	>	Planning	– Adjusted plans – Mitigated construction delay – Added work (time)
2.4.2 – Re-opening ceiling panels	Cl. – MC – MEPs.	– Task interdependency – Planning discrepancies	Liability	<	<	>	>	Execution	– Added work (time) – Lower quality finish
2.4.3 – Damaged ceiling panels	Cl. – MC – MEPs.	– Task interdependency – Product fragility	Quality	<	>	>	>	Planning	– Adjusted plans – Added work (time)
2.4.4 – Order of backup ceiling panels	Cl. – MC – SubC.	– Production complexity – Product fragility – Construction damages	Quality	>	=	=	=	Fundamentals	– Adjusted contract arrangements – Added order (time & costs)
2.4.5 – Contorted ceiling alignment	Cl. – MC – SubC.	– Task interdependency – Margin for deviation – Durability of information	Time	=	<	=	>	Execution	– Lower quality finish
2.4.6 – Replace ceiling panels	Cl. – MC – SubC.	– Production complexity – Construction damages	Liability	>	=	=	>	Fundamentals	– Adjusted contract arrangements – Reorder (time & costs)
3.1.1 – Covering balustrade rail	Cl. – MC – SubC.	– Effectivity of precautions – Unclear responsibilities	Liability	<	<	>	>	Execution	– Added work (time)
3.1.2 – Cluttered balustrade rail	Cl. – MC – SubC.	– Task interdependency – Unclear responsibilities – Behaviour of contracted party	Liability	<	>	>	<	Planning	– Adjusted plans – Construction delay – Added work (time & costs)
3.1.3 – Glass damages (balustrades)	Cl. – MC – SubC.	– Planning discrepancies – Behaviour of contracted party – Safe material storage	Liability	<	<	>	>	Execution	– Damages – Reorder (time & costs)
3.2.1 – Misfit of balustrade banisters	Cl. – MC – SubC.	– Task interdependency – Behaviour of contracted party	Time	=	<	>	>	Execution	– Low quality finish
4.1.1 – Taking project control by client	Cl. – MC – SubCs.	– Task interdependency – Planning discrepancies	Time	>	=	>	>	Fundamentals	– Adjusted contract arrangements – Mitigated construction delay
4.1.2 – Scale up work pace for furniture	Cl. – MC – SubCs.	– Task interdependency – Planning discrepancies	Time	=	>	>	>	Planning	– Adjusted plans – Mitigated construction delay
4.2.1 – Installation of lecture furniture	N.E. – Cl. – Contr.	– Planning estimations	Time	*n.a.*	>	*n.a.*	>	Planning	– Adjusted plans – Construction delay
4.2.2 – Install lecture furniture plugs	Cl. – MEP – SubC.	– Task interdependency – Reliability of information	Liability	<	<	>	>	Execution	– Damages – Rework (time & costs)
4.3.1 – Leaking couch planters	N.E. – Cl. – Contr.	– Product fragility – Construction damages	Liability	*n.a.*	<	*n.a.*	>	Execution	– Damages – Rework (time & costs)
4.3.2 – Damages to installations	N.E. – Cl. – MEP	– Task interdependency – Product fragility – Construction damages	Liability	*n.a.*	>	*n.a.*	=	Planning	– Adjusted plans and contract – Rework (time & costs)
4.4.1 – Misfit lamppost and couch	N.E. – Cl. – Contr.	– Task interdependency – Information reliability	Liability	*n.a.*	<	*n.a.*	>	Execution	– Reorder (time & costs)

5 ANALYSES

This chapter elaborates on the analysis results, which derive from cross-case pattern searching. Using the dataset deriving from the previous chapter (Table 16), an explanation is explored to clarify the course of construction incidents. Primarily patterns, related to the relative bargaining position of the involved parties, are conspicuous. The arrangement of specific combinations of relative power and interest positions seem to influence the course of coordination intensively. Also, in regard to uncertainties particular consistencies are uncovered. Based on the overall data apparent categories of distinct types of uncertainties can be distinguished. Lastly, in terms of information exchange particular sharing mechanisms are found, which correspond with the identified levels of coordination. Nevertheless, based on this research no explicit relation is found between communication methods and the course of incidents. In conclusion, the chapter will discuss the distinguished patterns found in this research.

5.1 INFLUENCE OF RELATIVE POWER AND INTEREST RELATIONSHIPS

During the development of the conceptual model it was suspected that particular barriers prevent apparent coordinative decisions from being taken. Presumably these barriers are imposed by the relative bargaining position of parties, who collaborate within the construction supply chain. Based on all examined critical incidents particular patterns are revealed, which concur with this suspicion and provide a clearer understanding of how these barriers are imposed (Table 17).

Undermentioned table consists of all examined incidents and is sorted based on the level of intervention at which coordination takes place during this critical incident. The relevant relative interest and power combinations are highlighted. To indicate mutual relations separate indicators are used to indicate the relative interest or power relation between higher tier parties (I_1 / P_1), typically the client and main contractor, and lower tier parties (I_2 / P_2), typically the main contractor and a subcontractor.

Table 17: Incident table sorted based on intervention levels and interest power relationships.

Incident	I_1	I_2	P_1	P_2	***Level***
1.1.1 – Unclear fire safety demands	– =	n.a.	=	n.a.	**Fundamentals**
2.4.4 – Order of backup ceiling panels	>	=	=	=	
2.4.6 – Replace ceiling panels	>	=	=	>	
1.3.2 – Postpone glazing deadline	>	=	>	>	
4.1.1 – Taking project control by client	>	=	>	>	
2.1.1 – W-subcontractor work pace	<	>	>	>	**Planning**
2.2.3 – Wrong positions armatures	<	>	>	>	
2.3.1 – Postponed ceiling panel delivery	<	>	>	>	
2.3.3 – Adjust plans to ceiling hold ups	<	>	>	>	
2.4.3 – Damaged ceiling panels	<	>	>	>	
4.1.2 – Scale up work pace for furniture	=	>	>	>	
4.2.1 – Installation of lecture furniture	n.a.	>	n.a.	>	
2.4.1 – Early closing of suspended ceiling	<	=	>	>	
2.2.2 – Amend ceiling panel order	=	>	>	=	

Incident	***I_1***	***I_2***	***P_1***	***P_2***	***Level***
4.3.2 – Damages to installations	n.a.	>	n.a.	=	
1.1.2 – Engineering the steel framework	<	=	>	=	
2.2.1 – Adjust the ceiling plan	<	=	>	=	
2.3.2a – Postpone armature delivery	<	>	>	<	
3.1.2 – Cluttered balustrade rail	<	>	>	<	
1.2.1 – Misfit of steel girders	<	<	>	>	**Process of execution**
1.2.2 – Poor fit of steel framework	<	<	>	>	
1.2.3 – Difficult fit aluminium framework	<	<	>	>	
2.1.2 – Too low W-installations	<	<	>	>	
2.4.2 – Re-opening ceiling panels	<	<	>	>	
2.4.5 – Contorted ceiling alignment	=	<	=	>	
3.1.1 – Covering balustrade rail	<	<	>	>	
3.2.1 – Glass damages (balustrades)	<	<	>	>	
3.2.1 – Misfit of balustrade banisters	=	<	>	>	
4.2.2 – Install lecture furniture plugs	<	<	>	>	
4.3.1 – Leaking couch planters	n.a.	<	n.a.	>	
4.4.1 – Misfit lamppost and couch	n.a.	<	n.a.	>	
1.3.1 – Unable to reorder glazing	<	– =	>	<	
2.3.2b – Unsolicited armature delivery	<	– =	>	<	

Generally, the findings show distinct compositions of relative power and interest relationships triggering coordination on particular levels of intervention. The patterns become clear when the individual incidents are sorted according to the applied coordination mechanism. Consequently, specific combinations are revealed, which can be explained by using the extensive case data.

Firstly, several patterns are found, which lead to coordinative interventions on the fundamental level. Coordination on this level is primarily triggered by a dominant client interest. Often the role of client is accompanied by a relatively high level of power, which allows them to act upon their interests and enforce more radical changes. Client power mainly derives from the formulated project requirements recorded in the contractual arrangements. When the main contractor is in default the client is able to rely on the agreed terms. However, when coordination takes place outside of contractual boundaries, for example in case of contractual ambiguities or additional demands, the relative power position is determined based on market dynamics. To establish fundamental adjustments within this context, a negotiation process is required with a dominant client interest to direct negotiations towards fundamental changes.

Secondly, specific pattern variations stand out in which planning interventions are applied. In these cases, a dominant interest of the central actor, usually the main contractor, is perceived. Planning adjustments are more common, than fundamental changes, because the client acquires a main contractor to manage the project and deal with process irregularities autonomously. Therefore, the client has little concern for minor construction incidents, unless they directly affect their primary interests. Furthermore, the main contractor usually has no intention or power to involve the client in these situations. Alternatively, the main contractor usually does have power over subcontracted parties. In accordance with the client situation, the main contractor mainly draws decision-making power from the initial contractual agreements. However, they are more susceptible to market dynamics because they rely on external resources and equipment delivered by a large variety of parties with diverging schedules and objectives. Consequently, planning intervention takes place when the central actor has a dominant interest, but only the power to solve the incident at a lower level in the project organisation. When the central actor is incapable to enforce any planning adjustments, negotiation with lower-tier parties is required.

Lastly, a category of incidents is coordinated on the executional process level. These interventions are primarily characterised by a dominant subcontractor or diverging supplier interest. Nevertheless, in some cases a more precise characterisation is considered the relatively low interest from the central actor. A low interest from the main contractor typically derives from a low level of criticality of the activity in regard to the overall construction process. Subcontractors generally have a relatively low amount of power to influence these processes. Therefore, they are unable to enforce coordination of higher levels of intervention. Consequently, subcontractors are often confronted with situations they have to solve themselves during the process of execution. Nonetheless, when subcontractors possess strategic resources or equipment, they are able to use this as leverage to affect construction processes. However, this type of market power tends to disturb project processes and impede higher tier parties to adjust plans. Especially supplier interests tend to conflict with project processes because they allocate their resources over multiple projects and they have little benefit from effective project processes. Therefore, suppliers with a strong market position are able to influence construction processes and make them fit with their production processes.

Based on the identified compositions of power and interest relations triggering particular coordinative interventions, a table is produced to concretise the findings (Table 18). Noteworthy, is that the party with a dominant interest is only able to accomplish interventions at their own level or lower levels of intervention. This is explained by the fact that parties have no direct influence on the requirements of higher tier parties. They merely have the ability to oppose particular measures that have been prescribed.

Table 18: Identified power-/interest compositions triggering particular levels of intervention.

Level	***Dominant interest***	***Dominant power***	***Translation (central actor)***
Fundamentals	Client	Client	Instructions from further up
		Lack of client power	Finding common ground
Planning	Central actor	Central actor	Willing to act, can’t go further up
		Lack of actor power	Requires negotiation, can’t go further up
Execution	Subcontractor / supplier	Central actor	Not willing to act, lack of interest
		Subcontractor/supplier	Can’t act, lack of power

Additional insights

In applying the conceptual model, relative interest is reflected as a fixed concept illustrating the interest ratio between collaborating parties within the limits of a single critical incidents. However, the concept of relative interest is highly volatile, as parties adapt to new situations striving to achieve their particular objectives. Consequently, the relative bargaining position of parties towards each other is constantly changing over time. A simple example of this volatility is the sequence of incidents concerning the delivery of armatures (IC 2.3.2a & 2.3.2b). Because the MEP contractor had to postpone their activities due to the late arrival of ceiling panels, they contacted the armature supplier and asked them to postpone their delivery as well. The supplier decided to be flexible and adapted the delivery schedule to the wishes of the MEP contractor. Nevertheless, as the MEP contractor kept delaying the delivery of armatures in response to the continuous postponement of ceiling panel deliveries, the supplier decided to stop waiting and delivered the armatures. In short, the dominant interest shifted from the MEP contractor towards a conflict of interests because the supplier became more eager to finalise their obligations and get paid for their services. Another shift in the relative interest position is experienced in the incident concerning the fire safety demands (IC 1.1.1). Initially, both parties disagreed about the interpretation of the fire safety demands. Neither of them wanted to be liable for the incident establishing a conflict of interests. However, solving this impasse situation took a considerable amount of time, which started to threaten the project deadline. Therefore, the interests of both parties aligned in favour of process continuation. Finally, the conflict of interests about liability shifted towards a shared interest in regard to time. In conclusion, both parties now accepted to share liability of the occurred incident and move forward.

As described in the previous example, interests sometimes align, which allows a consensus to perform certain coordinative measures. Nevertheless, similar interests do not necessarily coincide with equal objectives. Parties might comply with particular measures for different reasons. For example, in the case of the contorted ceiling panel alignment, the main contractor decided to continue activities without rectifying the poor alignment (IC 2.4.5). The client agreed with this course of action to ensure project continuation in order to finish the project in time. Nevertheless, they were not content with the quality of the ceiling alignment and addressed the deficiency after project completion. The main contractor, however, had no intention of rectifying the ceiling alignment. They claimed to have fulfilled their contractual obligations and have warned the client of the possibility of poor alignment due to the product characteristics. In short, both parties advocated a similar measure for different reasons. Later the interests changed, which resulted in a subsequent incident (IC 2.4.6). Definitively, the example illustrates that interests change depending on the situation and reveal how a party aims to achieve their predetermined project objectives. Therefore, the relative interest of a party in a specific situation might be considered a reflection of their strategy to accomplish objectives and corresponding priorities.

Additionally, the interests of parties in particular situations also relate to the application of specific types of power. As explained, power derives from either contractual arrangements or market contexts. However, the relevancy of particular types of power depend on the type of interests involved in the situation at hand. When interests in terms of quality and liability are at stake, contractual power is often decisive to settle incidents. Parties can be held accountable for agreed terms and conditions, which are recorded in legal contracts. Even when parties disagree about particular contract interpretations the matter can be settled in court to establish clear decision-making power. However, coordinating incidents based on contractual powers is often time consuming because parties have to perform rework or settle disputes by several meetings. Consequently, whenever time interests are at stake, a dynamic of contractual and market powers becomes relevant. For example, when some glass panes for the roof of the study gallery broke the main contractor could not enforce the contract with their subcontractor to rectify the problem within time because glass suppliers were closed for summer maintenance (IC 1.3.1). Similarly, the main contractor could not enforce the suspended ceiling panel supplier to accelerate production or switch to another supplier (IC 2.3.1). To mitigate production delays, they had to be more creative and utilised contractual power to enforce cooperation for contract adjustments.

5.2 TYPES OF UNCERTAINTY

During the analysis of the various incidents examined in this research particular categories of different types of uncertainties were identified. Coping with uncertainty is a complex endeavour, mainly because it causes an unpredictable process. By determining distinct categories of uncertainties, an improved insight is achieved in where uncertainty derives from. Consequently, more direct measures to cope with particular types of uncertainty can be undertaken. Based on the examined critical incidents five different categories are identified. These categories comprise uncertainty deriving from interdependency, demands, products, information and planning.

Firstly, uncertainty derives from interdependence between parties collaborating to perform construction activities. Due to this collaborative relationship, parties become reliant on each other’s performances. When a party does not fulfil their obligations, other subsequent parties are affected. This network of mutual interdependencies causes a complex setting to control and predict. Interdependence between parties extends further than merely task performance. Also, attitude, willingness to cooperate with potential interventions are issues concerning interdependency between parties.

A second category of uncertainty is considered the formulated demands of clients in relation to their actual requirements. Throughout the project change orders are imposed to rectify incomplete or incorrect demands. These change orders derive from the volatility of these demands, which are susceptible to new insights and changing requirements.

Another type of uncertainty is related to product characteristics. Throughout the construction activities parties work with a variety of different products and materials. Each of these products have specific complexities induced by their characteristics and peculiarities. Dealing with product complexities cause unexpected issues, especially when parties are inexperienced at working with particular products.

Furthermore, uncertainty derives from the quality of information exchanged between collaborative parties. Quality of information concerns the reliability and interpretability of the provided information. Additionally, information is prone to time and might become outdated, Therefore the durability of information is also uncertain because things change during the construction process. Furthermore, parties are dependent on each other to share information and also act on it. In some cases, parties deliberately ignore this responsibility for strategic reasons. Technically, information uncertainty might also be classified as interdependence because parties have a responsibility to provide each other with the required information to perform a specific task. However, information characteristics are distinctly different from operational processes and are therefore classified as a different category.

Lastly, the planning is also considered a source of uncertainty because theoretically elaborated plans are likely to turn out differently in practice. Mainly due to the complex nature of construction it is difficult to oversee how plans will work out. In order to minimise complexity, simplified versions of reality are assumed by means of standardisation. Also, people are prone to different forms of bias, such as optimism bias, which leads to unrealistic impressions of how plans will proceed. Consequently, elaborated plans always deviate, to some extent, from real-life processes.

In summary, the five identified categories of uncertainty are listed in undermentioned table, including a brief description of each type (Table 19).

Table 19: Identified categories of uncertainty affecting construction incidents.

