Enabling effective project-team communication in the design phase of a BIM-enabled construction project

USING ACTIVITY THEORY TO EXPLORE PROJECT TEAM COMMUNICATION PRACTICES IN THE DESIGN PHASE OF A BIM-ENABLED CONSTRUCTION PROJECT

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Enhancing Society Together

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Acknowledgments

Before you lies my graduation thesis, the final step in completing the master Construction Management and Engineering at the Delft University of Technology. In the past six months I have been studying communication practices in project teams in light of the digitalization of the industry. I have had the privilege of being able to do my graduation research at Royal HaskoningDHV. Defining the topic of this thesis was my first challenge. When I first started brainstorming on a topic, a varied list of topics came to mind which was slowly narrowed down to the relationship with BIM and communication. Although the analysis method was not one that I was familiar with, I was glad to take on the challenge. The journey towards this final thesis report has been challenging at times, but more importantly very educational.

I have come to the understanding that interpersonal communication is at the heart of any project, in the construction industry or beyond, and cannot be easily replaced digital solutions. It is important to ensure that the technological developments are fitting in the current ways of working, while simultaneously challenging the ways of working. I will take these insights with me in my future endeavors as an engineer.

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Executive summary

Productivity in the Architecture, Engineering, and Construction (AEC) industry is lacking. Projects in the industry have become larger and complex, leading to increasing amounts of information involved in the life cycle of a project. The low productivity of the construction industry over the previous decades has been linked to a 'lack of communication and collaboration through information sharing' (Boktor et al., 2014). In response, the industry has been searching for ways to systematize information sharing in a project. Information management systems have a promising value added to this issue. Consequently, Building Information Modelling (BIM) has been widely embraced by the AEC industry as the answer to the difficulties in the industry.

However, the implementation of BIM has not gone as smoothly as hoped. Extensive research has been done towards the barriers to BIM implementation and has resulted in the identification of three main categories of barriers: people, process, and technology. However, these results fail to acknowledge BIM is not the only method for communication in a project. The AEC industry is a knowledge-based industry, that heavily relies on the experience of the people and their ability to collaborate with one another. As such, this research considers a communication processes adept to the exchange of tacit knowledge, messy talk. Messy talk is a relatively new concept, thereby providing many angles for research. This research will focus on the relationship between BIM and messy talk. The main question is this research reads:

How can an organization enable effective project team context communication practices in BIM-enabled construction projects?

The research is made up of three phases and was conducted using qualitative methods. The first phase consisted of creating a comprehensive understanding of the two concepts of this research, use of BIM in BIM-enabled construction projects and messy talk. A literature review was conducted, leading to the development of a conceptual framework. This framework describes the theoretical relationship between BIM and messy talk, thus representing the research proposition.

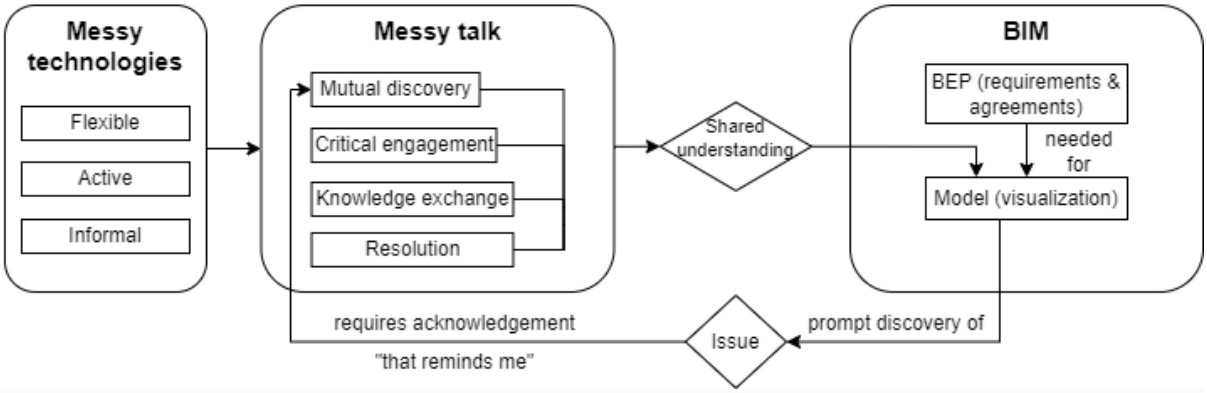

Figure 1 Conceptual framework

The second phase of the research was focused on testing this research proposition based on empirical data, collected through interviews and a case study. The empirical analysis was done using activity theory. Activity theory is a descriptive theory, well-suited to mapping so-called activity systems. The results from this analysis show that there are two scenarios in which messy talk occurs, characterized by the difference in the relationship of BIM and messy talk. The two scenarios, labelled as "problem identification" and "solution ideation", can be linked to different aspects of the problem-solving cycle. The research proposition, identified in the previous research phase, is updated with the results from the second phase. In this conceptual framework, the blue

cycle represents the scenario problem identification, whereas the orange cycle represents the scenario solution ideation.

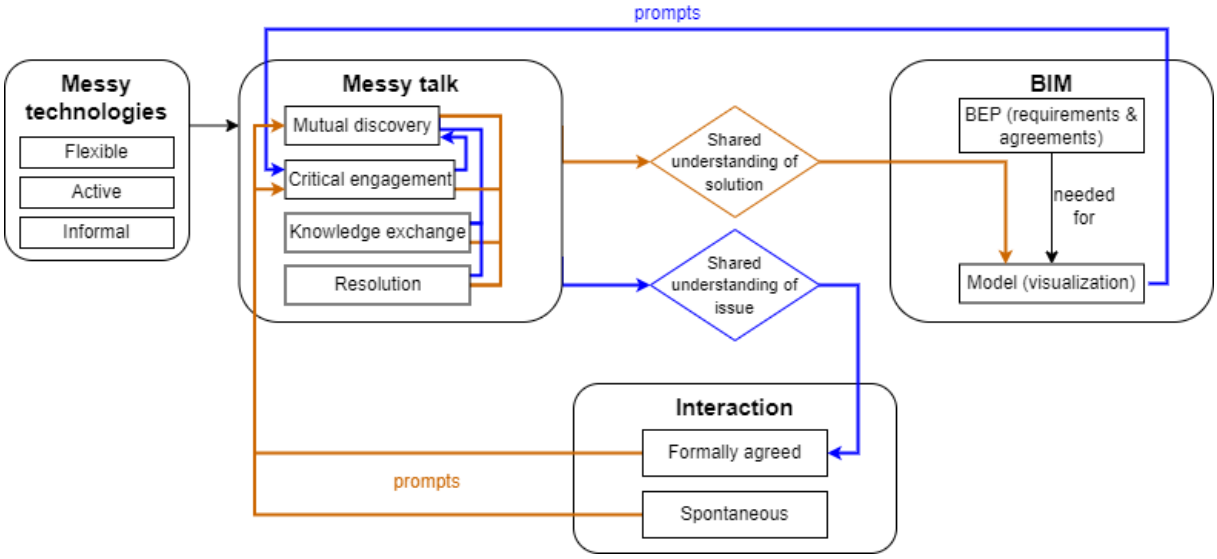

Figure 2 Relationship between BIM and messy talk

Finally, the research is concluded in the third phase, where a strategy for enabling effective communication in a BIM-enabled construction is designed using the results from the empirical research. Based on the tensions and coping mechanisms identified in the activity systems, management interventions have been designed with the purpose of enabling messy talk, BIM, or both of these processes. The two scenarios can be placed in the larger design phase, thereby offering insights as to which management intervention should be employed when.

The research has led to a more extensive understanding of the communicative potential of BIM and messy talk, and how this might be enabled. However, there is still much to be uncovered on this topic. As such, several recommendations for avenues for further research and applying the results to practical situation are done. Based on the results of this research, two main avenues for further research have been identified. These are messy talk and the enabling strategy. The most important possibilities will be further discussed below.