Uncertainty	***Description***
Interdependence	The attitude and performance level of collaborative parties performing interrelated tasks.
Demand	The extent to which the client's demands match their actual requirements.
Product	The complexity of product characteristics in relation to the familiarity with the product.
Information	The quality and availability of information required to enable parties to perform their activities effectively and the willingness of parties to act upon it.
Planning	The extent to which plans deviate from reality in terms of accuracy and effectivity.

6 DISCUSSION AND CONCLUSIONS

This chapter constitutes the main conclusions, which derive from the performed research. The conclusions are drawn based on the answers to the several research questions presented in the introduction. Nevertheless, the generated insights are exploratory and derive from a single construction case. Therefore, results are not necessarily valid in other contexts and require additional reflection. With this in mind, this chapter will discuss the findings by comparing them to literature. As a result, awareness of how the results from this research relate to existing theory is provided by placing them in a broader context. Furthermore, practical implications of the established results are discussed and finally limitations are considered to identify and suggest opportunities for future research.

6.1 MAIN CONCLUSIONS

The main aim of this research was to generate an in-depth understanding of how coordination and communication are currently applied during incident situations in order to contribute to future improvements. Therefore, a grounded approach was applied to identify critical incidents and find out how these are dealt with in practice. Consequently, the following research question was formulated:

How do coordination and communication take place during critical incidents within the examined construction supply chains and how do external factors influence this practice?

In order to provide an answer to the central question several sub-questions were drawn up to guide the research towards achieving the main research objective. These questions have been answered throughout the research process and within the consecutive chapters of this thesis. In general, the individual sub-questions were categorised per subsequent research step based on the guidelines provided by Eisenhardt (1989). In line with the structure provided by the research sub-questions the final conclusions will be presented, which together represent the final answer to the central research question. The last two questions considering how the gathered insights relate to existing theory and what practical implications can be learned from them are answered in the subsequent sections (chapter 6.2 & 6.3).

1. ***How is coordination applied over the course of the identified critical incidents?***

Based on the identified critical incidents a common structure was identified, which exemplifies the course of coordination during construction incidents. This structure contains three subsequent levels, which are performed by specific actors. Firstly, the client formulates project requirements and records them in contractual demands. These are considered the fundamental arrangements from which the subsequent processes derive. Thereafter, the client procures a main contractor to perform and develop plans that comply with the requirements. Therefore, as a second level, elaborations of the standardised requirements are produced, which results in extensive construction plans. Lastly, the main contractor subcontracts specific tasks to special trade contractors, or subcontractors, who execute the formulated construction plans and transform inputs into definitive outputs. As a result, final components are realised, which eventually constitute the finished structure. Nonetheless, these three specific levels of coordination are based on a main contractor perspective. When considering coordination from further down the supply chain these distinctive levels shift down as well, but the approach remains similar because the prospective client changes. However, when incidents occur throughout the construction process, adjustments are required. Consequently, changes have to be implemented at one of the three identified levels of coordination. These changes can be considered interventions performed by particular parties in the construction supply chain. The different levels of intervention are formulated as follows:

– (Re-)negotiate fundamental arrangements;
– (Re-)adjust construction plans;
– (Re-)do additional or altered work

After an intervention has been implemented the subjacent levels of coordination are adjusted until the process of execution has produced the final result.

A more detailed elaboration in regard to this research question is provided in chapter 3.1 (pg. 18).

2. ***What external factors affect the occurrence and course of these critical incidents?***

The research distinguishes two specific external factors that have an effect on the occurrence and course of critical incidents. Firstly, uncertainty is identified as the main cause of construction incidents instigating the need for coordinative interventions by particular parties. Secondly, the level at which interventions take place is variable. Based on this research, the applied level at which coordination takes place is considered to be determined by the relative bargaining position of the involved parties. This factor consists of two components; the relative interest and power.

Uncertainty is considered the main cause of construction incidents, because theoretically elaborated plans often turn out differently in practice due to a variety of unanticipated occurrences. The inability of parties to predict these occurrences imposes the necessity for adjustments during the course of the construction process. Uncertainty emerges in many different forms deriving from several aspects. Therefore, several categories are identified by this research from which uncertainty derives. These categories are regarded interdependence, demand, product, information and planning (See chapter 5.2). Coping with uncertainty is considered difficult due to the high level of complexity it imposes. Especially, the constant need for adjustment throughout a complex network of collaborative parties might constrain construction efforts if not properly dealt with.

Dealing with incidents induced by uncertainty is achieved through interventions on different levels. However, these coordinative measures affect multiple collaborative parties because each individual level of coordination is based on the arrangements established in the previous level. Consequently, each of the involved parties have a particular interest in what intervention should be applied. The relative interest positions of parties constitute the potential to find common ground in favour of a particular intervention. However, in case of conflicting interests, some kind of authority is required to enforce decisions to overcome arisen impediments. This authority is established based on the relative power position of those involved. Two main sources of power are considered to be the contractual arrangements and the applicable market context. The combination of both components constitutes the external factor called relative bargaining power.

A more detailed elaboration in regard to this research question is provided in chapter 3.2 (pg. 21).

3. **How does communication facilitate the coordination process during critical incidents?**

Communication is considered an important aspect of coordination, especially in the transference between the identified levels of coordination. Following the process of coordination and its iterative characteristics, information progresses down the supply chain and expands consistently. In the first place because initial standardised demands are translated into extensive construction plans and procedures and secondly because interventions involve additions and alterations of existing arrangements. As a result, the total body of information grows extensively throughout the project timeline. Acquiring and processing all this information is complex, but of vital importance to manage construction projects. Apart from establishing the importance of communication during coordination activities this research merely managed to identify how information is exchanged. Primarily pooled information sharing systems were applied between project members. However, to determine the effectivity of information sharing mechanisms in regard to coordination efforts, more extensive research is required. This is discussed further during the chapter concerning this research's limitations.

A more detailed elaboration in regard to this research question is provided in chapter 3.3 (pg. 24).

4. ***How can the gathered insights, in regard to the course of coordination during critical incidents, be constituted into a conceptual model?***

The previous questions primarily focussed on individual concepts concerning the course of coordination during construction supply chains. However, these concepts are related based on cause-effect relationships. Therefore, the integration of these components results into a definitive conceptual model. The developed model provides insight in the course of coordination during critical incidents. Also, it provides a means to analyse individual incidents and produce comparable results. Displaying more extensive events is achieved by linking multiple incidents with each other. The generated output of the first incident is then considered an impediment, which requires intervention, for the next incident. The final conceptual model is presented in the figure below (Figure 32):

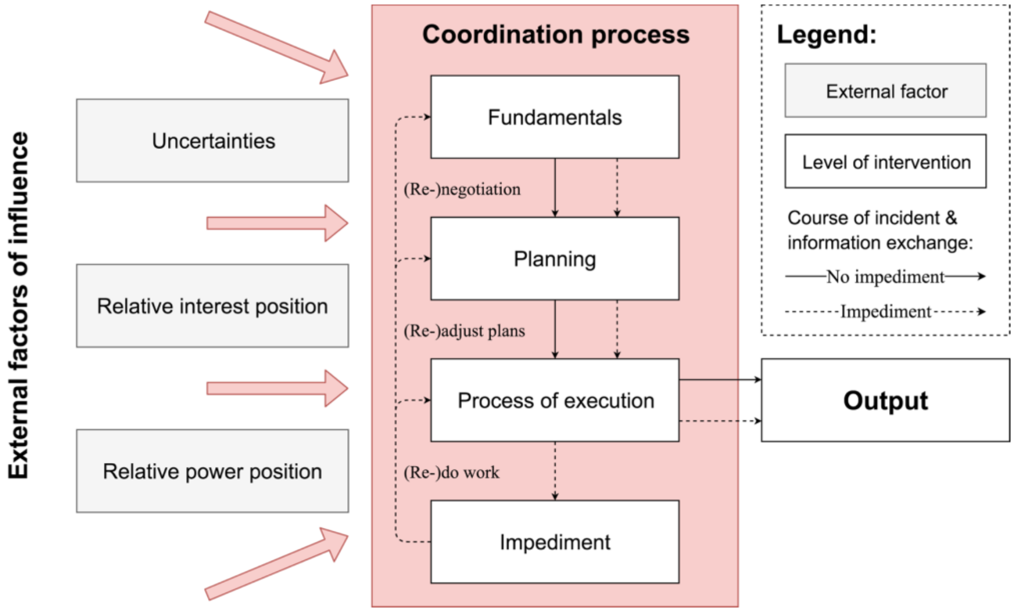

Figure 32: Final conceptual model as produced by this research.

A more detailed elaboration in regard to this research question is provided in chapters 3.4 (pg. 25).

5. ***What patterns can be identified, using the developed conceptual model, which explain the course of critical incidents?***

The developed conceptual model was used as an analytical framework to produce comparable results. Based on these findings distinct compositions of relative power and interest relationships are revealed that trigger specific interventions. Within these compositions especially the dominant interest position appears to be decisive in determining what level of intervention is applied. In most cases, the party with a dominant interest attempts to enforce a specific intervention based on contractual power or market leverage. When a lack of power exists, the party with a dominant interest will negotiate with the relevant opposing party to establish an intervention. However, in case of equally dominant but conflicting interests, the most powerful party determines what level of intervention is applied. As an additional note it is conspicuous that parties are not able to enforce interventions on a higher level than they are at. They only have the ability to oppose prescribed measures.

A more detailed elaboration in regard to this research question is provided in chapter 5 (pg. 57).

6.2 DISCUSSION OF RESULTS

This section is dedicated to the sixth research question and is aimed at contextualising the gathered findings by comparing them to existing theory. The concerned research question is formulated as:

> ***How do the insights concerning coordination and communication during critical incidents relate to existing theory?***

Within this section the final insights are discussed in order of the main conclusions. Firstly, the dynamic of coordination in construction incidents, as presented by this research, is discussed. Subsequently, external factors of influence, such as power, interest and uncertainties are examined. Lastly, the role of information exchange is considered. An elaboration of the existing theories on coordination and the identified external factors of influence is provided in the appendices (App. IV).

The process of coordination constituted in a dynamic model

This research extends current theory about coordination mechanisms with a relevant new insight. The developed conceptual model recognises the necessity for continuous adjustment and switching between different types of coordination when dealing with construction incidents. This aspect of coordination is currently not very well documented in theory. Nevertheless, Bankvall et al. (2010) already suspect the existence of this dynamic in their conclusions. They state that coping with complex interdependencies and high levels of uncertainty requires continuous adjustment. Also, they notice that adjustments affect the entire downstream supply chain, which complies with the multi-level character of coordination identified by this research. Dealing with specific incidents brings about interventions on multiple levels in the project hierarchy, while outcomes progress towards lower or higher levels in the supply chain. The developed model exemplifies these aspects by conceptualising different strategic levels of intervention and recognising that generated outputs might be cause for successive interventions by affected parties.

In a general sense, the three levels of intervention correspond with the coordination mechanisms identified by several authors (Galbraith, 1974; Mintzberg, 1983; Thompson, 1967; van de Ven, Delbecq, & Koenig, 1976). In the first place, the fundamental level can be seen in light of the standardisation mechanism. When establishing the fundamentals, definitive construction processes are still very uncertain and parties determine standardised requirements and agreements to diminish uncertainty. Based on these standardised arrangements, plans are established. These plans constitute the second level incorporated in the conceptual model, which also corresponds with the coordination by plan mechanism. Lastly, the process of execution level is dominated by mutual adjustment mechanism because parties work together within a confined space wherein product interfaces converge. This type of coordination is required to anticipate small deviations and manage the discrepancies between plans and reality. Despite the resemblance between the different levels and individual coordination mechanisms, it should be noted that they form a Guttman-type scale (Thompson, 1967, p. 55). Within the fundamental level, also planning and mutual adjustment takes place and within the planning level, mutual adjustment takes place.

An important limitation of the findings is that they are primarily aimed at revealing the course of coordination within project situations, while there are also other dimensions of coordination to discover. In light of Dubois and Gadde (2002), it can be stated that the conceptual model is situated within the temporary project network and focusses on coordinating interdependencies between project participants. In other words, the coordination efforts, exemplified by this research, are aimed at controlling the interaction between construction tasks. Malone and Crowston (1990), on the other hand, seem to identify additional dimensions of coordination beyond the temporary project. They add the preceding coordination process of strategically assigning actors to predetermined tasks based on predefined objectives. This type of coordination is more in line with the management of vertical interdependencies in the more permanent network and can be considered more like a strategic exercise in managing relationships, instead of managing the sequence of tasks. Moreover, it extends coordination practices by including managerial activities, such as procurement; selecting actors and assigning them to activities.

Although the conceptual model does not elaborate on the dynamic of coordination beyond the temporary network, it does consider the effect of coordination efforts in other dimensions. Namely, coordination in the permanent network has a significant impact on the power and interest relationships between project participants. Consequently, in reflection of the model these efforts have a direct effect on the possibilities for coordination in the temporary network. Thus, the attainability of each intervention is limited based on the effect of coordination efforts beyond project boundaries. This consideration is substantiated by other authors who also consider the limitations of coordination depending on each situation (Bankvall et al., 2010; Bemelmans et al., 2012; Briscoe & Dainty, 2005).

Divergent interests and power structures

Within the context of this research, power proves to be a vital management resource in order to control the construction process. It provides a means necessary for parties to look after their interests and drive others to cooperate in these endeavours. The importance of power becomes clear during conflicts of interest among project participants during construction incidents. Within these situations interventions are required, which change the initial course of events affecting project participants. In accordance to Cox and Ireland (2002), it is recognised that parties are less able to take care of their interests and achieve objectives when they are pushed into captive buyer or supplier situations. When a party is unable to enforce their interests due to a lack of power, other parties tend to obstruct measures in support of their own interests. Alternatively, equal power relations generally transition into a renegotiation processes between parties to establish new arrangements. Conclusively, based on the findings, this research strongly complies with findings established by Cox and Thompson (1997), who state that collaboration can only be fostered through unequal power relationships or by incentivising suppliers to align conflicting interests.

In consideration of power, this research distinguishes two different sources of power. Authors generally recognise power deriving from market situations, which allows parties to act opportunistically by leveraging specific capabilities (Cox & Ireland, 2002; Cox & Thompson, 1997). However, based on the established results, power can be seen as a combination of both contractual and market power. The first derives from contractual agreements between the individual parties, which provides a legal basis to fall back on when the arrangements are violated. When situations occur that are clearly in conflict with the initial agreement, parties are able to enforce the contract and execute interventions. Market power, on the other hand, proves particularly decisive when unexpected situations occur, which are not covered by the contract, or when strategic resources are in play. These circumstances are quite common in construction projects due to the high amounts of uncertainty. Consequently, in consideration of the diverse interests of multiple different parties working together within project boundaries, both types of power are vital to establish successful collaborations.

Different types of uncertainty

Based on the examined incidents, this research identifies several categories of uncertainty, which cause the occurrence of incidents. Being aware of different kinds of uncertainty helps managers predict and anticipate incidents in advance and make more realistic considerations in terms of risk. In light of Bensaou and Venkatraman (1996), it provides more detailed knowledge about information processing needs, which have to be matched by information processing capabilities, which derive from an array of coordination mechanisms. Therefore, the results produced by this research in regard to uncertainties are significant because it extends current theory with two additional sources of uncertainty.

Firstly, the client demands are recognised as separate source of uncertainty. This category concerns the discrepancy between the formulated client demands and the actual requirements. When both aspects do not coincide, the client might be inclined to change demands during the process of execution. Demand uncertainty differs from uncertainty deriving from interdependencies because it concerns a more intrinsic type of uncertainty, which indicates the difference between what a client actually requires and what it demands. Secondly, information is identified as additional source of uncertainty. Galbraith (1974) recognises that too much unexpected occurrences cause incidents. Therefore, he proposes coping mechanisms based on the improvement of information processing systems. Nevertheless, based on the results from this research information can also be considered unreliable, volatile or susceptible to interpretation. Hence, uncertainty might also derive from the quality of information. Therefore, it can be concluded that this research extends current categorisations of uncertainty by recognising that information can also be considered an uncertainty. This conflicts with current theory, which refers to information as a means to diminish uncertainty.

Besides the two additional categories of uncertainty identified by this research, other categories do relate to existing classifications but on a more general level. Firstly, the planning and product uncertainties are consistent with factors identified by Gidado (1996). These different types of uncertainty primarily reflect on uncertain planning estimates and product application, which potentially brings about discrepancies that cause deviations from the coordinated plans. Furthermore, the three types of uncertainty as identified by Bensaou and Venkatraman (1996) primarily relate to the category of interdependence. Nonetheless, in comparison their classification provides additional depth. Firstly, environmental uncertainty relates to uncertainty deriving from the permanent network and corresponding market situations. The development of the market relative to projects is unpredictable. Furthermore, task and partnership uncertainty might, respectively, relate to discrepancies in succeeding tasks and the attitude of interdependent parties within the supply chain. Considering the additional depth provided by these studies, it is likely that the additional categories identified by this research also have more deepening layers and nuances.

The exchange of information

Lastly, the role of information exchange is discussed in contemplation of the literature. Communication mechanisms are considered vital in the support of coordinating interdependencies within the project network. Nevertheless, this research produced little significant results in regard to how information exchange affects the effectivity of coordination. This lack of insights is firstly caused by a shortage of time to further analyse the case study data with a particular focus on the relationship between information exchange systems and the effectivity of applied coordination. Secondly, parties primarily shared data through pooled information systems, which provided little opportunity to compare the effects of different information sharing systems in regard to coordination. Based on the established findings it can merely be concluded that within the context of this project parties still use email and face-to-face meetings as primary medium to communicate. Additionally, the client, main contractor and co-makers made use of a document management system to verify documentation, which is distinguished as a networked IOS. This limited use of interorganisational ICT in construction projects, however, corresponds with comments made by Adriaanse, Voordijk, and Dewulf (2010).

6.3 PRACTICAL IMPLICATIONS

This section is dedicated to the seventh research question and is aimed at determining practical implications based on the established findings. The concerned research question is formulated as:

> ***What practical implications can be learned from the acquired insights concerning coordination and communication in construction supply chains?***

The main practical implication of this research is the improved understanding of how relative power and interest relationships between project participants have an effect on coordination processes within the project context. This knowledge provides two specific advantages where main contractors can benefit from. Both advantages are listed below:

- Firstly, the main contractor can use the model to assess their capabilities to control specific situations. In captive buyer situations, they are unable to enforce particular interventions when incidents occur. This can be considered a significant risk due to the high levels of uncertainty in construction activities. Therefore, the main contractor is now able to detect the risk and take it into account when making construction plans by implementing, for example, additional planning slack.
- The second advantage, deriving from the specified knowledge, is the additional insights considering the importance for main contractors to position themselves more strategically within the permanent network to attain advantages during projects. More clearly, the conceptual model provides insights in what type of suppliers have an advantage over the main contractor during the construction project. Using this knowledge, the main contractor can take action to improve their market situation in regard to these suppliers by developing improved relationship management strategies. These might help to eliminate coordinative barriers within the project context by improving the relative power position of the main contractor.

In regard to the second implication, literature describes several possibilities to improve the strategic position of main contractors in the permanent construction network. The strategies all have in common that main contractors should improve their understanding of the extensive network of dyadic power relationships in order to enhance construction performance and develop more effective relationship management strategies (Cox, Ireland, Lonsdale, Sanderson, & Watson, 2002; Cox, Sanderson, & Watson, 2000). As indicated, this type of knowledge is considered the main practical implication of this research.

Several possible strategies are delineated below:

- Firstly, many authors recommend contractors to engage in *partnership relationships* with suppliers and enhance supply chain integration (Bresnen & Marshall, 2000; Briscoe et al., 2001; Dainty, Millett, & Briscoe, 2001; Love et al., 2004). These practices are considered to help aligning interests by establishing joint operations and increasing interdependence between buyer and supplier. Furthermore, these types of relationships are supposed to develop mutual trust and the collaborative sharing of information to overcome construction problems.
- Alternatively, Cox and Ireland (2002) believe that an exclusive focus on partnership arrangements is dangerous unless there is no ground for opportunism on either side, which is rarely the case in construction. In line with Cox and Thompson (1997), these authors propose ‘fit for purpose’ relationships based on unequal power relationships and incentives. To manage this, *a portfolio management approach* is advocated with the aim of moving towards buyer dominance situations.
- Lastly, Dubois and Pedersen (2002) argue that strategies, such as portfolio models, might be counterproductive in regard to achieving purchasing efficiency. Instead they discuss a third possibility wherein continuous development is achieved through *interaction between multiple firms*. They explain that the use of a dyadic purchasing perspective might obscure possibilities for enhancing productivity and innovation because parties collaborate within networks, instead of isolated bilateral relationships.

6.4 RESEARCH LIMITATIONS AND FUTURE STUDIES

To conclude the research, some limitations of this study are identified, which provide reason for future studies to extend and strengthen the established findings. The limitations comprise weaknesses in regard to the applied research methodology, inconclusive results and interesting opportunities in response to the established conclusions. The paragraphs below each present a particular opportunity for future research in light of the limitations of this research.

1. **Replication of the research in a different context and theory-testing studies to strengthen the validity of the established findings.**

The applied research methodology was of an explorative nature to identify the course of coordination during construction incidents within the context of a single construction project. Therefore, outcomes are context-bound, holistic and explanatory with the aim of building theory. Although the established results are contextualised extensively by reflecting on a comprehensive amount of literature, the developed conceptual model requires more testing in different contexts. This would strengthen the identified relationships and sharpen the produced findings into a more generally valid theory.

2. **Establish objective measurement instruments to examine the operationalised concepts constituting the developed model.**

The grounded approach resulted in relatively subjective outcomes. These might be considered soft, flexible and regulative due to the multi-interpretability of the qualitative data. First of all, the criticality of incidents is arbitrary and determining relevant uncertainties is dependent on the creativity and understanding of the researcher. Consequently, the course of incidents can be interpreted in various ways, which potentially creates different point of views. Especially, the determination of relative power and interest relationships is subjective and requires additional insights. The same issue is pointed out by Chicksand (2015), who states that the measurement of power is very complex and there are still many unanswered questions about how to accurately accomplish this.

3. **Further research concerning the impact of communication and information exchange systems on the effectivity of coordination.**

This research produced limited insights in regard to the role of information exchange in coordination efforts. It would be particularly interesting to unravel the impact of communication mechanisms on the effectivity of coordination. As indicated, information exchange could fulfil an important role in incident prevention, especially in regard to the reduction of uncertainty preceding incident situations. However, as stated earlier in this research, information management is a complex endeavour due to the substantial amount of information produced during construction projects. Nonetheless, it is vital for managing and controlling the project environment and deserves additional attention from future research, also in relation to developed conceptual model.

4. **Further research in regard to the effectivity of the applied coordinative interventions considering the achieved output.**

Studying the effectivity of particular coordinative interventions might provide a valuable opportunity for additional insights in coordination in relation to construction performance. This research primarily aimed on identifying how coordination is applied during critical incidents and why distinct interventions are applied. Therefore, the effectivity of the applied interventions was not included in the scope of this research. Nevertheless, this aspect, in regard to the achieved output, could potentially provide new insights to improve coordination efforts and help construction managers to employ better coordination strategies.

5. **Further research considering the effect of different relationship management strategies on coordination effectivity.**

The practical implications suggest that main contractors should position themselves more strategically within the more permanent construction network by developing effective relationship management strategies. However, many authors have adverse ideas about how main contractors should achieve an improved market position. Based on the literature it seems there exist two main lines of thought. The first aims at supply chain integration to align interest throughout the construction supply chain and foster more extensive collaboration through partnership arrangements. A second perspective favours the establishment of ‘fit-for-purpose’ relationships in order to prevent overdesigned relationships, which are unsuccessful. Considering this apparent dichotomy, additional research is required to investigate relationship management strategies and their specific effect on the effectivity of coordination efforts.

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TABLE OF FIGURES

TABLE OF TABLES

APP. I BACKGROUND OF THE INDUSTRY

The construction industry is often criticised for its low performance and backwardness (Dainty, Millett, et al., 2001; Hong-Minh et al., 2001; Vrijhoef & Koskela, 2005). More specifically the industry is blamed for its inefficiency of operations (Cox & Thompson, 1997), a short-term perspective; which hampers innovation and promotes sub-optimisation (Dubois & Gadde, 2000; Gann, 1996) and a lack of integration; characterised by adversarial relationships, disjointed supply chains and a lack of trust (Briscoe & Dainty, 2005; Fearne & Fowler, 2006). A series of UK governmental research reports, concerning the construction industry, stressed that especially the fragmented nature of the industry in combination with poor inter-organisational cooperation is to blame for the perceived low performance (Egan, 1998; Latham, 1994). Therefore, some authors seem to agree that the construction industry should learn from other industries to improve performance and adopt techniques that have proven successful in those contexts. Examples of these techniques are lean manufacturing (Ballard & Howell, 2003; Koskela, 1993; Salem, Solomon, Genaidy, & Minkarah, 2006), just-in-time (Akintoye, 1995; Bertelsen & Nielsen, 1997; Pheng & Hui, 1999), total quality management (Arditi & Gunaydin, 1997; Pheng & Teo, 2004; Shammas-Toma, Seymour, & Clark, 1998), supplier partnering (Bresnen & Marshall, 2000; Cox, 1996), supply chain management (Vrijhoef & Koskela, 2000) and the 'industrialisation' of manufacturing processes (Gann, 1996). However, other authors claim that construction follows a different logic, due to its specific characteristics, and therefore requires a different approach to improve performance (Bankvall et al., 2010; Dubois & Gadde, 2002; Gann & Salter, 2000; Rutten, Dorée, & Halman, 2009; Winch, 2003).

Considering that construction is supposedly different compared to other industries, it is important to understand the specific characteristics exemplifying the industry. (Adriaanse, 2014); Vrijhoef and Koskela (2005) describe the industry based on three 'peculiarities' of production, establishing three levels of characteristics: product, production and industry. Firstly, constructed objects are always produced on the construction site. The main reasons for site production are product related characteristics, such as the size of a building and its rootedness. Furthermore, constructed objects are unique due to a singularity of needs by clients. Combined with the site-specific nature of production, this brings about an industry, wherein distinct buildings are constructed only once. Thirdly, a diverse and changing combination of resources is required for production to satisfy a building's unique specifications. Acquiring these resources is often organised locally, because of production on-site and firms usually work concurrently on multiple geographically dispersed project sites (Briscoe & Dainty, 2005; Dainty, Millett, et al., 2001; Gadde & Dubois, 2010). Therefore, constructed objects are almost exclusively realised within temporary organisations. Consequently, the construction of objects is mainly organised within projects, which are defined as temporary organisations consisting of multiple firms working together on a single final product (Cherns & Bryant, 1984). Dubois and Gadde (2000) typified these temporary organisations as temporary project networks, which exists within a permanent network of construction firms.

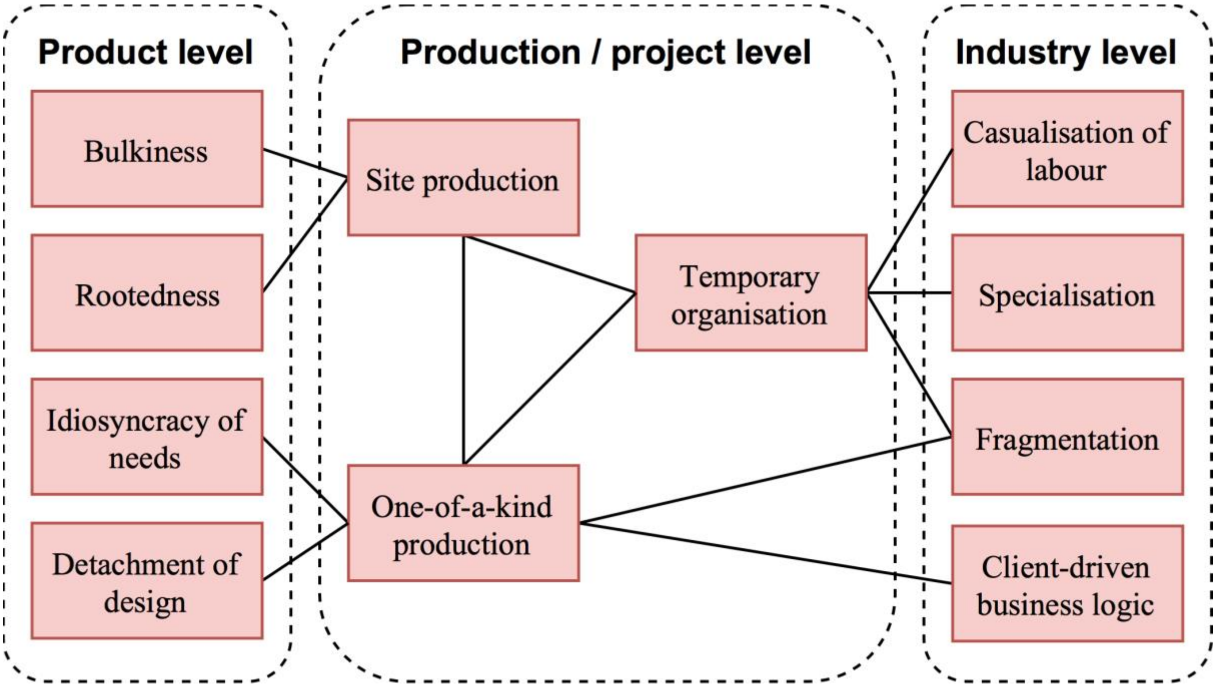

Figure 33: Three characteristics of building on product, production and industry level. Adapted from Vrijhoef and Koskela (2005).

The described peculiarities of production in the construction industry lead to multiple difficulties. The singularity of needs and long lifespan of constructed objects engender a market demand, which is described to be volatile (Segerstedt & Olofsson, 2010). Because of this volatile market demand, firms experience a discontinuous workflow. Such discontinuity results in the inability for firms to produce products in advance, creating a buffer stock, and furthermore the production on-site impedes achieving scale benefits. In comparison to other industries these shortcomings generate particular cost inefficiencies (Dorée et al., 2003), which is further exacerbated due to a lack of learning. The temporariness of the project organisation and one-of-a-kind products cause a lack of repetition and a narrow project focus, which prohibits learning across multiple projects. Dubois and Gadde (2002) point out that individual projects are considered to have a life of their own without particular history or future. This perspective is supported by Briscoe and Dainty (2005) and Fearne and Fowler (2006), who argue that construction projects are treated as a series of sequential and predominantly separate operations. Such a perspective, by construction firms, induces a lack of integration between business and project processes, which is considered paramount in order to attain a competitive advantage (Gann & Salter, 2000).

Another issue, the construction industry is exposed to a high degree of uncertainty. Uncertainty is often associated with unpredictable environmental circumstances such as the weather and ground, which are complications deriving from site production (Cox & Thompson, 1997; Eccles, 1981). Uncertainty, however, is also a consequence of a lack of repetitiveness (Vrijhoef & Koskela, 2005) and demand volatility (Eccles, 1981). A lack of repetition can be considered in terms of product singularity, considering that products are always prototypes (Koskela, 2000), and in terms of temporary organisations, wherein firms work together infrequently in constantly changing project coalitions. Hence, designs, corresponding production processes and business processes within the temporary organisations are never fully optimised resulting in an uncertain project environment. Furthermore, demand volatility influences uncertainty in terms of irregular business opportunities causing, as mentioned in the previous paragraph, discontinuities in the firm's workflow.

In compliance with the three 'peculiarities' of production, the construction industry has a distinctive degree of complexity (Dubois & Gadde, 2002; Fearne & Fowler, 2006; Gann & Salter, 2000; Gidado, 1996; Rutten et al., 2009), which is, according to Vrijhoef and Koskela (2005), a result of the intertwined relationships between construction characteristics. Dubois and Gadde (2002) perceive the complexity of construction operations and the subsequent problem-solving capability to be formidable. This is further emphasised by Gidado (1996), who claims that complexity in construction projects is continuously increasing. He also suggests that the sources of complexity can be divided in two main categories, namely uncertainty and interdependence (Table 20). Firstly, uncertainty is subdivided in four specific causes: (1) absence of complete activity specifications, (2) unfamiliarity with local resources and environment, (3) lack of uniformity of resources regarding time and place and (4) unpredictability of the environment. This perception of causes for uncertainty substantiates and complements the interpretation explained previously. Moreover, Gidado (1996), also subdivides interdependency in numerous causes for complexity: (1) the amount of required technologies and the interdependence among them, (2) the rigidity of subsequent tasks between the main operations and (3) the overlap of phases or components of construction. These causes derive from two characteristics, which are identified by Eccles (1981). Firstly, the production workforce is organised into a variety of trades requiring different skillsets and technologies. Due to this variation, firms specialise in specific trades and are therefore interdependent in order to develop a final product. Furthermore, primary contractors do not maintain all specialties in-house and are therefore reliant upon the practice of subcontracting parts of a project to special trade contractors. The specialisation of the required workforce is one of the main reasons for fragmentation in the supply chain through multi-layer subcontracting, which attributes to organisational complexity on the construction site (Fulford & Standing, 2014; Kornelius & Wamelink, 1998; Rutten et al., 2009).

Table 20: Complexity factors in the construction industry. Adapted from Dubois and Gadde (2002).