Further research could be focused on deepening the understanding of other elements with a probable influence on messy talk. Such elements could be project team culture, being either national, organizational, or otherwise or the diversity in the disciplines involved in the interaction. This could be extended by considering the role of the contract in the division of labor. Furthermore, it could be interesting what the hierarchical and seniority levels mean for the occurrence of messy talk. Lastly, there is also need for research towards team members willingness, ability, or both to engage in messy talk and their personality.

As this research has focused on the relationship between BIM and messy talk, other prompts of messy talk have not been considered thoroughly. This could be an interesting topic for further exploratory research. Additionally, more research is necessary on the influence of BIM and messy talk in other phases of a BIM-enabled construction project. This research shows that the level of information available in a specific step of the design phase can be linked to the messy talk prompt. As the level of information increases as a project progresses, it is worth researching if the relationship between BIM and messy talk transforms as well.

This research provides strong indications that communication practices differ between disciplines. Problem solving is different depending on if it is an inter-disciplinary or intra-

disciplinary dialogue or meeting. The occurrence of messy talk in these interactions can be argued two ways: intra-disciplinary interactions allow for a deeper level of knowledge exchange whereas inter-disciplinary interactions could potentially lead to more mutual discovery because of 'innocent questions' from team members who are not as specialized in a certain discipline but who do have enough general knowledge relating to the project (and related projects) that they do understand the general tendence.

Based on the results of this research, three main recommendations for practice can be done. First of all, on the project level, it is recommended to establish the effectiveness of the management interventions in practice through trial-and-error. While a specific management intervention might generate positive results for one project team, it might be less beneficial to another. The proposed enabling strategy has been designed in such a way to aid managers and leaders in making an education assumption as to which management intervention might generate the desirable results depending on the characteristics of the situation.

Furthermore, enabling effective communication is a continuous process. It is therefore recommended to employ the enabling strategy in the early stages of the design process and adapt as the project progresses. Doing so will avoid sudden changes to the way team members are encouraged to work and thereby hopefully limit resistance. Furthermore, this will give the manager or leader a better feel for what works for the team, thereby supporting the recommendation above.

Finally, on an organizational level, it is recommended to encourage the use of the enabling strategy through setting an example. This is in line with the bottom-up approach incorporated in the enabling strategy. As such, it is recommended to start on a small scale, with projects with willing and accepting managers or leaders, and encourage others to employ the enabling strategy by proving its value added. Taking on this approach will avoid coercion and top-down pressure.

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Abbreviations

AEC	Architecture, Engineering and Construction
ASM	Activity System Model
AT	Activity Theory
BECP	BIM-Enabled Construction Project
BIM	Building Information Modelling
CDE	Common Data Environment
CE	Critical engagement
HCI	Human-computer interaction
IM	Information Management
IMS	Information Management System
IPD	Integrated Project Delivery
ISO19650	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling
KE	Knowledge exchange
M&I	Mobility and Infrastructure
MD	Mutual discovery
MT	Messy talk
O&M	Operations and Maintenance
OKA	Ondergrondse kruising Albertkanaal
PPT	People, Process, Technology
R	Resolution
RHDHV	Royal HaskoningDHV
VDC	Virtual Design and Construction

1 Introduction

This chapter introduces the cause for this research. First, section 1.1 provides background information on the topic of this research. Following this, section 1.2 introduces the main problem that will be researched and section 1.3 states the research objectives. Next, the main and sub research questions that will be answered in this researched are formulated in section 1.4. Finally, the relevance of the research, in terms of scientific relevance as well as societal relevance, are discussed in section 1.5.

1.1 Background

"For nearly the entire population of the world, the built environment heavily influences quality of life" (Rodrigues De Almeida et al., 2016). Every single day, humans come into contact with the Architecture, Engineering and Construction (AEC) industry in one way or another. The houses we live in, the transport networks we use, the offices or institutional buildings we work and learn in, and the commercial and recreational buildings and areas we spend our free time in, these are all products of the AEC industry. The economic impact of the AEC industry is immense: it accounts for roughly six percent of global GDP (Rodrigues De Almeida et al., 2016). In the Netherlands, the AEC industry accounts for roughly 10% of GDP. Its construction output is worth EUR 82 billion (Bouwend Nederland, n.d.). With AEC products being such a considerable part of our lives, it stands to reason that the industry has a notable impact on the environment. As the largest global consumer of raw materials and resources, the industry consumes around 50% of global steel production and three billion tons of raw materials every year (Rodrigues De Almeida et al., 2016). In short, the AEC industry has a significant impact on our lives and way of living.

However, the AEC industry is falling behind in productivity (Green, 2016) and projects often go over budget and take longer than initially planned (Koppenjan et al., 2011). The McGraw Hill SmartMarket report attributes the low productivity of the construction industry over previous decades to the 'lack of communication and collaboration through information sharing' (Boktor et al., 2014). Projects are becoming larger and more complex (Luo et al., 2017). Consequently, substantial amounts of information are required and created in these projects. The AEC industry is highly fragmented (McKinsey & Company, 2022): numerous companies are involved in single projects. At the same time, every project is considered to be unique. The complexity of projects has been recognized as one of the main characteristics of the industry interfering with project success. Project failure has been linked to the increasing complexity of projects as well as the underestimation of complexity (Bosch-Rekveldt et al., 2011).

In order to deal with the lack of productivity and increasing complexity of projects, it is becoming more common to consider in which ways projects are not unique and systematize the processes involved in the life cycle of a project. The increasing amounts of information combined with the fragmented nature of the industry introduced the need for information management (IM) (Koutamanis, 2022). IM involves collecting, storing, distributing, archiving, and deleting or destroying this information (Hicks, 2007). Its main goal is to manage the information flow such that that the right people have the right information at the right time, enabling them to make the right decisions (Mithas et al., 2011; Koutamanis, 2022). The motivation for IM was that structuring the information would make it easier to find, thus simplifying communication. IM introduced clean technologies, which are digital solutions for storing, sharing, and exchanging data. In other words, clean technologies are capable of communicating explicit knowledge.

BIM has been introduced as a solution to the information management challenges in the AEC industry. It is said to have the ability to create a collaborative design process stimulating the involved parties to improve communication throughout the project life cycle (Wang et al., 2022). The building industry has used digital information management for some time. In the construction

and infrastructure industry, the uptake of digital information management has been slower but has taken off in recent years, especially after public clients introduced BIM as a means of changing the working practices of actors in the industry (Vass and Gustavsson, 2017). Researchers started out researching what the implementation of BIM could offer the AEC industry as a whole, as well as specific actors, such as contractors, designers, and engineers. This attention has caused the uptake of BIM technology and processes to surge. However past research is prone to presenting the positive features of technology adoption "in isolation of the implementation process" (Dowsett and Harty, 2018).

The design process of an AEC project is highly dependent on knowledge exchange and information sharing, meaning that the outcome of the designs are dependent on project teams being able to effectively communicate with one another. Besides explicit knowledge for understanding the "what", tacit knowledge is needed for understanding the "why" of an issue. Both these types of knowledge are needed for generating ideas. Tacit knowledge cannot be codified in the same way that explicit knowledge can, meaning that it cannot be managed with the same clean technologies that explicit knowledge is. The exchange of tacit knowledge has been identified to be a messier communicative process. BIM is broadly used in the AEC industry for exchanging explicit knowledge. BIM has been the industry answer to issues due to accessibility and availability of information in the AEC industry. Better collaboration is often cited as one of the main reasons to work with BIM (Dossick & Neff, 2011).

The implementation of a new information system has been studied from multiple angles. Issues that result from the implementation of a new information system are not uncommon. Research from both the AEC industry as well as in other industries have found a multitude of issues that can be linked to the introduction of a new information system. Much research has been focused on identifying barriers and enablers of implementation of BIM. This research is built on the assumption that productivity issues stems from the lack of structure in the substantial amounts of information (Nesan, 2012). This neglects the need for the exchange of tacit knowledge in project teams. Rather than focusing solely on the issues following the implementation of a new information system, it is worthwhile to study the implementation in a broader context to create an understanding of the consequences of implementation on knowledge sharing. As such, it is important to consider which types of knowledge sharing are required in the project.

1.2 Knowledge gap

Studies focusing on the actual use of BIM are often geared towards the maturity of BIM implementation and less so towards on the transformation of the work environment as a consequence of BIM implementation. BIM implementation is regarded to be more than a change of the software packages or processes used. Rather, it can be seen as an ongoing transformation of business processes and practices (Abbasnejad et al., 2020). Kahn and Bokhari (2018) argue, based on past research, that the socio-technical aspects of a transformation are important. These aspects are commonly defined along the lines of the process-people-technology framework (PPT framework), in which the process, people (also referred to as culture or organization) and technology (also referred to as tools) are used as a basis to analyze a transformation, be it a societal transformation, an organizational transformation or otherwise. The implementation and use of BIM, in light of the digital transformation, is regarded as an organizational change. People are at the heart of change, as underpinned by Lauer (2020): "The implementation of change is not a purely mechanical process, but requires the active support of employees and thus of people who have their own needs, ideas, experiences, emotions, characters, etc. and who are also embedded in social structures that are not only defined by the formal, official company organization, but have often grown informally, quasi 'wildly'". Implementation of new technologies are done in existing work practices and therefore need to be considered in the environment they are introduced in to

(Harty and Whyte, 2010). Technological change or people related change in isolation can lead the transformation to fail (Nightingale and Srinivasan, 2011). Thus, better understanding the effects of the BIM-induced change can lead to insights that will help in the transformation.

Implementing and adopting of BIM consists of several phases. As each subsequent phase is reached the promises of BIM will supposedly become more apparent to the project team and present in the construction project. The barriers and challenges related to implementation can be regarded as criteria for reaching the next level in BIM maturity. This implies that if the criteria are met, the next level of BIM is achieved (Siebelink et al., 2020). As the implementation and use of BIM is an ongoing process, BIM maturity models have been created to determine how far an organization is in the implementation and acceptance of BIM. These models are often descriptive: they describe previous trends, rather than prescribing recommendations. In other words, BIM maturity models are often based on what happens in the industry rather than scientific research is used for industry decisions.

Impact in terms of technology and process has been broadly covered in research considering the interoperability of BIM processes and software with existing processes and software. In the field of BIM implementation research, technology related barriers and challenges, such as interoperability, have received notable attention (Oaree et al., 2017). Exploratory research has identified the barriers in BIM technology and further research has offered multiple solutions to these barriers. Common categories of issues are technical issues, such as difficulties with the interoperability of current and new systems, and people related issue, including willingness to change, ability to use the new IS. While technology related challenges in BIM implementation remain, the area can be deemed to be well covered by past research and current efforts. As technology factors are being tackled, attention has shifted to the challenges and barriers related to organizational aspects. As much as the technology has advanced, this means little if the organization does not advance alongside. Winfield (2020) observes: "The industry has, primarily, managed to create digital drawing boards rather than rethinking its way of working in a completely new digital way". The largest gaps in the body of knowledge related to implementation and use of BIM in construction projects have been found in people and process focused issues. In research by Oaree et al. (2017a), the gaps in the body of knowledge on collaboration on BIM-enabled construction projects have been identified to be in the areas of individuals, teams, and tasks. Liu et al. (2017), who stress the organizational challenges faced in BIM-enabled projects, share this verdict. The success of BIM implementation depends on more than the technical issues (Tong and Phung, 2021). Where the technology is commonly presented as the solution, organizational challenges are limiting collaboration. Recently, the socio-organizational BIM transformation barriers have been receiving more attention in research, but there is more to do. People-related challenges have not yet been as thoroughly researched as technology-related barriers. Although exploratory research has identified specific barriers and challenges in the people-domain, research towards the impact of the transformation is lacking.

The so-called productivity paradox, coined by Robert Solow in 1987, describes the paradoxical relationship between investment in information technology and gains in productivity. However, results from most industries have shown an improvement which can be strongly linked to investments in IT enabling collaboration between organizations (Fulford and Standing, 2014). Project teams within large organizations often have a temporary nature and are made up of members from different groups within the organization. This leads one to wonder, can the same be said for communication within organizations? Effective communication has been identified as an important factor in reaching the project requirements and delivering a successful project and, by extension, improve the productivity in the AEC industry (Gamil and Rahman, 2018). BIM has led to a reconfiguration of the collaborative environments of a project (Poirier et al., 2017). The

influence of BIM on collaboration and collaborative environments has been broadly covered by previous research (Chen et al., 2022). However, communication practices in these BIM-induced collaborative environments remain to be understood. This research will focus on communication practices for problem-solving in a BIM-enabled construction project. Problem-solving requires both explicit and tacit knowledge. Whereas BIM is adept at enabling explicit knowledge sharing, it is less suitable for sharing tacit knowledge. Messy talk has been identified as a process well-suited to sharing tacit knowledge (Dossick and Neff, 2011). The concept of messy talk has not yet been broadly researched. Efforts so far have focused on defining the concept and operationalizing the definition, based on case studies in virtual teams (Dossick and Neff, 2011; Dossick et al., 2015). However, there is much more to be uncovered regarding the appearance of messy talk in BIM-enabled construction project. This research aims to better understand the roles of BIM and messy talk in intra-organizational problem-solving communication.

Research to date has been exploratory or descriptive (Fürstenberg, 2020); it is mostly conceptual with a small portion of empirical theory. Different methods have been used to analyze BIM implementation, resulting in similar categories of barriers and challenges thus implying that the results are robust. Even so, BIM implementation is not reaching the full promised potential implying that something is missing from these analyses. The barriers and challenges are identified in cases where BIM has been implemented and BIM is at a certain maturity level within the organization. Due to the complex, socio-technical nature that is at the heart of the issue, it is worth analyzing the problem using a human-system interaction theory, such as Activity Theory. Post-implementation issues can be found on different levels. These levels of issues have been defined as:

- Micro level: issues related to the individual user level, such as technology acceptance and communication failures
- Meso level: issues related to the organizational level, such as organization-wide communication policy
- Macro level: issues related to the governance, such as national health standards

The main area of interest in this research is issues found on the micro level, however the use of activity theory will allow for consideration of influences from the meso and macro level as well. Activity Theory is commonly used to analyze information systems in other areas of research (Weeger et al., 2021). Previous research has shown the added value of applying Activity Theory as a method for analyzing BIM implementation (Lu et al., 2018) and the impact of implementation of work practices (Akintola et al., 2020). Using Activity Theory for analysis offers insights in contradictions between aspects of the activity, such as the subject and the tools, and creates an understanding of the interventions done to mitigate these contradictions and how these take shape in practice. As such, using Activity Theory allows to analyze BIM implementation as a continual change process rather than a static act. These insights could be used as a basis for further research on the socio-organizational barriers of the BIM transformation (Siebelink et al., 2020).

1.3 Research objective

The main objectives of this research project are threefold.

The first objective is to create a foundation for the rest of the research by exploring and defining BIM and messy talk. This will be done by means of desk research. Understanding the background of BIM and messy talk will be used to create framework describing the current understanding of how these two concepts are related.

The second objective is to explore the barriers and enablers of project team communication in a BIM-enabled construction project. This will be done semi-structured interviews and a case study, which will be modelled and analyzed using activity theory. This will offer insights in contradictions and interventions in the process, which can be used in reaching the final objective.

The final objective is to create an enabling strategy for effective communication in a BIM-enabled construction project. The aforementioned objectives, resulting in insights from both previous research and own analysis, will be used to form a strategy for that will support a project team in reaching the intended goals of communicative practices in collaboration.

The objectives of the scientific research are made specific and concrete in the following deliverables:

- An exploration of the current body of knowledge on communication practices for knowledge sharing;
- An exploration of the theoretical communicative potential of a BIM-enabled construction project;
- An analysis of the actual communicative practices in a BIM-enabled construction project from a socio-technical perspective, resulting in an overview of current practices and challenges;
- An exploration of possible management approaches to enabled effective communication in a BIM-enabled construction project using a human-technology interaction analysis;
- A feasible strategy to enable effective communication practices in a BIM-enabled construction project.