COMPLEXITY IN CONSTRUCTION

UNCERTAINTY	INTERDEPENDENCE
– Absence of complete activity specifications	– Amount of technologies and interdependencies
– Unfamiliarity with local resources and environment	– Rigidity of subsequent tasks between the main operations
– Lack of uniformity of resources regarding time and place	– Overlap of phases or components of construction
– Unpredictability of environment	

The degree of fragmentation experienced in contemporary construction supply chains is not single-handedly caused by a demand for specialisation. Also risk mitigation might be identified as a factor instigating fragmentation through multi-layer subcontracting. Main contractors only perform a small portion of a project by its own personnel and capacity in order to compensate for an unstable market (Segerstedt & Olofsson, 2010). The instability of the market, in regard to the volatile market demand, demands firms to be flexible (Cox & Thompson, 1997; Eccles, 1981). According to Egan (1998) this degree of flexibility is a key strength of the construction industry allowing them to deal with the discontinuous workflow. However, flexibility has come at a price, which is an intensified supply chain fragmentation caused by low barriers of market entry, resulting in many small firms (Briscoe & Dainty, 2005), and a dominance of localised markets (Green, Fernie, & Weller, 2005). More clearly analysed, firms in the construction industry experience high amounts of risk, which are predominantly financial risks caused by the inherent complexity of construction, cost inefficiencies and high degrees of competition (Cox & Thompson, 1997; Dorée et al., 2003; Segerstedt & Olofsson, 2010). To cope with the perceived amount of financial risk, firms often adopt a radical cost focus, which causes them to restrain fixed costs by downsizing on permanent specialist and working staff; and equipment (Dorée et al., 2003). During projects, firms then compensate for their lack of in-house capabilities by subcontracting the work. This phenomenon is called the ‘flexible firm’, which is an exclusive focus on the management and coordination aspects of projects by main contractors (Briscoe & Dainty, 2005). Dorée et al. (2003) suggests that these lean cost structures cause firms to be almost interchangeable, which aggravates the fierce price-based competition.

As described, competition is one of the main drivers of financial risk. Some authors even describe the fierce competition as one of the most characteristic features of construction (Dorée et al., 2003; Fulford & Standing, 2014). According to Dorée et al. (2003) the construction industry seems highly vulnerable to ruinous competition. However, mostly due to traditional procurement strategies, companies struggle to start up new business cycles, because price-based selection assumes that firms are providing products of equal value. These practices discourage contractors to find solutions to create additional value. As a result, contractors have less sensitivity for client demands, do not invest in innovation and adopt lean cost structures, which incites them to initiate price wars to beat the competition in order to cope with the discontinuous workflow (Dorée et al., 2003). These price wars lead to unreasonably low bids, which corrupts the market and stimulates opportunistic behaviour (Tam et al., 2011). As a consequence the current market has to deal with low profit margins between the 1% and 3% (KPMG Advisory N.V., 2012; Visser, 2015). Furthermore firms reduce budgets by eliminating contingencies to surpass competitors, which makes them even more vulnerable for uncertain circumstances (Fulford & Standing, 2014). In the end firms have to operate under considerable financial risk, which intensifies the adoption of flexible firm strategies and exacerbates the fragmentation of the construction supply chain.

All things considered, the construction industry is coping with an extremely difficult web of influential aspects interacting on multiple fronts. Nonetheless, fragmentation appears to be the most important issue, which summarises the problems distinctive for the construction industry (Dave & Koskela, 2009; Winch, 1998). Usually, this high degree of supply chain fragmentation is considered a merely problematic issue. Even so, some authors claim that the involvement of many specialist trades is not necessarily causing low levels of efficiency (Vrijhoef, 2011). Moreover, Pryke (2002) even claims that fragmentation could increase the efficiency of resource allocation and the speed of information exchange between firms. However, it has been acknowledged by many that coping with supply chain fragmentation is quite demanding and requires extensive coordination and communication activities to ensure high levels of performance (Hong-Minh et al., 2001; Love et al., 1999; Tam et al., 2011).

APP. II EMBEDDED CASES

This appendix contains background information on the examined embedded cases concerning distinct construction supply chains.

II.I STUDY GALLERY

A general case description of the performed construction work is composed based on observations, informal talks, interviews and document review. This appendix, concerning an embedded case, comprises the construction of a steel frame, façade, glass roof construction, installations and floor, together constituting the study gallery positioned at the north side of the new building. As indicated the embedded case contains a single structure consisting of multiple structural elements. Especially, the construction of the steel framework, façade and glass roof construction are focussed on. However, also the applied installations and interfaces with the existing structure are considered. Firstly, a general description of the composed products is presented. Thereafter, the supply chain arrangement, including the involved parties, is introduced and presented. Lastly, the work procedure is elaborated and visualised through an overall process map diagram, which represents the dynamics of the construction supply chain by displaying material, information and labour inputs. The main aim of the developed diagrams is to comprehend subsequent tasks and interdependencies between tasks and the parties involved.

The study gallery is an extended structure, which connects the new building with the existing structure. It is attached to the new building and primarily consists of a white coated steel support framework of columns, girders and joists. The girders are connected to the floor of the second level of the new building and the columns are positioned next to the wall of building section C. By taking out the wall of building section A, the existing study gallery is extended, which creates a long open space providing a connection between the several buildings. To connect both study galleries a joint construction is devised where both structures converge. On top of the steel framework of the new study gallery, an aluminium structure is positioned, wherein glazing is affixed. The glass roof makes the structure waterproof and provides an open atmosphere. Similarly, the structure of the façade is constructed with an aluminium raster, which is attached to the steel framework. Glass windows are affixed in the raster. To prevent the aluminium to collapse due to the heavy glazing, a support structure is incorporated in the steel framework. In front of the façade, a canopy roof is constructed, made out of an additional steel structure, partly supported by the structure of the study gallery. The portal is finished with a white coated perforated metal plating with black sheets underneath them. Inside the study gallery, a self-supporting floor is composed, consisting of coated reinforced concrete. Incorporated in the concrete floor are cables and pipes enabling the instalment of, for example, revolving doors, power sockets and water faucets. Attached to the steel girders of the framework are armatures to provide additional lighting to the gallery. For fire safety purposes a roof sprinkler network is applied. Initially, the sprinklers would have been integrated in the steel framework, but it was decided to deviate from this plan and design a separate grid. For accessibility purposes, overpass connections between the first floors of the new building and section C are made, which pass through the study gallery. The overpasses are made out of steel frame, wherein a concrete floor is poured. It is primarily finished by using wood, which also conceals the cables running between the buildings. Lastly, a revolving door is installed as an entrance for the study gallery. An impression of constructed study gallery is provided in the figures below (Figure 34 & Figure 35).

Figure 34: Study gallery before installing the glass roof construction.

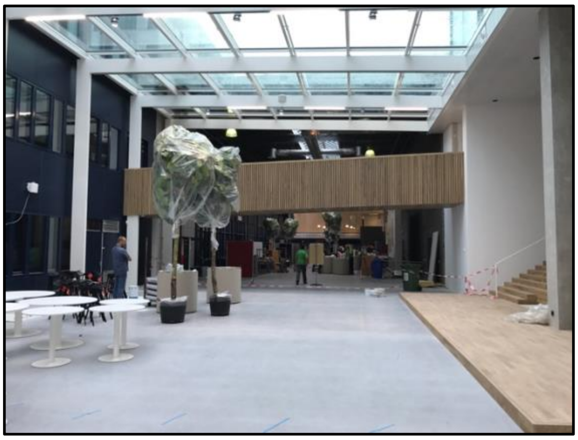

Figure 35: Study gallery during the installation of the interior.

Supply chain arrangement

For the construction of the study gallery the main contractor procured several subcontractors. However, primarily the subcontractors acquired for the main constructional components are discussed in this chapter. Therefore, the case focusses on the subcontractors responsible for the steel elements, façades, glass roofing and installations, including their mutual interaction.

Firstly, the contractors responsible for the façades and installations were acquired by the main contractor as co-makers of the project and were already involved in the tender stage of the project. They were contracted to take-over some of the responsibilities of the main contractor and participate in the tender and design stages. Additionally, these parties accepted responsibility for their own operations and demand verification, which alleviated the liability position of the main contractor.

The façade contractor was inquired to collaborate in the project based on previous experience on another project. They were responsible for the outer skin of the building and are a project agency with no in-house production or assembly capabilities. Instead they focus on the engineering of products, which consist of intermediate products procured externally. These products were then installed by a subcontracted party. For the construction of the study gallery suppliers were acquired for both the frame, the glass and the revolving doors. The subcontracted installer, also arranged the equipment to assemble the façade of the study gallery. Because of the particular role the subcontracted installer played, they were also in close contact with the main contractor to arrange on-site activities.

Besides the façade contractor, also the MEP contractor was acquired as co-maker in the project. They were responsible for all the MEP installations in the building. For the study gallery, these installations predominantly comprise armatures, speakers and fire safety measures. In particular the sprinkler installations are of importance, because of the interaction between the sprinkler and the constructional framework. The MEP contractor was mainly acquired based on the BREEAM requirements, because not every installation company was able to meet the sustainability requirements. Also, this co-maker subcontracted work to subjacent parties, however, mainly to acquire additional employees to perform specific tasks. Nevertheless, they also employed their own operational staff to work on the project. Products are acquired at multiple different suppliers and are mostly standardised. However, the sprinkler network was specifically engineered for the study gallery as separate network structure.

Furthermore, a subcontractor was procured for the required steel structures incorporated in the building, including the study gallery. The acquired subcontractor engineered the final products and also manufactured and installed them without hiring supplementary parties. Suppliers provided the basic resources to the workshop of the subcontractor, who produced the final product. This product was then shipped to the construction site and assembled by the operational staff of the subcontractor. The required equipment on site, to lift the heavy products, is arranged by the main contractor based on the subcontractor's needs. Additionally, in this case the steel structure is of particular importance because it concerns the support structure whereupon the other parties are dependent.

Lastly, the subcontractor responsible for the glass roof construction of the study gallery is discussed. Their services were also procured based on previous experience in another project. In this particular project the combination between main contractor, façade contractor and the glass roof subcontractor is similar, which seemed to have satisfied the main contractor. Within the current project the subcontractor was responsible for multiple glass roof constructions throughout the building. Therefore, they were responsible for both the engineering, production and installation of the product. These responsibilities are mainly arranged in-house, because the company has multiple internal divisions. Production, however, mainly comprises the ordering of standardised materials, which are customised to fit the project requirements.

A graphical display of the described actors and their mutual relations is depicted in Figure 36.

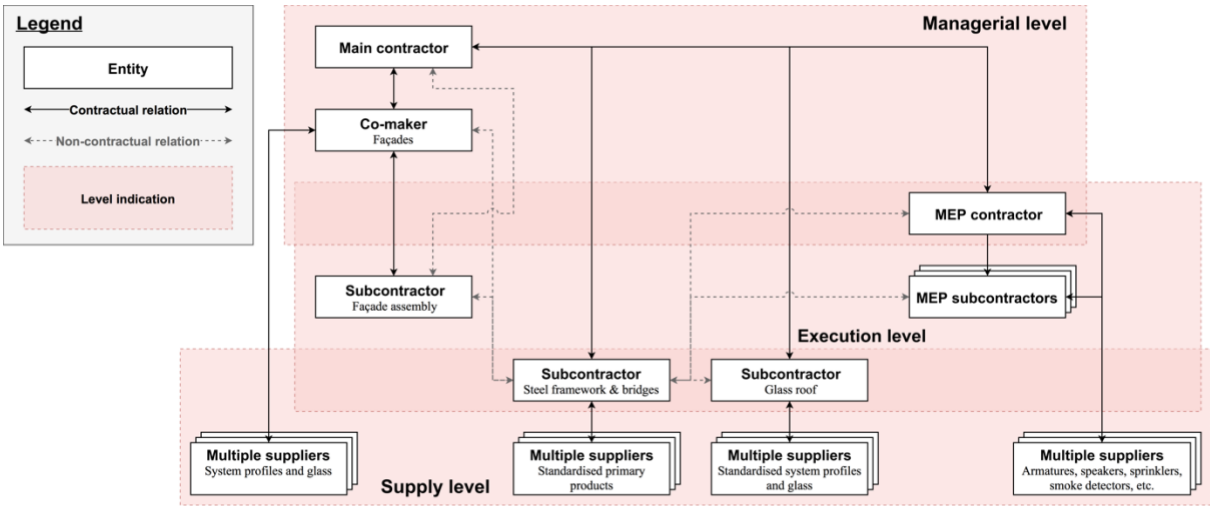

Figure 36: Graphical display of the parties involved in the construction process of the study gallery and their mutual relations.

Process description

The construction of the study gallery is performed concurrently with the finishing activities performed inside the new building. Based on the design, produced by the architect, the operational process commenced with the engineering of the architectural design into a constructional design. Firstly, the main contractor commissioned the constructional engineer to perform an electronic survey of the existing structures to make sure of the correct dimensions. Based on these dimensions and the architectural design, the structural preconditions of the study gallery are determined. Then, the steel subcontractor started engineering the support framework, which would be attached to the new building section. Based on the framework, the succeeding parties engineered their structural elements comprising the glass roof, façade and MEP installations. During the engineering process the parties primarily further developed and elaborated the design of the architect. Consecutively, the designs were processed by the constructional engineer into the 3D BIM model, because the individual parties utilise 2D drawings. Subsequently, the involved parties placed their orders and/or started producing the required building components. The subcontractor responsible for the steel framework manufactured the components in their workshop. In similar fashion, the glass roof subcontractor manufactures their products in-house. However, they mainly adapt existing frame mechanisms into the required dimensions. Additionally, the glazing is ordered from an external supplier, which is also the case for the façade contractor. They subcontracted every component externally towards parties, who would produce the custom elements. The MEP contractor requires a wider variety of products, which are ordered from external suppliers. In terms of delivery, the large structural elements, such as beams and frame components, were planned to arrive on the construction site a few days prior to assembly. Small standard products arrived continuously over the course of the project. The shipping of components to the construction site was arranged by the suppliers in agreement with the main contractor.

On the construction site the operations commenced with setting the measurements for the steel framework by the subcontractor. The framework was built on a piled structural concrete floor, which was already constructed by the main contractor in an earlier project phase. After the measurements are set, the steel columns and girders are installed. Meanwhile, the steel overpasses arrived and were installed, because they are supported by the steel columns. Additional joists and wind braces provide the structure with stability, rigidity and provide support for the glass roof structure. Subsequently, the frame subcontractor installed the studs and girts at the front of the study galley for the support of the façade. In the meantime, the MEP contractor started with the installation of the sprinkler network. Afterwards the façade installer commenced with the installation of the aluminium framework. Within this framework, the glazing is positioned, after which aluminium casings are attached on top to keep the glass in place. Furthermore, side doors were installed in the façade as emergency doors. At the other end of the study gallery, the glass roof subcontractor started off operations. Their system is similar to the façade and also consists of an aluminium framework, wherein the glazing is positioned. Next, the MEP contractor starts with preparing the under-floor cabling and floor heating. In the façade opening the preparations for the revolving doors are made. Lastly, when all the concerned parties are finished the main contractor takes over to start floor isolations after which a reinforced monolithic concrete floor is poured. Then the study gallery is ready for the finishing phase, wherein the last installations and material finishes are applied. The construction process of the considered elements in the study gallery, described in this paragraph, is visualised in Figure 37.

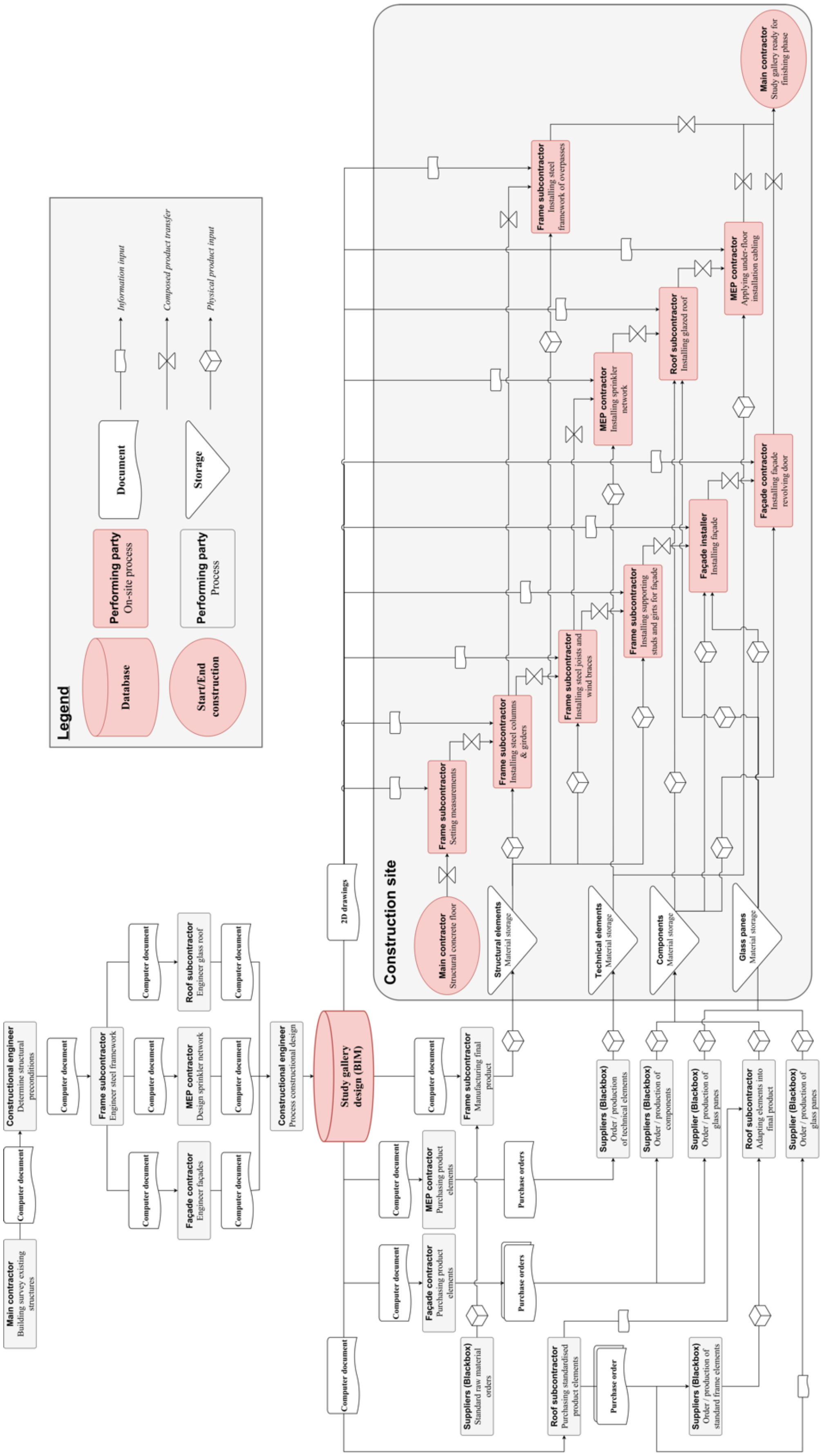

Figure 37: Process diagram of embedded case No. 1 – Study gallery

II.II SUSPENDED CEILING

Based on observations, informal talks, interviews and document review a general case description of the performed construction work is composed. This specific chapter is concerned with the assembly of the suspended ceiling and the mechanical, electrical and plumbing (MEP) installations embedded in these ceilings. Within the project several types of ceilings are applied. In this case description, only the suspended ceilings applied in the hallways and study domains, on the ground level up until the sixth level, are included. First, a general description of the type of product is presented. Then the work procedure is deduced based on the available data and an organisational chart of the parties involved is developed. Based on the acquired information an overall process map diagram is constructed, which represents the dynamics of the construction supply chain by displaying material, information and labour inputs. The aim of the diagram is to clarify subsequent tasks and interdependencies between the several parties involved.

The suspended ceiling applied in the hallways and study domains are made out of perforated steel panels. Each ceiling panel spans the total width of the hallways and is suspended in a Z-shaped fixture profile. These fixture profiles are attached to the walls, while in the study domains, a suspended frame is attached to the concrete floor of the next level. Embedded in the ceiling panels technical elements are assembled, such as sprinklers, speakers, armatures and sensors. The suspended ceiling has four distinct functions including acoustic comfort, fire resistance, aesthetics and support of the required installations. In terms of acoustic comfort, a perforated pattern is applied into the ceiling to diminish reverberation times. Moreover, acoustic felt is applied onto the metal plates to ensure the demands, concerning acoustic comfort, are satisfied. Additionally, the panels have to satisfy fire resistance preconditions. The suspended ceiling, also, has an aesthetic function, because it conceals the MEP-installations running above the ceiling. Furthermore, the functional elements, embedded in the ceiling, have to be supported. Therefore, the ceiling was specifically designed based on the positions of these technical elements. The specific panels each have a distinct position in the lay-out and the recesses, for the instalment of technical elements, are prefabricated. Correspondingly, approximately 280 different ceiling panel types are produced specifically for the project. The installations embedded in the ceiling are mainly concerned with lighting, sound and safety functionalities. Armatures are installed to provide sufficient light within the involved areas, speakers are installed for announcements, sprinklers and smoke detectors are applied for fire safety, while specific lighting is installed to indicate escape routes. An impression of the suspended ceilings is provided in Figure 38 and Figure 39.

Figure 38: Open ceiling with single technical panel.

Figure 39: Ceiling application in open space.

Supply chain arrangement

For the assembly of the ceilings the main contractor procured a subcontractor, who was chosen based on price and previous experience. An important aspect, for the main contractor, was the assurance of a high work pace to be able to complete the finishing phase within the short project timeline. Previous experience with this particular subcontractor provided the necessary confidence in their capabilities. In addition to the suspended ceiling, the subcontractor was also procured for delivering the interior walls. The main contractor considers these types of works to be specialist jobs and therefore acquired the subcontractor for both the procurement of materials, assembly and engineering of the product. The required product was ordered by the subcontractor from an Austrian supplier specialised in metal ceilings. However, they operated as a trader and acquired the ceilings from another manufacturer located in Germany. Moreover, the Austrian supplier arranged the delivery of the materials to the building site. For the logistics on site, both horizontal and vertical movement, a service company was acquired by the subcontractor. The main reason for acquiring these services was to facilitate the efficiency of the specialist installers, employed by the subcontractor, through diminishing their logistical movements. The work performed by the subcontractor is closely related with the MEP installations, which are located above and embedded within the suspended ceiling panels. Especially in regard to the technical elements embedded in the ceiling, extensive coordination was required between the parties involved. In general, the main contractor procured a MEP contractor, who was responsible for all types of installations. However, the general MEP contractor subcontracted specific components to smaller specialised contractors. In particular, the subcontractor, responsible for the E-installations and cable routing systems, was involved in the assembly of the technical components embedded in the suspended ceiling alongside the general MEP contractor. Furthermore, some other MEP subcontractors, such as the contractor responsible for the fire safety installations, were involved in the process. Additionally, the MEP contractor acquired suppliers to deliver the specific components embedded in the suspended ceilings. Conclusively, an indirect non-contractual relationship between the subcontractor and MEP contractors existed. Also, in regard to the engineering of the ceiling the subcontractor had to coordinate the ceiling design with the general MEP contractor. The design had to incorporate the embedded technical elements, which have specific positions determined by the MEP contractor. A depiction of the described actors and their mutual relations is displayed in Figure 40.

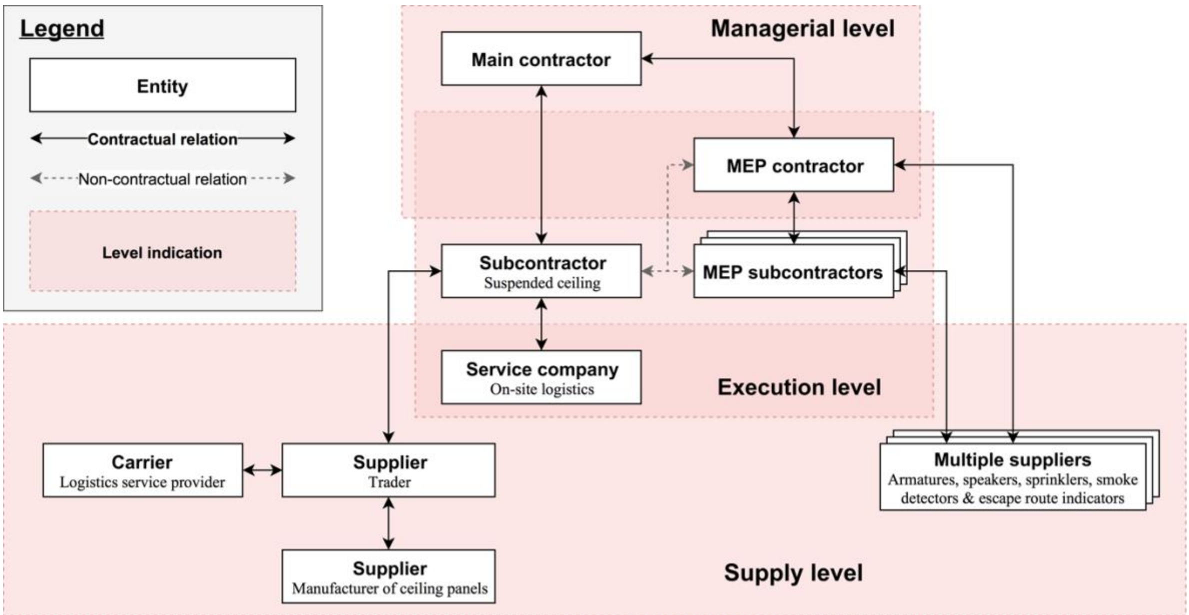

Figure 40. Graphical display of the parties involved in the construction process of the suspended ceiling and their mutual relations.

Process description

The operational process, concerning the suspended ceilings, commences with the construction design of the final ceiling. This ceiling plan entails the exact position and dimensions of the ceiling panels, along with the allocation of the embedded installations. A first concept, based on the architectural design, is produced by the constructional engineer, who included the structural preconditions of the ceiling in the overall BIM-model based on the raster provided by the architect. Using the first concept, the MEP contractor designed the installations, both running above and embedded within the ceilings panels. The design comprises a zoning plan containing the approximate positions of the embedded installations. Meanwhile, the subcontractor, responsible for the suspended ceilings, drafted a ceiling raster with exact panel measurements. This was sent to the MEP contractor, who allocated the installation positions within the ceiling design. Subsequently, a final ceiling plan was produced by the subcontractor, who then placed an order with the supplier for the ceiling panels. After an order was placed with the trade supplier, the panels were produced and shipped to the construction site by freighter. First, the frame system elements for the suspended ceiling were delivered to the construction site and later the ceiling panels. The panels were bundled in packages containing several identical ceiling panels, which were stacked on pallets, labelled by floor. Horizontal and vertical transportation on site was arranged by the acquired service company and meanwhile panels were stored in designated lecture rooms on the specific floor. The installation of the ceiling by the subcontractor started off with setting the measurements for the fixture profiles and suspended frame. These were installed based on the designed ceiling heights, which were laid out using a laser. When the measurements were set, the ceiling frame was installed. Subsequently, the customised ceiling panels were suspended, leaving the ceiling open for the MEP technicians to install the embedded technical elements and connect these to the installations running above the ceiling. When the MEP technicians were finished, the subcontractor closed the ceiling by suspending the standardised ceiling panels. The process of installing the suspended ceiling described in this paragraph is visualised in Figure 41.

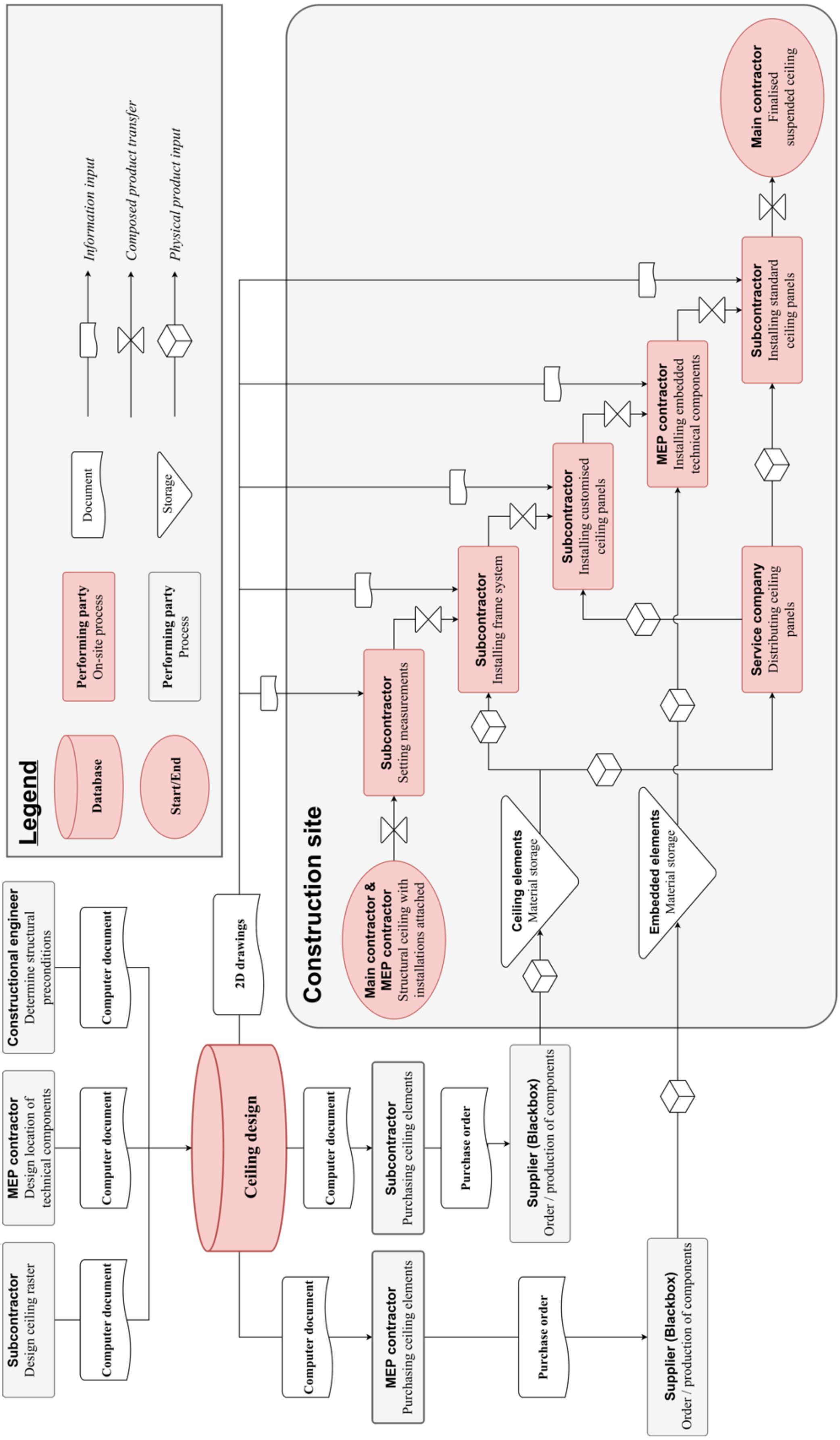

Figure 41: Process diagram of embedded case No. 2 – Suspended ceilings

II.III BALUSTRADES

This specific chapter consists of a description of the performed construction work in this embedded case. Based on observations, informal talks, interviews and document review, an outline of the process constructing the glass balustrades is composed. Multiple types of balustrades are applied within the project, but in this particular case description the balustrades located at the study platforms and corridors are examined. However, the steel and wooden balustrades applied in the several stairways throughout the building are not discussed. To provide an insight in the discussed product, a general description of the product is presented first. Following, the supply chain arrangement of the parties involved is introduced, after which the performed work procedure is elaborated. The composed process map will represent the dynamics of the supply chain by demonstrating material, information and labour inputs for each process step. Eventually, this clarification will provide an insight in the sequence of tasks and interdependencies between the parties involved.

At the edges of the study platforms and corridors, the balustrades are positioned around the large atrium of the building. They consist out of several components, which are produced and assembled by multiple parties. In between assembly stages a temporary wooden structure is applied to ensure safety during the construction timeline. Firstly, balusters are attached to the concrete floors and form the framework of the structure. Additionally, they support the cove construction concealing the installations attached to the ceilings. At floor level, a railing is attached to the balusters, wherein glazing is placed. On top of the glazing and balusters a laminated wooden banister is positioned. However, before the glazing is placed the steel balusters are submerged in a cement screed coat, which is poured on top of the structural floor. The balustrades possess several functionalities including fall protection, fire resistance and aesthetics. The fall protection is mainly ensured by the strength and stability of the structure. Especially the steel balusters function as load bearing structure to provide these qualities. Fire resistance is primarily provided by coating the individual elements. However, the glazing is selected to meet the required specifications concerning fire safety. Lastly, the balustrades have an aesthetic function, because it contributes to the unified appearance of the building. An impression of the constructed balustrades is provided in Figure 42 and Figure 43.

Figure 42: Impression of balustrades before and after installation of glass elements.

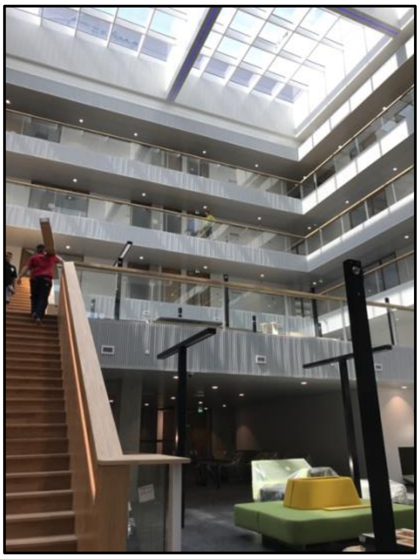

Figure 43: Impression of finished balustrades over multiple floors.