1.4 Research question

This section will define the main research question and elaborate on how the main research question will be answered. First, the sub questions that will aid in the answering of the main research question will be presented. This research will consider the socio-technical aspect of the digital transformation in social work setting. The goal of the research is to enable a project team's ability to engage in effective communication in a BIM-enabled construction project, so knowing when and how to communicate.

The main research question reads: *How can an organization enable effective project team context communication practices in BIM-enabled construction projects?*

The main research question will be answered using the following four sub-questions:

1) What are the constituent elements of project team context communicative practices?
2) What is the communicative potential in a BIM-enabled construction project?
3) How has messy talk developed as a result of working in a BIM-enabled construction project?
4) Which management interventions can be identified to enable effective communication in the project team context in a BIM-enabled construction project?

1.5 Research relevance

This section discusses the relevance of the research on a scientific and practical level. This research aims to deepen the scientific understanding of communicative practices in BIM-enabled construction projects (BECP) and offer the AEC industry guidance for applying this knowledge in practice.

1.5.1 Scientific relevance

Research on the impact of BIM implementation in terms of communication so far has focused on the inter-organizational impact. This research offers a theoretical and data-driven approach for

enabling intra-organizational project team communication within a BIM-enabled construction project.

In recent research, the impact of BIM on communication in inter-organizational collaboration has seen some attention (Liao and Teo, 2018). However, the impact on communication practices in intra-organizational project team remains underexposed. Attentions in previous research of BIM and communication have been focused on the benefits of BIM in terms of the improvement of information flow, in other words the role of BIM in terms of communicating explicit knowledge. However, research on the role of BIM in terms of communicating tacit knowledge is sparse. This is logical, as BIM concerns the communication of explicit knowledge. However, as with all forms of transformation, it is expected there is an influence outside of its direct scope. This research aims to further extend the knowledge on the development of communicative practices as a result of the implementation of BIM. Previous research has focused on the characteristics of messy talk and how it differs from BIM. This research will add to this knowledge by further exploring the characteristics of messy talk in practical settings in the AEC industry.

1.5.2 Practical relevance

In the AEC industry, there is a lack of understanding on how BIM can be combined with current communication practices (Gu and London, 2010). This research partly consists of mapping the current status communication practices in the design phase of a project in terms of messy talk and BIM use, and how the system has evolved to reach this status. This poses the question to Royal HaskoningDHV (RHDHV) and the industry in general if the current communication practices, and the tools playing a role in these processes, are delivering a desired outcome. By further understanding the implications of BIM implementation on project team communication, managerial interventions with the purpose of enabling effective communication in a project team of a BECP can be identified.

The measures that flow from this research stem from the case study within RHDHV. However, this does not mean that the measures are RHDHV specific. Although the industry is well known for boasting the individuality of their project, in recent years it has become more accepted that parts of projects do have similarities and can learn from each other. Therefore, it is expected that the outcome of this research will be valuable to projects with similar characteristics, and therefore to the industry as a whole.

2 Research design

In this section, the design of this research will be elaborated on. First, the scope of the research will be defined along the lines of the approach and domain. Following this, the methods for data collection and analysis will be described. After this, the flow of the overall research design, which follows the hourglass logic – from general to detailed and back to a general level again, will be expressed visually.

2.1 Research scope

This research is performed in partial fulfillment of the requirements for the master's degree of Construction Management and Engineering at the Delft University of Technology. The study is conducted at Royal HaskoningDHV, a Dutch design and consultancy firm that focuses on the integration of engineering work with digital ways of working, in the department Mobility and Infrastructure. This will be used to the advantage of this research, as it provides the opportunity to take on an intra-organizational view. This research will be limited to studying communication practices within the project team of an organization involved in the design phase of large infrastructure projects. Due to the nature of the topic, this research will mostly use qualitative methods. The social aspects of this socio-technical issue are best captured in a qualitative manner. Both an empirical and desk research approach will be applied to this research. The theories in which further empirical research will be grounded are studied through desk research using previous research and literature. The empirical component of the research will take place in a later stage after which the results will be validated and verified. As the empirical data for this research is collected within a large infrastructure design project, the scope that the results are representative for are somewhat limited. The implications of this will be discussed in section 8.1.

By limiting the research domain geographically, the cultural aspect is slightly more of a 'background' feature. The same applies to limiting the research domain to one organization. Organizational and national culture do not need to be taken into account in the way it would when the focus would be on comparing the differences in ways of working between two or more organizations or countries.

The research approach is designed by positioning the research along the lines of three key decisions described by Verschuuren et al. (2010). These decisions will help to determine which research methods will be used. The research will be done from the theoretical perspective of pragmatism and critical realism. A pragmatic worldview is not uncommon in this field. This theoretical perspective implies the use of mixed methods for data collection, meaning that data will be collected through a combination of qualitative methods (Fürstenberg, 2020). By taking on a critical realist view, the research will look beyond the theoretical and hypothetical promises of BIM and messy talk and dive into the practical application in an attempt to understand the value added of these two concepts. This research will attempt to deepen the body of knowledge on the topic of messy talk, while creating a broader understanding of the impact of BIM. The impact of BIM in terms of people related factors is often studied by taking on an interorganizational view. This research will take a step outside of this view, and take on an intra-organizational view, thereby broadening the body of knowledge on the change impact of BIM.

2.2 Research methodology

In this section, the research methods applied in this study and how they will contribute to answering the sub-research questions will be elaborated. An inductive approach will be applied to answer to main research question. The generic research methods identified by Verschuren et al. (2010) are: survey research, experiment, case studies, grounded theory approach, and desk research. The research methods used in this study are in line with the research approach detailed

in section 1.4. The research consists of three main sections: review of previous research, empirical research, and operationalization. The methodology for the research is summarized in figure 3.

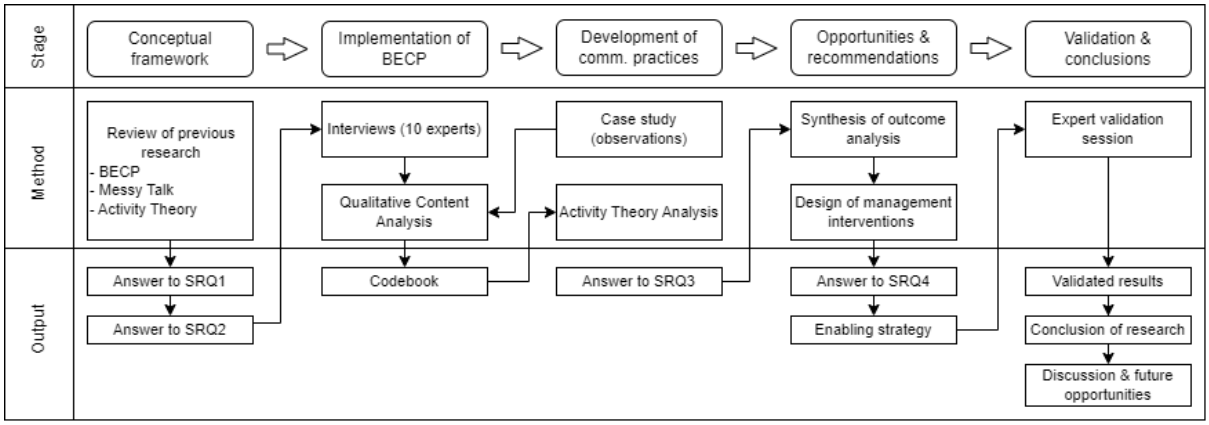

Figure 3 Research methodology

Exploration of the current body of knowledge (SRQ1 and SRQ2)

This first section will involve desk research in which current knowledge on BIM and messy talk will be explored. The desk research will use secondary data from previous research and international standards. This will form the basis for the rest of the research. The need for this is twofold. Firstly, BIM is a complex and diverse concept therefore a synthesis of current understanding of the topic will provide an in-depth overview of what the concept entails, concluding with the definition that will be used in this research. Secondly, an operational definition of messy talk is needed for empirical data collection and analysis. Finally, the definitions of the two concepts will be used to describe their communicative potential.

The following section will start by providing the theoretical foundation of the analysis. Researching and explaining Activity Theory will be done by means of desk research using secondary data. This data will be collected using previous research on Activity Theory that is found in academic sources, such as Google Scholar, Scopus, and Springer.

Empirical study (SRQ3)

There is a danger in defining a potential as it can create a rosy outlook on reality and set unrealistic expectations (Linderoth and Isaksson, 2016). Therefore, empirical data will be collected and analyzed to get a deeper understanding of the applicability of the potential to practical situations. Using the theoretical foundation of Activity Theory and the current knowledge on BIM implementation, an analysis will be carried out to identify the development of messy talk as a result of the implementation of BIM. An abductive strategy was applied to data collection. The data resulting from the first round of interviews was used as input for the following round of data collection.

First, exploratory interviews will be held to create an understanding of the implementation of BIM and the current status of communicative practices for collaboration. These interviews were held with BIM specialists, relevant project team members and management to gain insights into the activity system, the contradictions that occur therein and the interventions introduced as an attempted solution to these contradictions. The exploratory interviews were semi-structured, thereby offering a level of structure that helps in comparison, but also allows for flexibility and personal input by the interviewee. The in-depth requirements of an interviewee and the extended interview protocol can be found in appendix A. The interviews were held over a period of three weeks. In total 10 semi-structured interviews were held. The division of the hierarchical position of the interviewees and division of years of work experience can be seen in, respectively, figure 4

and 5. A more in-depth breakdown of the characteristics of the interviewees can be found in appendix A.

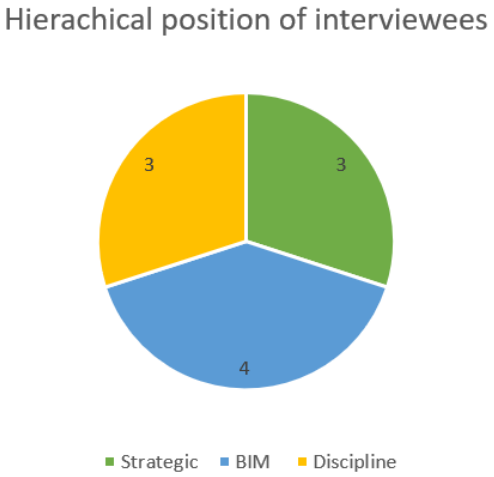

Figure 4 Hierarchical position of interviewees

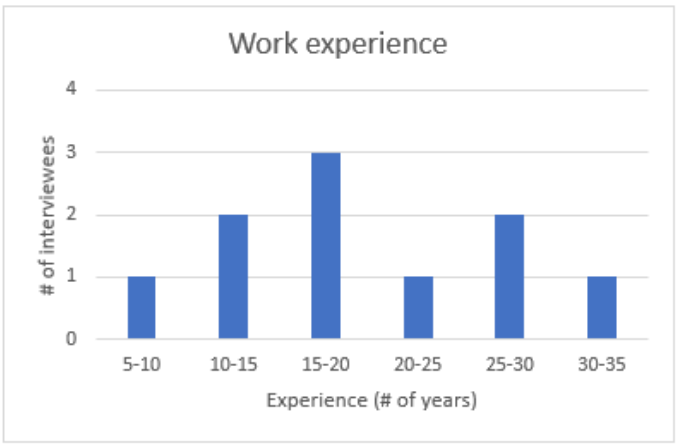

Figure 5 Experience of interviewees

After this initial interview phase, a case study at Royal HaskoningDHV was selected. The project selected for the case study is OKA (Ondergrondse kruising Albertkanaal). OKA, which is part of the Oosterweelverbinding, is a large infrastructure project in which tunnels will be replacing the current viaduct crossing the Albert channel in Antwerp. This large project is so-called full BIM, which provides plenty of opportunity for observation of messy talk situations and numerous candidates for short follow-ups who will have had experiences on other BIM projects as well low BIM projects. The case study requirements and a more in-depth description of the project can be found in chapter 5.

Interactions of project team members in this case study will be observed. Due to the time constraints of the research, observation will be limited to team meetings and in-person interactions, and thus exclude discipline meetings, interface meetings and hybrid or online interactions. When a relevant interaction has occurred, several questions will be asked to the respective parties. This is done to get a deeper understanding of the communicative practices and the effect of a BIM on these interactions. These interviews will be structured. The requirements of an interaction to be followed-up and the follow-up interview procedure are included in appendix B. The observation period had a duration of one month. The case study is used for the purpose of understanding the communication practice aspect. In total, four meetings were observed, after which four follow-up interviews were held.

In both rounds of interviews, the interview questions will be based on the insights gathered from a review of previous research. The interviews in both rounds will be held face-to-face, in as much as the circumstances allow for this. Face-to-face interviews allow for observation of facial expressions and body language of the interviewee that can offer additional insights for interpretation of the answers given. In cases where this is not possible the interview will be conducted over MS Teams, to allow for some level of observation.

This research will focus on the impact of the implementation of BIM, and more specifically the BIM-induced change of communicative practices. It will not only focus on the outcome of messy talk in BIM-enabled construction projects, but also on the process of reaching this outcome.

The processing of the data was done in two main steps. First, the records of the interviews were transcribed. This was done using transcription software and then manually checked. After these rough transcriptions of the interviews were completed, the data had to be coded. Coding is the process of assigning labels to blocks of raw data with the purpose of identifying potential relationships in the data. Codes can be assigned in three ways: theory-driven, data-driven, and structural. Theory-driven codes are determined a-priori by using existing theory or concepts from previous research. Data-driven codes are codes that are developed from the raw data. Finally, structural codes are codes that come from project specific research goals and questions. The elements included in the codebook are the code name, the description of the code name and an example. There are two levels of coding: open coding and axial coding. Open coding is the process of splitting the data into smaller pieces and creating groups based on overarching themes in the data. In this research, this level of coding is data-driven. Axial coding is the process of analyzing the currently identified overarching themes and determining a higher-level theme that these can be described as. In this research, this was theory-driven, as the overarching themes were used to create an Activity System. The main goal in the coding process is to determine the contradictions in the activity system, thus the codes described these contradictions rather than the elements that make up the initial activity system.

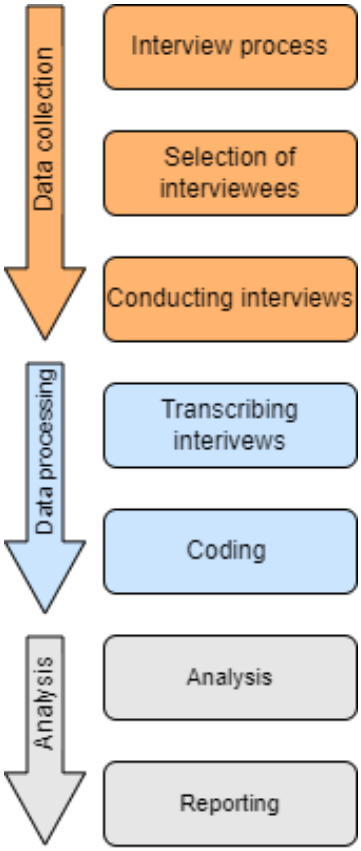

Figure 6 Analysis process

Activity theory is a descriptive framework rather than a predictive theory, and as such allows for an understanding of everyday practices (Nardi, 1995). Activity theory accounts for several factors of the activity system (this will be further explained in section 4.2). Activity theory has been applied in a multitude of research for a variety of purposes. These purposes are activity systems analysis for understanding developmental work research; activity systems analysis for describing real-world learning situations; activity systems analysis for designing human-computer interactions systems; and activity systems analysis for planning solutions to complicated work-based problems (Yamagata-Lynch, 2010). Activity theory offers a new focus in the research towards understanding the potential of BIM. Previous research has been able to link issues and opportunities of communication after BIM implementation. In this research, implementation is considered to be more of an ongoing process that does not end after BIM was initially introduced in the organization. Activity theory allows for the ability to look at the developmental dimension of a communal activity (Engeström, 1999). The term "communal activity" is important, it implies that multiple actors are involved in the activity. In other words, AT allows for a system perspective rather than considering an individual level of analysis. Finally, using activity theory offers insights in which interventions have been done to tackle issues that came up during or due to the implementation, and if these interventions were capable of solving or mitigating these issues. Besides giving insight into which interventions have been done in an activity system, activity theory provides insight into the tensions in the activity system thus into areas where interventions could be done.