Supply chain arrangement

The balustrades are assembled and manufactured by several parties procured by the main contractor. In this chapter, the involved parties responsible for the components of the balustrades are discussed. A focus is placed on the parties working consecutively on the product. In the first place, the supplier of the glazing for the balustrades was acquired for multiple activities in the project. Mostly, they were acquired as supplier of exterior and interior glazing such as glazing for the façades. However, in this case they acted as subcontractor because they also arranged the installation of their product. Therefore, the glass supplier/subcontractor operates, in this case, in both the supply and managerial level. Because the subcontractor primarily focusses on the production of the product, the installer is also a point of contact for the main contractor when they work on the construction site. The key component of the balustrades, however, are the balusters. These products are already installed at the beginning of the finishing phase and have an interface with every other component. The subcontractor acquired for these components is contracted for multiple steel structures within the building and is also involved in the engineering of the product. Following the engineering of the product the balusters are produced in-house. Also, installation of the components is performed by the subcontractor. Another party involved in the process is the subcontractor responsible for the floors. After the main contractor assembled the cove constructions the subcontractor smoothens the surface of the floor. They pour a cement screed coat on top of the concrete structural floor embedding the balusters in it. Primarily standardised products are utilised by the floor subcontractor. The screed coat and moisture barrier, for preventing damage due to a lack of setting time of the floors, are standard wholesale products. The rubber floor is acquired at a specific supplier located in Germany. Lastly the subcontractor supplying the wooden banisters is discussed. However, the specific contractor, acquiring the banisters, is merely responsible for the covering of the main staircases and their balustrades. Another installer is employed to install the banisters, supplied by the other subcontractor, onto the balustrades. A graphical display of the described actors and their mutual relations is depicted in Figure 44.

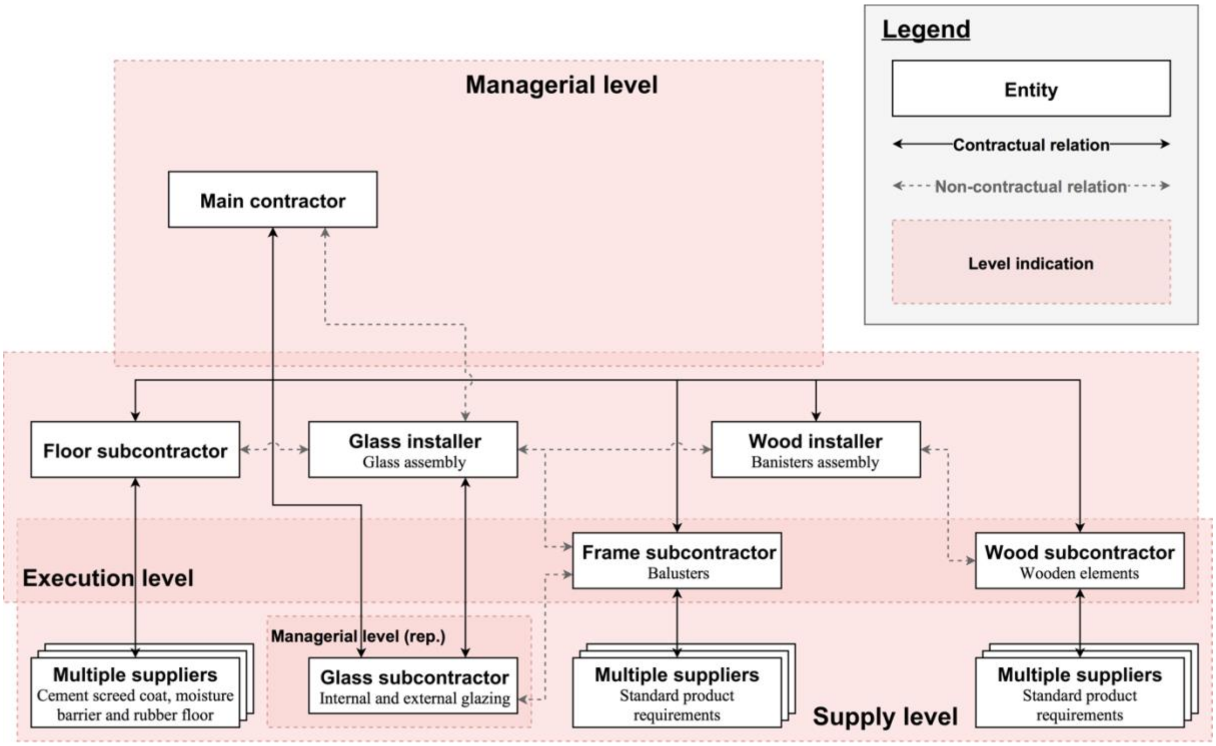

Figure 44: Graphical display of the parties involved in the construction process of the balustrades and their mutual relations.

Process description

The operational process commences with developing the construction design of the balustrades based on the architectural design. Firstly, the structural preconditions are processed into a 3D model by the constructional engineer. The baluster design is then developed by the subcontractor. Finally, the engineered construction is processed into the final 3D BIM model by the constructional engineer. Based on the final design the involved parties start the manufacturing process by scheduling the production and order of materials. The steel framework contractor manufactures the components in-house and therefore makes regular product orders to fit the input demand of their workshop. Similarly, the subcontractor arranging the glazing produce the required products themselves, but the company has different departments with distinct names working together. Alternatively, the cove construction is produced by an installation firm hired by the main contractor. Standardised timber is acquired, which is sawed into a framework, whereupon another subcontractor, not included in this general description, applies steel profile plating. Also, this installation firm applies a sheet to shroud the joint and allow the floor subcontractor to pour the cement screed coat, without it leaking through. The applied screed coat is also a standard product, which is depicted in the diagram. However, the rubber floor, applied by this subcontractor and produced by an external supplier, is not within the scope of this embedded case. Lastly, the wood subcontractor acquires specific banisters for the balustrades, which are also applied on the stairways and overpasses. Furthermore, this supplier is acquired for other wood elements applied in the building. Construction on site starts off with setting the measurements of the balusters by the frame subcontractor. Based on the measurements the balusters and corresponding frame are installed. In practice, the installation firm employed by the main contractor also assist with installing the balusters. Successively the cove construction is produced and installed on-site by the installation firm, after which the cement screed coat is applied. Next, glazing is installed and lastly the banisters are applied. In between the installation of the balusters, glazing and banisters, a temporary wooden structure is applied pending the subsequent step. The described process is visualised in Figure 45.

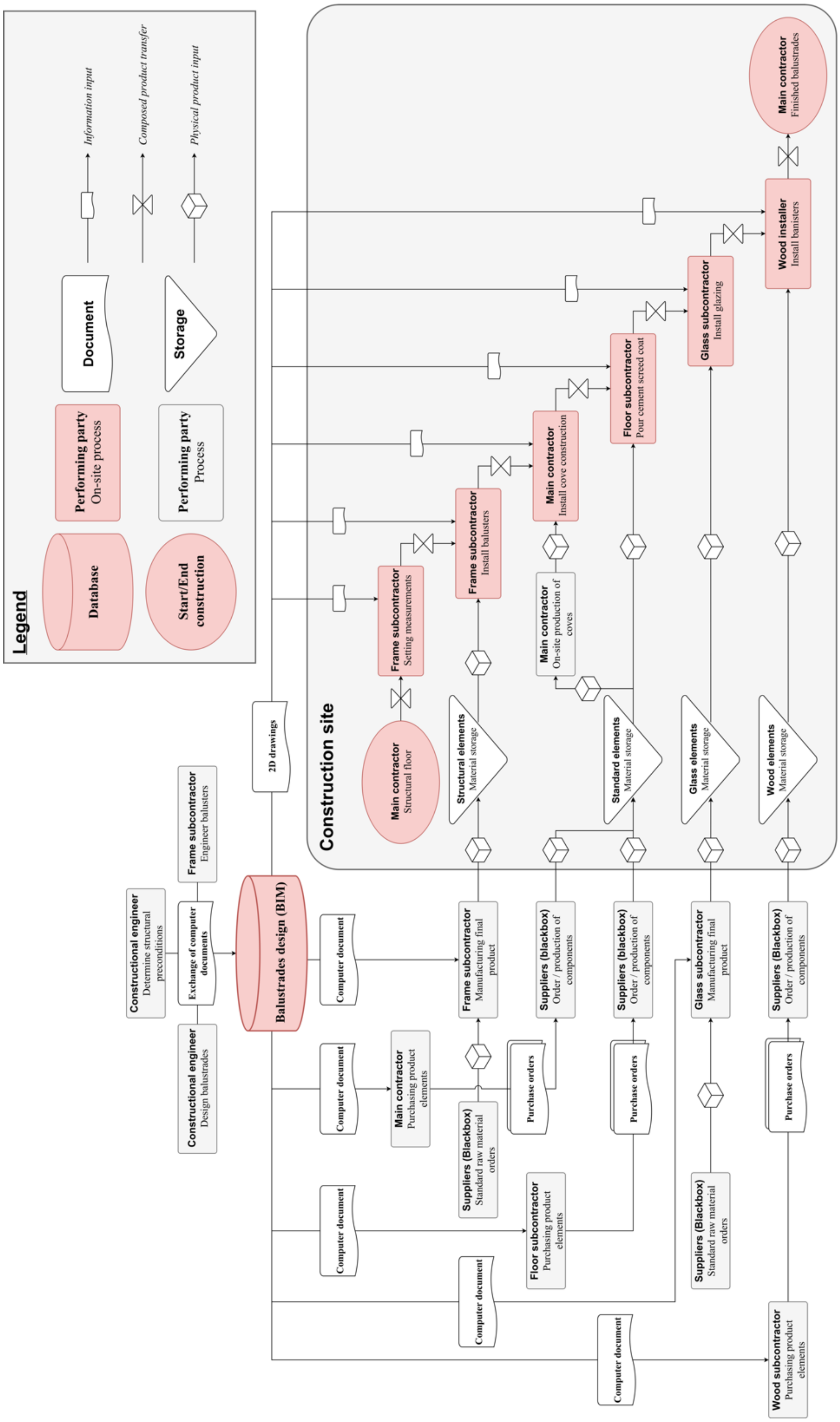

Figure 45: Process diagram of the embedded case – Balustrades

II.IV FURNISHINGS

Based on observations and interviews a general case description of the performed construction work is composed. This specific chapter is concerned with furnishings in the building performed by several subcontractors hired by the client. Several types of furnishings are applied including standardised furniture, customised furniture and AV-installations. In this appendix, a less extensive background and merely textual context is elaborated because less information concerning the involved parties was gathered. Apart from the incident identification through observations and an interview with the client concerning the arrangements in regard to the furnishings, no extensive number of documents concerning this product was available. Nevertheless, the gathered information proved sufficient to analyse the identified incidents in similar fashion in comparison to the other embedded cases.

The furnishings are procured separately by the client in individual tenders. Firstly, the standardised furniture is provided by a fixed supplier based on an existing framework contract. These items are chosen based on a catalogue and contain for example lecture desks and chairs. Secondly, customised furniture is commissioned based on a mini tender between predetermined suppliers who acquired the right to compete in this tender in an earlier procurement procedure. These products contain for example customised couches, bookcases and whiteboards. Additionally, kitchenettes and a bar in the study gallery were custom-build. The last category contains AV-equipment such as smartboards and control equipment. These components were procured to a subcontractor, but installation was executed based on separate directives. In establishing the interior design, the client worked together with the architect and coordinated separately with the contracted furnishing subcontractors. An impression of the interior furnishings is provided in Figure 46 and Figure 47.

Figure 46: Installation of furnishings on study platform on third floor.

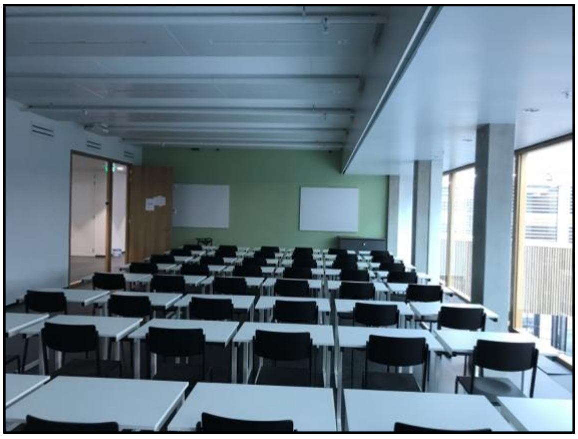

Figure 47: Layout of lecture room after furnishing

APP. III EXPERT MEETINGS

Attendants: *Adriaanse, A.M., Olthof, R., Voordijk, J.T. & Vries, de A.M.R.*

Date: 15-02-2018

In an earlier stage, prior to this meeting, several incidents were elaborated using multiple methods. Firstly, descriptions were produced, after which a static analytical model was used to find within and cross-case patterns. However, this method did not generate the desired outcome, which required a change of method. The reason for this particular meeting is to discuss the outcomes of a within-case analysis method based on Langley (1999) and work towards a cross-case analysis method to find patterns across multiple incidents. Therefore, visual mapping/swim-lane diagrams were produced, which are within-case analyses of the observed incidents, to provide an outline to work with.

Pre-meeting

Prior to the meeting two initial analytical models were developed by Ruben and Alexander. In regard to both models a gut feeling existed that both models are only an approximate representation of reality and missed out on elements to become a closer approximation. However, in a later stage it was assumed that a convergence of both models would likely result in a more realistic model as both participants clearly worked on a different approach.

The first model is primarily based on explaining how existing uncertainties and interdependencies result in incident situations (Figure 48). The several uncertainties and interdependencies are assumed to derive from the design and applied planning mechanism. Furthermore, it is assumed that potential unanticipated uncertainties would exist based on the presumptions of the parties working on the design and planning. A distinction was made between uncertainties based on 'time' and 'space'. Primarily unanticipated uncertainties proved to result in negative effects within the incidents. However, it did not explain the dynamics of coordination during the construction process, but rather the sequence of events resulting in an incident and its effects.

The second model is more concerned with the coordination process during construction processes, wherein incidents occur (Figure 49). It is a rudimentary draft of a potential analysis model, which was developed on a scrap paper, based on the coordination structures of Thompson (1967). It assumes that before the construction process starts arrangements and agreements are made between parties, which are mainly considered standardisations. Subsequently, a planning is developed wherein the arrangements are incorporated. Important is to consider the planning as an elaboration of the agreed upon arrangements on the basis of time. During the construction process mutual adjustment is applied between parties to solve problems. The feedback arrows represent the possibility to return to a specific step, whenever problems are not solved through mutual adjustment and require a more fundamental adjustment. Therefore this model is a more dynamic approach to Thompson (1967) his classification of coordination structures.

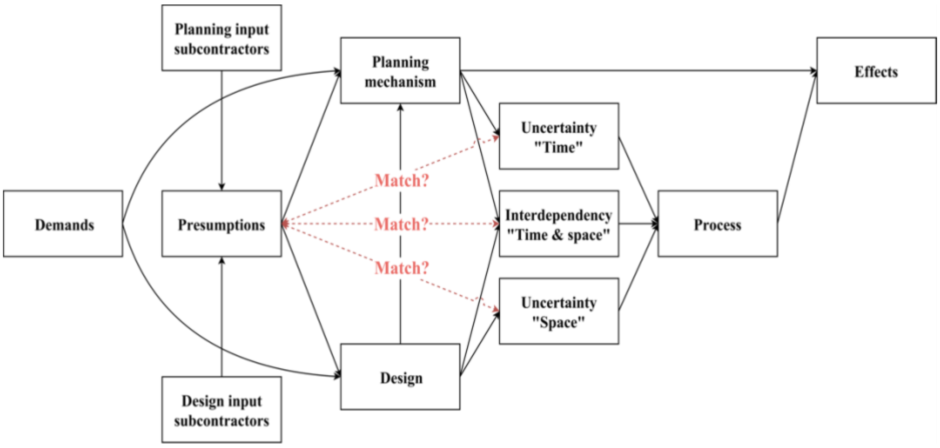

Figure 48: Analytical model based on identifying uncertainties.

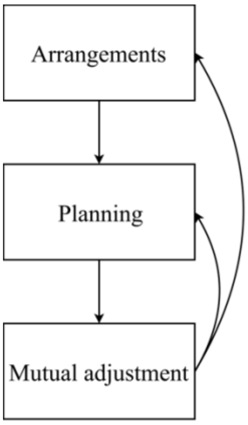

Figure 49: Analytical model based on the coordination process.

Consecutively, a combined model is produced, as a primary set-up for the upcoming meeting (Figure 50). The coordination process, depicted on the right-hand side, is regarded to be influenced by uncertainties, which result in effects in terms of time, space and quality. Quality is added based on ???, while the uncertainties, on the left-hand side, are further subdivided, considering Bensaou and Venkatraman (1996). Additionally, product uncertainty is added, as the classification of environmental uncertainty, by Bensaou and Venkatraman (1996), could be split-up in both environmental and product related uncertainties. Lastly, it seems that particular return barriers exist between the coordination layers. Based on the incidents it seems that previous steps are not revised after they have been completed.

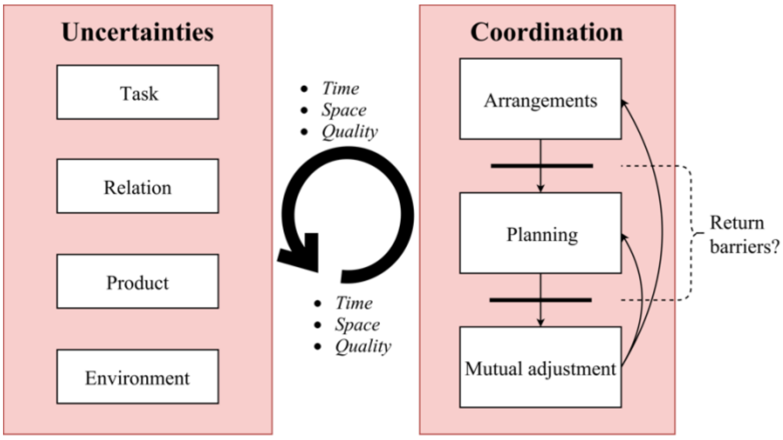

Figure 50: Combined analytical model based on the previous models.