Operationalization and validation of the recommendations (SRQ4)

The insights gathered in the previous phases will be combined into a workable and enabling strategy for facilitating communicative practices for collaboration through the implementation of BIM. This strategy will be a combination of the new knowledge on contradictions and currently

applied interventions. The strategy will be validated in an expert validation session. In this session, the strategy will be presented to and discussed with experts working with BIM. The results from the session will be used to validate the proposed enabling strategy and to adjust the strategy where necessary.

Conclusion & discussion

In this final section of the research, the focus will be on drawing conclusions from the research done and relating this to the broader spectrum defined at the beginning of the research. As such, the results will be discussed in the initial context they were set in. This final section will also discuss the limitations of the research and provide areas for further research in this field that stem from this research.

2.3 Research outline

The outline of the research is visualized in figure 7. The arrows show the direction of the flow of research. In most cases, the direction of the flow is to the following step. However, the results and validation form an exception. The feedback provided in the validation stage will be used to fine-tune the recommendations made in the results step. The outline for the research corresponds to the outline of the report and gives an overview of the chapters of this research report and their contents.

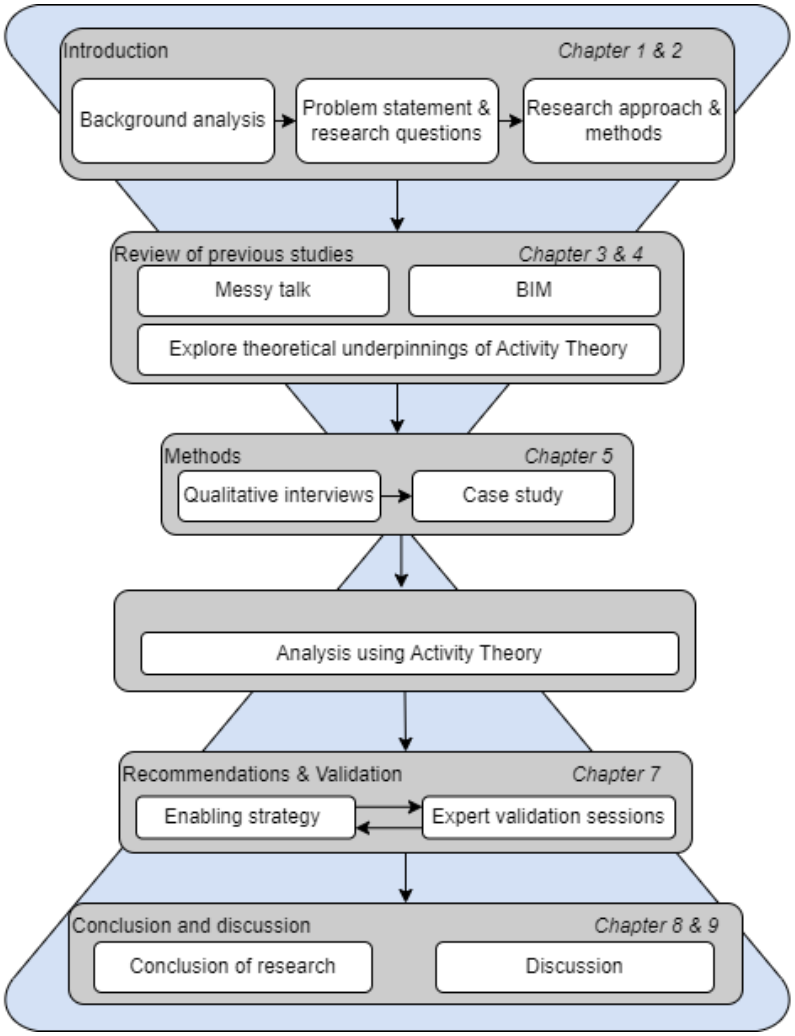

Figure 7 Outline of the research

3 Conceptual framework

Over the last several decades, the interest in information management, and more specifically BIM, has grown in the Dutch construction industry as well as the academic world. Firstly, the three main concepts of the research as discussed, namely messy talk, BIM-enabled construction projects and the design phase of a BECP. This will be approached by means of desk research. Together these concepts form the conceptual framework. This conceptual framework will define the scope of the empirical research. The goal of this chapter is to answer the first and second sub-question which read *What are the constituent elements of project team context communicative practices?* and *What is the communicative potential in the BIM-enabled construction project?*

3.1 The design process

This section concerns the general design process of a construction project. This is done by first discussing the overall life cycle of a project, including the phases in the design process. Following this, the information needs in the design process are discussed. Finally, management approaches applicable in the design process are reviewed.

3.1.1 Phasing

The PMBOK guide defines four main phases of a project: initiating processes, planning processes, executing processes, and closing processes (Project Management Institute, 2008). These main project phases are further detailed into more granular phases on a construction project. Although the naming is slightly different depending on the contract, the essence is the same. The main difference in phasing among the different contracts is related to the when the pricing occurs. As this is not taken into consideration in this research, the DNR-STB 2014 will be used to give an example of phasing. The DNR-STB 2014 is a general guideline that describes the design phases in the context of a construction project from the perspective of the client (BNA and NLingenieurs, 2014). The responsibilities among the client, contractor, and engineer differ depending on the project phase. As this research focuses on the perspective of the design consultancy, not all of these phases are relevant. However, it does provide insight as to where in the overall project the design consultant plays a role in the project. The role of the design consultant can be drawn out over multiple design phases or limited to only one of the design phases. The level of information varies in the different design phases. As the design phases build on one another, the level of information progresses the further the project progresses. Even after the final design phase, the execution design, has been completed, the level of information will increase. This is due to the fact that situations will occur during execution which require amendments to the execution design. However, contrary to the design phases, this information is not always recorded.

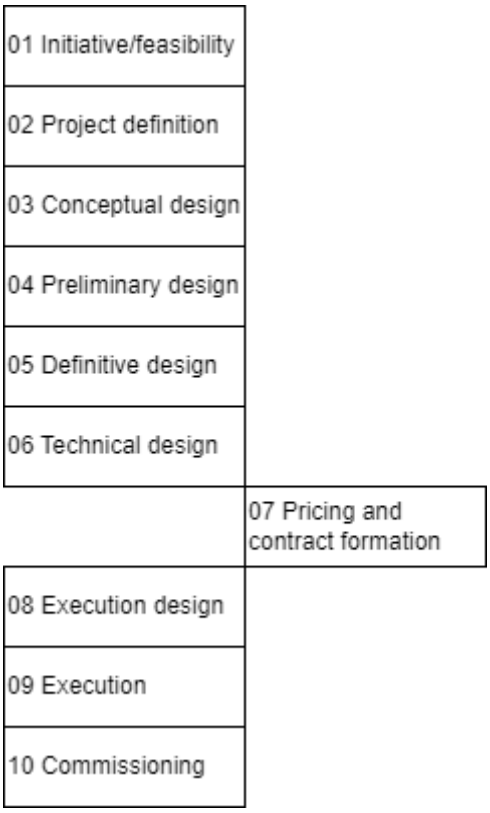

Figure 8 General project phasing in DNR-STB 2014 (Adapted from BNA & NLingenieurs, 2014)

3.1.2 Management of communication in the design process

Communication can be either synchronous or asynchronous. Synchronous communication occurs in real-time, either face-to-face in dialogue and meetings, or at a distance supported by electronic means, such as MS Teams. Asynchronous communication does not occur in real-time, and information can be received and decoded as it suits the receiver. Channels for asynchronous communication include e-mail, websites, and internet platforms. Communication channels can be distinguished along the lines of the one of two organizational strategies for knowledge management: codification or personalization (Snyder and Lee-Partridge, 2013). The strategy of codification uses information technologies to capture, codify and store employee knowledge (Ribiére and Tuggle, 2007). In doing so, a knowledge database is created. This database is dependent on employees adding their knowledge to it, so that a colleague can access this information whenever and wherever they want to. The codification strategy is well suited to the exchange of explicit information or knowledge. On the other hand, the strategy of personalization promotes the development of an interpersonal network for sharing tacit knowledge, which cannot be codified (Ribiére and Tuggle, 2007). This strategy is based on the assumption "that employees will openly share their knowledge with one another" (Snyder and Lee-Partridge, 2013). Communication channels can range from completely analogous, face-to-face communication, to modern technology options, such as a CDE, and more classical technologies, such as e-mail and the (mobile) telephone. Previous research has done tremendous effort in understanding employees' choice for a certain communication channel. In this research, attentions will be shifted to understanding how the introduction of a new communication channel influences a communicative practice in a team environment. The communication channels of interest in this research are BIM and messy talk.