Discuss incident diagrams

At the start of the meeting four incident situations are discussed, which were elaborated by Alexander using a visual mapping strategy (Langley, 1999). Within these incidents particular factors of influence are identified. These factors comprise: (1.) divergent interests/objectives between parties (especially the strong main contractor interest for process continuation stands out), which creates locked-in situations, (2.) contractual agreements and (3.) uncertainties.

Based on the within-case analyses, a discussion is started to proceed towards a cross-case analytical model. The discussion is put on edge by raising questions about the focus of analysis. It seems that the current approach is mainly aimed at understanding the sequence of operations, rather than the coordination processes. In regard to the research objective, a focus on coordination processes is decided to be preferable. Also, the current within-case analyses are cross-sections of the incidents based on time, while the aim should now be to establish cause-effect relationships through interpretation of these timelines. A proper cause-effect model could show the dynamics of coordination throughout the project timeline and identify important factors of influence across incident situations.

After a short break the pre-developed model, presented in the previous figure, is discussed (Figure 50). In relation to the model and the examined incidents a pattern of re-negotiation is identified. Whenever problems occur in the construction process and alterations are required, a re-negotiation of terms occurs between parties. However, these negotiations result in different measures. In some cases, problem situations are solved within the process itself and no re-negotiation is required. Therefore, it seems that the feedback arrows show re-negotiations at multiple levels of intervention, which are triggered by irregularities in the construction process. The balance of power between parties and their particular interests are assumed to have a strong influence on the re-negotiations, triggering a feedback arrow to a specific level of intervention. Uncertainties are mainly considered as input for the primary arrangements. However, unanticipated uncertainties might also be a cause for irregularities in the construction process. Altogether a transitional version of the analytical model is developed during the meeting (Figure 51). As a side-note it is argued that the process of re-negotiation happens on multiple levels in the project organisation (e.g. Thompson (1967) distinguishes between process, managerial and institutional level).

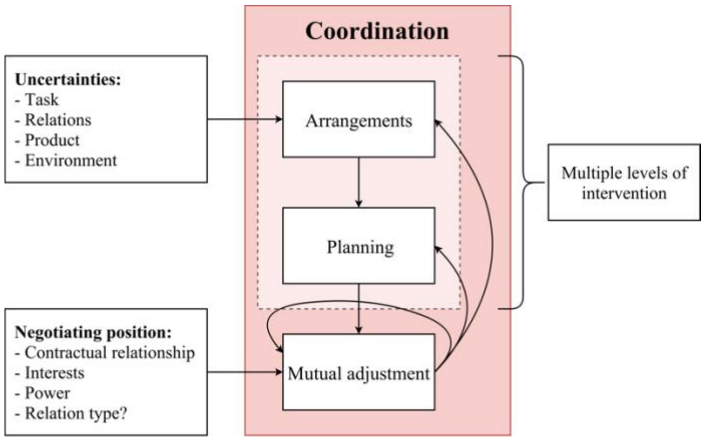

Figure 51: Transitional analytical model.

At the end of the discussion the model is revised into a final structure (Figure 52). The process of mutual adjustment is repositioned as the re-negotiation loop and an extra layer is applied to make the subsequent process steps clearer. First the initial arrangements between parties is determined, whereupon a planning is developed. Following the planning an executional process is performed. Whenever an impediment arises, parties adjust mutually and re-negotiate the terms of either the initial arrangements, planning or solve the problem within the execution process. Furthermore, a next step is to identify how external factors influence the process of coordination and how this influences the particular level of intervention. Mainly, uncertainties and the relative power position of parties are externalities, which derive from findings at the beginning of the meeting.

After-meeting

After the meeting Ruben and Alexander proceeded to test the developed model and analyse several incidents to make sure the model fits their dynamics. During this process some additions were incorporated. Primarily, the model lacked an output, which was added, because the process requires a visual end point. Furthermore, the influence of the relative power position is altered. Based on the analysed incidents the process of coordination seems to be influenced by objectives and power. When objectives are aligned it seems more likely that re-negotiation results in a positive outcome for the executional process. This means that the appropriate level of coordination is adjusted to deal with the arisen impediment. However, when the interests are not aligned, in particular when an imbalance of interests, disadvantageous to the main contractor, occurs, the executional process likely suffers. Therefore, it seems that the relative power position corresponds with the buyer-supplier portfolios described by Bensaou (1999). The final model is portrayed in the figure below (Figure 53).

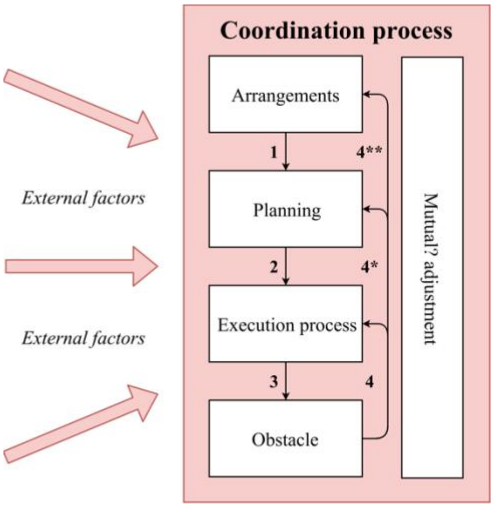

Figure 52: Renewed structure at the end of the analytical model by the end of the meeting

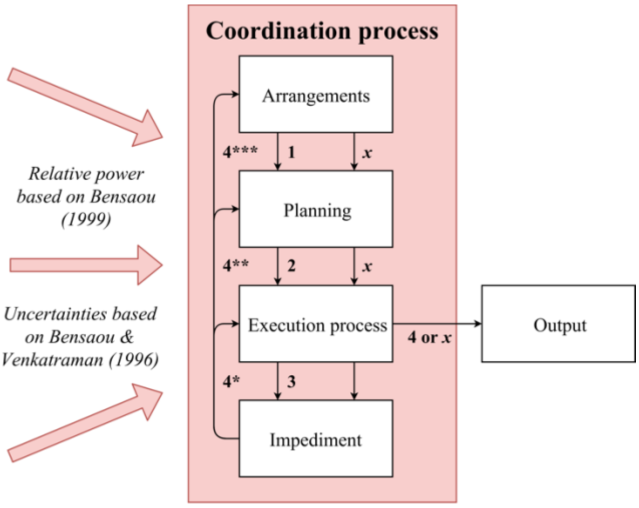

Figure 53: Final analytical model developed after the meeting

Based on the findings established in the first meeting several subsequent meetings were organised to further discuss and elaborate on the model, which led to the final model presented in the main text.

APP. IV ENFOLDING LITERATURE

The main insights gained from this research are considered the course of coordination during critical incidents, how this course is affected by power and interest positions from different supply chain actors, what types of uncertainty cause the occurrence of critical incidents and how information is exchanged during coordination activities. Consequently, literature is presented, which comments on these issues, to base upon a reflection of the findings presented in this research.

Coordination in construction supply chains

Many authors have performed studies about coordination in many different disciplines. The main concept of coordination is not considerably different in construction when compared to other disciplines. Nevertheless, the main characteristics of an industry determine the complexity of coordination. Malone and Crowston (1990) broadly refer to coordination in a common-sense approach by defining it as: “The act of working together harmoniously” (p. 358). In relation to this definition, construction consists of an extensive amount of parties working together to achieve a final product within a complex context, specific to the nature of the industry. Consequently, a need arises to coordinate all these activities between numerous supply chains and construction sites (Bankvall et al., 2010). Managing the interdependencies deriving from this collaborative endeavour is therefore vital for construction performance. In conformance with this line of thought Malone and Crowston (1994) define a more narrow definition: “Coordination is managing dependencies between activities” (p. 90). Given that coordination deals with managing dependencies between parties, the eminence of understanding it in more detail becomes clear considering that the fragmented nature of the construction industry is considered one of the main reasons for problems in construction activities (Briscoe & Dainty, 2005; Cox & Ireland, 2002; Fulford & Standing, 2014).

Fundamentally, interdependence emanates from collaborative behaviour of construction firms. When parties work together on projects, interdependency between their activities is formed. The degree of interdependence and its distinct complexity are determined by a rich context, which differs per specific relationship (Bildsten, 2014). Several authors describe different types of interdependency, which characterise construction supply chains. Dubois and Gadde (2002) approach interdependency by addressing specific couplings between dependent elements in an organisation. Based on work by Weick (1976), they distinguish couplings between elements, such as organisations, hierarchical levels and construction activities. In their research Dubois and Gadde (2002) recognise that interdependency in construction exists both within individual projects, but also in a more permanent network. The interaction between these networks is portrayed in the following figure (Figure 54).

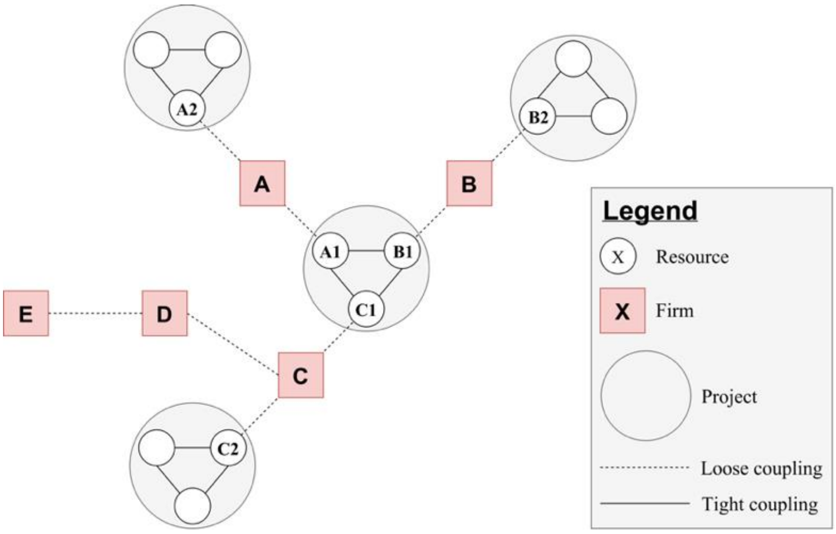

Figure 54: Construction projects in the context of the permanent network of the industry. Adapted from Dubois and Gadde (2002).

Managing the different interdependencies is achieved by establishing loose and tight couplings between the identified elements. Dubois and Gadde (2002) reveal that within construction loose couplings generally dominate the permanent network, while tight couplings are established within project boundaries. The loose couplings are characterised by decentralisation of decision-making, localised adaptation and a low extent of coordination. Generally, this type of linkage is adopted to behave as buffering mechanism (Weick, 1976). Tight couplings, on the other hand, are mainly achieved by collective adaptations, or standardisation, and a strong community of practice throughout the industry (Dubois & Gadde, 2000; Kadefors, 1995). However, these measures primarily aim to reduce uncertainty, while interdependence is not managed by means of proper coordination. Conclusively, it seems particularly problematic to coordinate effectively through bilateral relationships (Kornelius & Wamelink, 1998).

Considering the previous paragraphs, interdependencies between parties in construction projects are very strong. This becomes evident considering all complex tasks, parts and units involved in the construction process, while coping with high degrees of uncertainty (Dubois & Gadde, 2002; Gidado, 1996). Therefore, construction supply chains retain flexibility by maintaining high buffers between the various nodes in the chain. In light of these considerations, the described interdependency in combination with uncertainty are the main constituents of complexity in construction (Gidado, 1996). In order to cope with both aspects simultaneously continuous coordination and adjustment of plans is imperative (Bankvall et al., 2010). Nevertheless, when plans change the firms further down the construction supply chain are also affected, which further exemplifies the complex network of interdependencies in the construction industry.

In a general sense, Malone and Crowston (1990) distinguish four components, which constitute the act of coordination. These components comprise the goals, activities, actors and dependencies, which are related to corresponding coordination processes. An overview of the provided components is presented in the following table, after which each component is elaborated more extensively (Table 21).

Table 21: Different components of coordination. Adapted from Malone and Crowston (1990).

Components of coordination	***Related coordination process***
Objectives	Identifying objectives
Activities	Determine activities to achieve objectives
Actors	Selecting actors and assign activities to actors
Dependencies	Managing dependencies

The first component, objective, can be regarded any observable and measureable end result, which is to be achieved within a particular amount of time. Within traditional construction projects, most parties are focussed on building structures and make a profit out of them. This also translates to clients, who try to get the best possible deal to acquire new buildings. However, different objectives, such as innovation, quality, sustainability or construction speed, can be recognised as objectives as well (Bemelmans et al., 2012). To achieve the identified objectives, activities have to be determined to convert inputs into outputs and work towards the desired end result. In construction several phases are passed through to establish a final building. Firstly, requirements have to be established by the client after which design, construction and maintenance follow (Adriaanse, 2014; Walker, 2015). When activities are drawn up, they have to be assigned to specific actors, who have to perform them. Many different actors work together in construction projects, consisting of the client, architect, engineers, builders, suppliers, carriers, etc. (Adriaanse, 2014). Additionally, the main contractors usually subcontracts up to 90% of the work to specialised parties (Bemelmans et al., 2012; Hinze & Tracey, 1994; Vrijhoef & Koskela, 2000). Because of the involvement of all these parties, a significatn amount of interdependencies are established between activities. Managing this complex network of parties within construction projects is considered a difficult endeavour.

In light of the complex interdependencies identified within construction, Thompson (1967) focusses on interdependencies between the various tasks performed during projects. He distinguishes three different types of interdependency, which are classified according to the degree of interdependency between the regarded activities. The defined types of interdependency are as follows (Also, see Figure 55):

- ***Pooled interdependency***: This is type is considered to comprise the lowest degree of dependency between activities. The involved parties contribute to the overall project and are supported by the project. An example is when two parties share a major piece of equipment such as a crane (Shirazi, Langford, & Rowlinson, 1996). Direct operational dependence is not necessarily the case, but failure of one, can threaten the whole of others involved.
- ***Sequential interdependency***: In sequential interdependency a direct operational link between activities exists because the output of one activity constitutes the input for the subsequent activity. Therefore, the first party has to perform well in order to enable the second party to perform good as well. Considering this operational link, the degree of interdependency is regarded higher than pooled interdependencies because actors exchange resources and depend more directly on each other's performances. An example of such a situation is when a steelworker produces steel beams after which a bricklayer can build a wall and thereafter the plasterer can plaster the wall (Bankvall et al., 2010; Shirazi et al., 1996).
- ***Reciprocal interdependency***: This is considered the highest degree of interdependency by Thompson (1967). It comprises dependent relations wherein the output of an activity is the input for the next, after which the input of this activity returns to the former activity as input. An example in construction is considered the interplay between heating, ventilation and electricity of a building, which have to be adjusted as a whole (Bankvall et al., 2010; Shirazi et al., 1996). According to Walker (2015), reciprocal interdependencies dominate construction process.

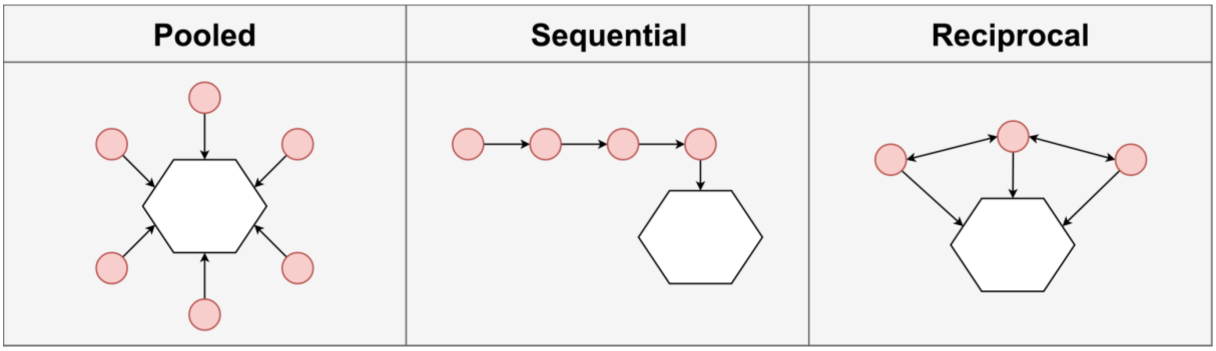

Figure 55: Different types of task interdependency. Adapted from van de Ven et al. (1976) and Kumar and van Dissel (1996).

Reflecting on this typology van de Ven et al. (1976) extend the latter by recognising another interdependency wherein actors work jointly and simultaneously. This team interdependence is recognised when parties work together simultaneously on the same task. They cooperate extensively to blend their efforts by closely interacting with each other.