3.2 The BIM-enabled construction project

The digital transformation, which occurred in the last couple decades, has improved productivity in many industries. As such, digital technologies have been introduced in the AEC industry as an answer to low productivity. The digital transformation has produced several new tools and software for managing information in projects, the so-called Information Management System (IMS). One of the most established IMSs is BIM. In the literature, there are multiple definitions of this acronym. The main definitions are building information model, building information modelling, and building information management. In the recent years, the most commonly used definition has been building information modelling (International Organization for Standardization, 2018).

Generally, BIM is seen as more than a product or model; it is a methodology or modelling technology (Haltulla et al., 2020) which includes "the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way" (Adel et al., 2022). The National Building Information Modeling Standard (NBIMS) Committee has defined BIM along the lines of three categories (Sacks et al., 2018):

1) As a product;
2) As an IT-enabled, open standards-based deliverable, and a collaborative process;
3) As a facility lifecycle management requirement.

Succar (2009) acknowledges the plethora of definitions of BIM and the need for a consistent definition. Consequently, they define BIM as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life cycle". This definition will be adopted for this research. The promise of BIM is to help standardize digital data and information (Rodrigues De Almeida et al., 2016), thereby reducing the loss of information over the life cycle of a project and

supporting the project team so that it can collaborate efficiently and satisfy the clients requirements. Rather than exchanging information in the form of physical drawings or in other limited digital forms, BIM entails a digital manner of exchanging information (Bormann et al., 2018). This digital way of working makes use of comprehensive digital representations of the project, something that cannot be achieved when working with line drawings on paper.

A BIM-enabled construction project (BECP) is a project where project information is managed by means of BIM. The goal of applying BIM on a project is to enable that the right information will be available to the right people at the right time. Information management in a BECP consists of two main concepts, which stem from the definition determined above. Firstly, it is made up of policies and processes. The policies and processes are recorded in a BIM-execution plan (BEP). The BEP is written at the start of a project and is a record of the agreements and requirements regarding information management. Although the agreements are recorded at the start of the project, this does not mean that they are fixed for the duration of the project. The BEP is a flexible document that adapts as the project develops. One of the main parts of the BIM methodology is defined as the information requirements of an asset and such of the project. BIM is grounded in the idea that actors in the project know what they want to know and are able to express this in concrete requirements. The information recorded in BIM is thus dependent on the requirements determined by a higher level of project management.

The second concept of BIM is technology. The BIM technologies support the creation of a model, thereby visualizing the output of respective disciplines in the project team. A BIM platform is made up of a collective of difference software programs and other tools. Using a BIM platform should give project team members access to information that is not only accurate, but also relevant to their work so that they can make 'the right' decision. This does not necessarily mean that the decision they make has to be correct decision for the project, but it must be correct based on the shared information and individual knowledge they possess. Creating, storing, and sharing this information in a digital manner can be done in several dimensions. Firstly, the same information is available to project team members even though they are not in the same physical location. Due to the fragmented nature of construction project, this characteristic makes working according to BIM attractive. Furthermore, BIM information can also be used in the temporal dimension. BIM is based on the concept that digital building models are used throughout the lifecycle of a built facility (Bormann et al., 2018). The use of BIM changes throughout the construction phases. Building information created in earlier phases of a project, such as the design or construction phase, can be used in future phases of a project, such as maintenance or even reuse of materials after demolition. Lastly, there is the potential of using BIM information between projects. This mostly relates to storing and sharing the information. This potential remains more of a theoretical one, as it is unknown if BIM can tackle the structural problem of retaining information for use on future projects.

BIM is often used in combination with a Common Data Environment (CDE). In the standard ISO19650, CDE is defined as an "agreed source of information for any given project of asset, for collecting, managing, and disseminating each information container through a managed process" (International Organization for Standardization, 2018). A CDE allows the user to find the information they need in the digital environment best suited to their needs. Including BIM in a CDE should improve collaboration, as project team members can add to the BIM model using software and tools that best suit their needs and tasks.

3.2.1 BIM as a life cycle platform

BIM also has opportunities in life cycle management of an asset. The model can contain several types of information, determining the so-called dimension of the model, which provides benefits over the life cycle of an asset. It is important to note the difference between the life cycle of the project and the life cycle of the asset. The life cycle of the project is defined by the duration of the

project, from initiative to commissioning (see section 3.1.1). The life cycle of the asset is extended by the operations and maintenance of the commissioned asset and the decommissioning and demolition of the asset. BIM is applied with a long-term vision of what information is needed over the life cycle of a project, and less so with a short-term vision of what information is needed on the project. However, benefits of its application are also described in a short-term timeframe, with one of the main benefits being that design issues can be found earlier in the project life cycle (Ullah et al., 2019).

A BIM model can encapsulate many different kinds of information. This is reflected in the number of BIM dimensions (Charef et al., 2018). The most basic dimension of BIM is 3D. 3D BIM contains the geometrical information of the project. This is the core of all higher dimensions of BIM. 3D BIM models can be used to perform clash detection and for providing vertical and horizontal cross section of the asset (Tulke, 2018). In 4D BIM, the temporal dimension is added to the model. By adding scheduling information, a visual representation of the evolution of the project over time. 4D BIM can be used for optimization of the schedule as well as improving the site planning. In 5D BIM, the monetary aspect is added to the model. This allows management to analyze the costs incurred over the duration of the project and identify costly scenarios. In a 6D BIM model, the aspect of sustainability is included. The sustainability dimension of the model can be expressed in terms of energy information. This information can be used for energy analyses to help make decisions in terms of reduction of energy consumption. 7D BIM includes facility management information of the asset. For example, the model could include a so-called materials passport, which includes information about the materials used in the asset. This information provides value for maintenance activities and potentially also for re-use of materials at the end of the lifecycle.

3.2.2 BIM and management approaches

The use of BIM on a project goes hand in hand with several, currently widely adapted, project management approaches. BIM can be placed in the broader context of Virtual Design and Construction (VDC). VDC is defined as “a generic process to model and manage design and construction projects” (Kunz and Fischer, 2020). The VDC framework includes the client and business specifications and the objectives used for performance measurement, project models of the process, organization and people, and the measured performance (Kunz and Fischer, 2020). In other words, it can be used to determine information flows in a project and identify where issues occur in the flow of information. In the VDC framework, BIM is considered as a tool that is used in the design and construction phases of a project. BIM is used as ‘a first-run study of the construction process’ as a manner of testing and improving the process before it is started outside (Sacks et al., 2018). This is a common practice in lean management approaches.

Integrated project delivery (IPD) is a newer procurement process that has collaboration at its focal point. This collaboration takes place between, at the very least, the project owner, the main engineer or designer and the main contractor, and starts in the early design phase and runs until the handover of the project. The main goal of IPD is for the project team to work together using their best collaboration tools and efforts so that the project meets the project owner’s requirements well within the scheduled time and budgeted cost (Sacks et al., 2018). The BIM dimensions that are described above can be used to evaluate parts of the design process. In this way, BIM is used to enable effective collaboration between the involved parties.