It is argued that construction is a complex industry due to all the interdependencies between elements in the construction process, which require coordination (Gidado, 1996; Winch, 1989). Considering the degree of interdependence and the variety of different types of interdependencies between particular elements, specific interdependencies require matching coordination mechanisms. Building on the identified typology for task interdependencies, Thompson (1967) distinguishes three ways to coordinate the several types. These coordination mechanisms are defined as follows:

- ***Standardisation***: This type of coordination corresponds with pooled interdependencies. Coordination takes place through predefined rules within relatively stable situations, which are repetitive and consistent to allow the determination of fitting rules. By applying rules and procedures, activities are standardised. This type of coordination closely relates to the elaboration of tight couplings referred to be Dubois and Gadde (2002).
- ***Coordination by plan***: Sequential interdependency relates to coordination by plan. Extensive plans are elaborated to predefine activity sequence and required outputs. Additionally, limited daily communication between departments is required to anticipate unpredicted situations. Plans can be considered less rigid, when compared to standardised rules and procedures and therefore provide the opportunity to make dynamic adjustments during the construction phase.
- ***Mutual adjustment***: In line with the typology, mutual adjustment is required to manage reciprocal interdependencies. When complexity levels rise, the degree of mutual adjustment is considered to increase. Applying coordination by means of mutual adjustment, continuous communication between the involved actors is required to foster regular adjustments. This coordination mechanism is particularly effective in unstable situation, such as construction wherein not all problems can be foreseen or resolved beforehand due to high levels of uncertainty.

According to Mintzberg (1983) coordination moves from mutual adjustment strategies towards standardisation and back, when complexity levels gradually increase. In the first place, little coordination is required when a single person performs an activity. The need for coordination arises when two people start working together. Initially, both parties will coordinate on an informal basis through mutual adaptation. However, when the group gets larger, managing activities through informal mechanisms becomes more difficult. Managing the group's efforts is subsequently attributed to a single person, who will perform direct supervision. When complexity further increases standardisation is applied to simplify the comprehension of tasks. Standardisation of work processes is utilised to establish uniformity of simple routine activities, while standardisation of outputs is applied for more complex activities. When confronted with very complex activities, wherein outputs cannot be specified, standardisation of skills is required. During unstable situations, standardisation might not be possible at all, which requires flexibility achieved through more simple coordination mechanisms, namely mutual adjustment. Considering the additional level of interdependency, van de Ven et al. (1976) distinguish different kinds of mutual adjustment by separating individual and group adjustment. Mutual adjustment between individual parties is performed through horizontal or vertical communication between the actors, while mutual adjustment between groups is achieved through scheduled or unscheduled meetings.

Furthermore, Galbraith (1974) considers mutual adjustment to be in place all the time when coordinating activities. Specific mechanisms are only utilised when mutual adjustment is no longer sufficient to manage activities. Within this line of thought he introduces four types of mechanisms:

- ***Hierarchy of authority***: This type of coordination mechanisms is comparable with the first step of coordination when dealing with increased complexity identified by Mintzberg (1983). Appointing representatives from the involved parties simplifies coordination between them.
- ***Rules, programs and procedures***: Establishing this mechanism is similar to standardisation in terms of Thompson (1967) or standardisation of output, as defined by Mintzberg (1983).
- ***Goal setting***: The determination of goals in this context corresponds with coordination by plan, as introduced by Thompson (1967), or standardisation by output characterised by Mintzberg (1983).
- ***Narrowing the span of control***: This type of coordination can be considered an extended version of the hierarchy of authority mechanism. It is introduced to further manage task uncertainty and mutual adaptation by introducing middle management to deal with higher levels of interdependencies.

Conclusively, the table below summarises the coordination mechanisms as identified by several authors and how the several mechanisms overlap (Table 22).

Table 22: Related coordination mechanisms as identified by various authors.

	Thompson (1967)	***van de Ven et al. (1976)***	***Galbraith (1974)***	***Mintzberg (1983)***
Coordination mechanism	Mutual adjustment	Individual mutual adjustment Group mutual adjustment	–	Simple mutual Adjustment Complex mutual adjustment
	–	–	Hierarchy of authority	Direct supervision
	Coordination by plan	Coordination by plan	Goal setting	Standardisation of outputs
	Standardisation	Standardisation	Rules, programs, procedures	Standardisation of process
	–	–	–	Standardisation of skills

Despite the strong influence of interdependency on project complexity, which is considered a significant obstacle for increasing construction performance, only limited coordination between construction firms is performed (Bankvall et al., 2010; Bemelmans et al., 2012). The main reasons for the limited application of coordination are considered the temporary character of the project network and fragmentation (Briscoe & Dainty, 2005). Conceivably, improved application of coordination will improve the performance of construction practices (Arshinder, Kanda, & Deshmukh, 2008).

The dynamic of power and interest in construction supply chains

Revisiting the concept of interdependency reveals that conflicting interests between collaborative parties in the construction supply chain derive from contrasting value creating logics. Construction firms throughout the supply chain apply different logics to create value. However, when multiple value creating logics coexist tensions are generated (Bygballe & Jahre, 2009). These tensions derive from the contrasting cost and value drivers, which belong to the particular type of activities and interdependencies involved with a value creating logic. More concisely, the organisational structure and corresponding objectives of a party are determined by the adopted logic of value creation and therefore contrasting logics would clash. Ultimately, the applied logic is decided based on the specific role of a firm within the construction project. Nevertheless, construction firms generally adopt different roles between projects and also cooperate with firms that apply different value creating logics. Therefore, competing logics coexist within the construction industry, which has to be handled both within and across cooperating firms (Dubois & Gadde, 2000; Håkansson & Jahre, 2005; Kadefors, 1995). Primarily in project arrangements, multiple value creating logics, and therefore organisational structures, collide where supply chain and project site meet. Mostly, construction firms are differentiated based on whether they are organised by project or manufacturing (Dorée & Holmen, 2004). Therefore, especially contractors and suppliers rely on competing logics, which are associated with the particular interests of the specific groups (Kadefors, 1995). Contractors often adopt a project management perspective, while suppliers usually adopt a supply chain management perspective (Bygballe & Jahre, 2009). In order to handle the tensions between them, Bygballe and Jahre (2009) conclude that more consideration is required for handling of interdependencies involved in the construction process. It is suggested that the complexity of coordination increases when multiple logics exist simultaneously.

Because of the conflicts deriving from different interests in regard to demand and supply, construction supply chains have not been able to move away from its fragmented and highly adversarial nature. In combination with the peculiarities of the industry, identified in the background study (App. I), this has developed in the emanation of complex structures of power between interdependent elements, such as materials, labour, equipment and professional services (Cox & Ireland, 2002). To settle interest differences, many authors advocate the implementation of supply chain integration strategies and partnerships (Bresnen & Marshall, 2000; Briscoe et al., 2001; Dainty, Millett, et al., 2001; Love et al., 2004). However, narrowing the focus on close collaborative partnerships and considering integrated supply chains as the single solution, is considered dangerous and demonstrates narrowmindedness (Briscoe & Dainty, 2005; Cox & Thompson, 1997). Correspondingly, Cox and Ireland (2002) argue that this myopia makes clear that construction companies do not understand what constitutes effective supply chain management and how improved performance might be achieved. They consider the concept of power a key factor in establishing business relationships.

More concrete, considering vertical relational exchanges between buyers and suppliers, Cox (2007) identifies a number of power resources to enable actors to fulfil their particular interests. He distinguishes particular circumstances wherefrom either buyers or suppliers gain power and leverage. The circumstances are presented in the following table (Table 23).

Table 23: Power resources from which buyer and supplier power derive (Cox, 2007).

Buyer power	***Supplier power***
Monopsony and oligopsony	Superior endowments of capital
Low buyer switching costs	Low supplier switching costs
Regular market contestation	Tangible and intangible assets
Buying consortia	Distinctive capabilities

Appropriate governance structure to eradicate opportunism	Intellectual property
No information asymmetry	High information asymmetry

Based on the identified power attributes, several power regimes are identified and constituted into a power matrix (Cox et al., 2000). The matrix is depicted in the figure below (Figure 56). In the buyer dominance box, the buyer has power relative to the supplier, which allows them to leverage the supplier's performance on quality and/or cost improvement to ensure the client only receives normal returns. The interdependence box entails relationships wherein both parties possess equal power resources which requires them to work closely together because neither can force the other to take particular actions. This situation causes supplier to potentially achieve above normal returns but must also convey value to the buyer as well as some degree of innovation. Thirdly, the independence box represents a situation when neither of the involved parties has significant leverage opportunity. Therefore, both have to accept existing price and quality levels. Due to little supplier leverage opportunities, they might be forced to operate at normal returns. Lastly, in the supplier dominance box only the supplier is able to leverage the buyer. In this case the supplier retains many isolating mechanisms to close-off markets to competitors to sustain high returns. In this case the buyer is considered both a price and quality receiver (Cox, 2001). Comparable to the power matrix introduced by Cox et al. (2000), Cox and Thompson (1997) already indicated similar relationships between buyers and suppliers based on mutual dependence. Also, Bensaou (1999) classified comparable buyer-supplier relationships by assessing their specific investments towards each other. Although, as an additional note, Cox et al. (2002; 2000) have widely discussed power attributes in buyer-supplier relationships, they have not provided managers with the tools to analyse who has power in a relationship and why (Chicksand, 2015).

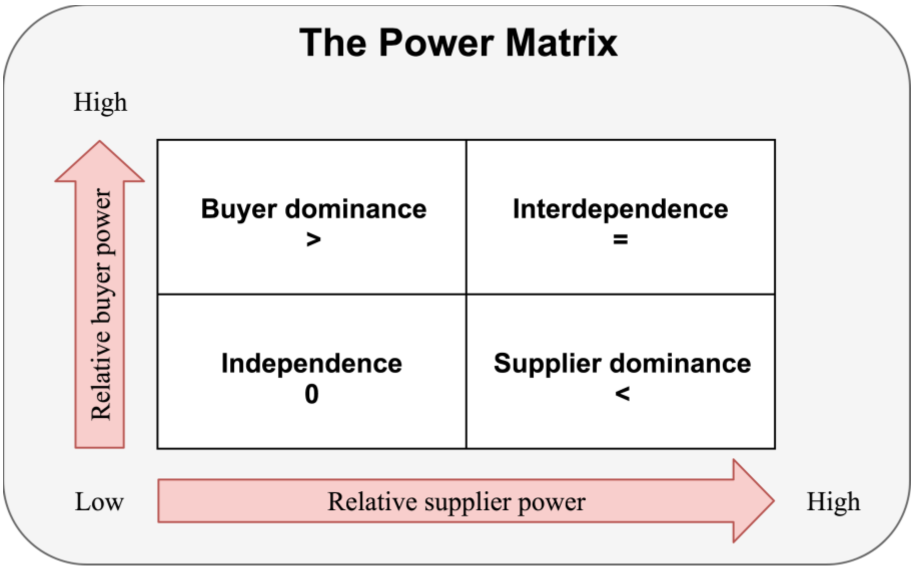

Figure 56: Power matrix used to classify relative buyer-/supplier power. Adapted from Cox et al. (2000).

Based on the previous paragraphs considering interest and power relationships between buyers and suppliers, particular decisions can be made on how to conduct relational exchange. Firstly, the strict distinction between adversarial and collaborative relationships is considered a false dichotomy. Instead, the relationship choice for both sides is between how much conflict over value appropriation is generated and how close both parties are required to work together to achieve their individual objectives (Cox & Ireland, 2002). Therefore, Cox and Thompson (1997) suggest relationships that are 'fit for purpose' based on a continuum, which is strategically aligned to the competencies of the firm and their degrees of asset specificity. To manage all these relationships a portfolio approach is suggested. Specific portfolio approaches are established by for example Kraljic (1983), Bensaou (1999) and Bildsten (2014), which can help designing relationships between buyers and suppliers through effective procurement. The purpose of these relationship management choices is to optimise the effectivity of collaborative relationships and improve on-site construction performance.

Uncertainty as constituent of construction complexity

Besides interdependency between parties, construction complexity also derives from uncertainty (Gidado, 1996). Complexity can be considered the result of breaking down large tasks into smaller subtasks and assigning them to various interrelated units (McCann & Galbraith, 1981). The concept of complexity as contingency factor extends and combines both interdependence, uncertainty and work unit size (Dubois & Gadde, 2002; Gidado, 1996; McCann & Galbraith, 1981). Nevertheless, considering that complexity refers to the number of interconnected elements and the number of different types of relationships among these connections, task complexity always includes interdependency, but not necessarily uncertainty. Tasks can be complex even when all the required information is available (Galbraith, 1973). Consequently, Galbraith (1973) defines uncertainty as: "… the difference between the amount of information required to perform the task and the amount of information already possessed by the organisation" (p. 5). However, when organisations are confronted with unplanned events, like for example weather influences or other unexpected occurrences, too frequently, they are not able to perform tasks as they should (Galbraith, 1974). Hence, uncertainty induces the occurrence of incidents within construction projects. In anticipation of uncertainties, organisations are able to make design choices to diminish uncertainty and enhance coping mechanisms. For this purpose, Galbraith (1974) designed several strategies for organisations comprising the reduction of information processing need and the improvement of information processing capabilities.

In line with these views, Bensaou and Venkatraman (1996) consider matching information processing needs and capabilities as framework for inter-organisational coordination. Using this perspective, they identify three different generic sources of uncertainty. These different sources are considered:

– ***Environmental uncertainty***: Concerning the general market conditions surrounding the relationship.
– ***Partnership uncertainty***: In regard to the central actor's perception of how a partner will behave in the future.
– ***Task uncertainty***: Relating to the distinct task parties jointly perform.

From a different perspective, Gidado (1996) differentiates other divisions of uncertainty inherent to construction complexity. These factors of uncertainty mainly relate to managerial complexity required to perform construction activities. The factors of uncertainty originate from within the task, environment and the employed resources, such as manpower, materials, plant and machinery and information. Sub-classification establishes the following categories:

– ***Lack of complete activity specification***: Construction activities are uncertain because not everything detail is predesigned and planned in advance.
– ***Unfamiliarity of the inputs and/or environment by management***: Activities are site-specific and therefore management is not always familiar with what is required and how plans turn out.
– ***Lack of uniformity of work***: This category entails the uniqueness of every project in terms of materials, work and teams with regard to place and time.
– ***Unpredictability of the environment***: For example, the effect of the weather is considered in this category and other events which cannot be anticipated.

The exchange of information between construction participants

For the coordination of interdependencies, information exchange between and within firms is required (Arshinder et al., 2008; McAfee, 2002). During construction projects, extensive amounts of information are produced alongside the physical processes of construction (Adriaanse, 2014). The build-up of information commences when the client initiates a project and the body of information expands during the subsequent phases of the construction process. For parties to be able to collaborate, it is vital to communicate information, which is complete and accessible (Adriaanse, 2014; Bemelmans et al., 2012). Therefore, parties use inter-organisational systems (IOS) in order to support communicative activities. An IOS is an information and communication technology-based system, which transcends the boundaries of a legal enterprise (Bakos, 1991; Chismar & Meier, 1992; Kumar & van Dissel, 1996). The functionality of an IOS can vary from information exchange required to perform operational processes or to introduce strategic initiatives (Saeed, Malhotra, & Grover, 2011).

In regard to the interdependencies and coordination mechanisms introduced by Thompson (1967), several IOS types are distinguished (Kumar & van Dissel, 1996). The IOS types match the coordination typology and therefore should support proper information exchange within the construction supply chain. Therefore, these three IOS types are discussed below:

- ***Pooled information IOS***: This type of information system supports information exchange between organisations by use of common databases, communication networks and applications. Standardised and common IT resources are applied, which require low investments to implement. Consequently, a low amount of risk is involved with implementation.
- ***Value/supply chain IOS***: Comprises systems that support buyer-supplier relationships and are applied to support information exchange throughout the supply chain in support of sequential interdependencies. Examples are order-intake and processing systems and CAD-to-CAD IOS (Hong, 2002).
- ***Networked IOS***: Supports the coordination of reciprocal interdependencies between parties. It mostly concerns joint-ventures or programs between multiple partners. Each party can contribute and receive information throughout the applied system. Systems can be used within temporary project relations, but also ongoing partnership arrangements.

Although communication in construction is considered to be imperative, considerable issues are experienced. Especially extensive problems concerning communication and ineffective use of ICT, are affecting the construction industry (Adriaanse & Voordijk, 2005). Principally, the temporary project arrangements are considered the primary cause of the identified deficiencies. Each firm has a particular language and approach in order to perform their specific tasks. Additionally, they have distinctive procedures, resources and objectives. To achieve effective coordination and communication these features have to be aligned. Therefore, collaboration over longer periods of time is required to induce incremental adjustments between multiple parties. Furthermore, investments in ICT applications to support IOS are limited, do not fulfil the initial expectations and provide inadequate value. Use of ICT across project boundaries would enhance these drawbacks (Adriaanse et al., 2010; Viljamaa & Peltomaa, 2014). Ultimately, the process of digitalisation provides significant opportunities for supply chain coordination and information exchange throughout all project phases. By enhancing ICT to allow for better use, exchange and processing of information, it would become easier to respond to changes in the construction process, because information is disclosed fast, simple, accessible and accurate (Tserng & Lin, 2002; Xue, Wang, Shen, & Yu, 2007).