3.3 Messy talk

As Winfield (2020) states “the industry has, primarily, managed to create digital drawing boards rather than rethinking its way of working in a completely new digital way”. BIM platforms have a strong focus on the technological aspects of communication. This is reflected in the main goal of BIM, concerning the creation, exchange, and storage of data. The BIM model creates a visual,

digital representation of the project. These are well suited to determining what issues and problems are at play. However, this alone is not enough for problem-solving and decision-making. Dossick and Neff (2011) introduced the term 'messy talk' to describe a form of knowledge creation which comes from the dialogue between project team members that occurs "between and after formally organized agenda items". Previous research has found that there is a divide between messy talk and clean technologies, such as BIM (Dossick and Neff, 2011). As Dossick and Neff put it, these two constructs describe a spectrum along which activities can be described. Both messy talk and clean technologies, such as BIM, are essential to in the collaborative problem-solving process. The link between these two concepts will be further elaborated in section 3.4.

Messy talk, coined by Dossick and Neff, is a relatively new concept that describes a process of opening up a conceptual space where knowledge sharing and synthesizing between interdisciplinary project team members occurs (Mandhana, 2022). It is a communicative process that allow discipline experts to coordinate across knowledge boundaries. As such, messy talk is a communication process that enables the exchange of tacit knowledge. The intended outcome of a messy talk interaction is to generate creative ideas and thereby contribute to problem-solving. This indicates that the topic of discussion in messy talk is always task related.

A key characteristic of messy talk is that it is "unplanned, unforeseen and unanticipated" (Dossick and Neff, 2011). Unplanned means that the participants did not plan the interaction, in the sense that it was not a pre-determined agenda item but rather it came up spontaneously, introduced with a phrase such as "that reminds me" (Dossick and Neff, 2011) . Messy talk is rooted in the idea that participants do not necessarily know what they want to know. This leads to unexpected mutual discovery of issues which may have an unintentional impact on previous or future actions. In other words, the discovery of the issues was not anticipated, and the impact of the issues is unforeseen. These characteristics, together with the goals of the interaction described above, set messy talk apart from other so-called processual constructs (Mandhana, 2022). While brainstorming too has the intention of generating creative ideas, it occurs in a planned and anticipated setting that has been scheduled (Mandhana, 2022). On the other hand, messy talk is also different to informal communication, which can be unforeseen but does not always lead to problem-solving or tacit knowledge exchange due to the fact that it is not always task related. Unexpected discoveries are quite similar to messy talk as they both have the characteristic of being unforeseen, unanticipated, and unplanned. However, an unexpected discovery can also be done by an individual working in isolation, whereas messy talk requires interaction between engaged participants. This requirement will be clarified further in the operationalization of messy talk. The differences in characteristics that sets messy talk apart from other processual constructs are specified in table 1.

Table 1 Characteristics of processual constructs (Adapted from Mandhana, 2022)

Processual construct → Characteristic ↓	**Informal communication**	**Brainstorming**	**Unexpected discoveries**	**Messy talk**
Unforeseen	Yes	Yes	Yes	Yes
Unanticipated	Yes	No	Yes	Yes
Unplanned	Yes	No	Yes	Yes
Only task related	No	Yes	Yes	Yes
Requires shared visualizations	No	No	Yes	Yes
Requires engagement	Yes	Yes	No	Yes
Problem solving	No	Yes	Yes	Yes
Exchange of tacit knowledge	No	Yes	No	Yes

The definition of a messy talk interaction has been operationalized in terms of four constituent elements that occur in iterative collaboration tasks. These are: mutual discovery (MD), critical engagement (CE), knowledge exchange (KE), and resolution (R) (Dossick et al., 2015). The detailed definition of these elements are provided in table 2. The operationalized definition of messy talk is used in the empirical research to identify messy talk through the various elements.

Table 2 Operationalization definition of messy talk (Adapted from Dossick et al., 2015)

Element	**Operational definition**
Mutual discovery OR	An issue/problem related to the aspects of an assignment or existing in the response to that assignment, which a team member highlights but other members have not noticed. A practical resolution that team members find to troubleshoot a technical problem.
Critical engagement OR OR OR	A statement to clarify a mutually discovered issue/problem, which is followed by a question or an opposing statement/explanation. A question whose answer is challenged or supplemented. A suggestion not accepted by the other which leads to reasoning by other. A suggestion accepted by others but is complemented by other as well.
Knowledge exchange OR	A fact related to one aspect of the assignment. A true statement sharing a personal experience or understanding.
Resolution OR	A solution suggested by a team member and agreed upon or not challenged by other, which solves a mutually discovered problem. A resolution agreed upon by everyone to be followed in order to achieve a final solution.

For an interaction to be considered a messy talk interaction, all four elements must occur in the interaction. However, there are cases where some these defined elements do occur, but not do constitute a messy talk interaction because not all four occur. For example, a case where there is simply mutual discovery but no further discussion about the issue, is described as discovery by Dossick et al. (2015). Another interaction typology consisting of several elements is so-called troubleshooting. This is defined as an interaction in which there is mutual discovery, critical engagement, and resolution, but knowledge exchange is missing. From this operationalization, it follows that messy talk occurs as the team-level. The definitions of the operationalized elements of a messy talk implies that they always involved two or more participants. While an issue can be discovered by an individual, acknowledgement of this issue by a team member is required for this discovery to prompt messy talk. Messy talk is a process that requires engagement with other team members, thus meaning it is a communicative process. Messy talk can occur in meetings as well as dialogue.

Dossick and Neff (2011) define three axes along which clean technologies, such as BIM, and messy talk differ, these are: (1) formal and informal communication; (2) passive and active communication; and (3) flexible and inflexible visual communication . An organization chooses a balance in these dimensions, thus influencing the communicative practices in a construction project. The first dimension is that of formality versus informality. Formality means that documents and artefact, such as contracts or a 3D model, serve as methods for accountability and authority within an organization. On the other hand, informality implies that documents are used as a talking point, especially when it concerns information that does not (yet) have to be precise or complete. The second dimension is that of passivity versus activity. This dimension reflects how active or passive participants interact with information. Passivity implies that action with which

a document can produce an effect is undetermined, the change is passive. Contrastingly, activity implies that participants have to actively work with a document to make it have an impact. The final dimension is that of flexibility versus inflexibility. This concerns the medium for communication and the ease with which one can manipulate it. A flexible communication medium means that one can easily manipulate, such as a drawing on paper or a whiteboard. Alternatively, an inflexible medium cannot easily be manipulated in real time and are used to discuss future actions rather than using the medium to create new knowledge in real-time. When defining BIM and messy talk along these lines a clear difference appears. The two concepts can be placed on a spectrum, which can be used to describe and analyze activities and practices that occur in the design phase.

3.4 The communicative potential

This research considers two concepts, messy talk and BIM, as conceptual constructs of knowledge exchanging processes in the design phase of a BIM-enabled construction project (BECP). In a BECP, formal communication between people is mediated through computers. The BIM platform captures formal communication and explicit information. Additionally, informal communication and tacit knowledge are of significant importance to the problem-solving and decision-making process. Problem-solving is made up of three stages. Firstly, problem identification, which is where the problem and its characteristics are identified. Secondly, solution ideation, which is where ideas for solving the problem are generated and evaluated after a which a final solution is selected. And finally, solution confirmation, which is where the selected solution is implemented and evaluated. Following the implementation of BIM, the focal point of change- and risk management is pulled forward and is focused on earlier moment in the process of the project rather than in the construction phase (Hartmann et al., 2011). As such, the problem-solving cycle is pulled forward in the project life cycle meaning that there is more discovery of issues and there is more need for problem solving earlier on. The decision-making power in construction project is the highly organizationally divided (Dossick and Neff, 2010). Tacit information, needed for problem-solving, is created and shared through processes such as messy talk. Due to its tacit nature, the output of messy talk is not as easily recorded in the BIM platform. Bryde et al. (2013) found that BIM-enabled construction projects have experienced benefits related to communication, albeit that these benefits were only experienced in roughly a third of the projects studied.

On the one hand, BIM is more useful for communication of explicit knowledge and information. It comes into its own most in situations where users are aware of what it is they are looking for. In other words, it provides a useful tool in determining known knowns and known unknowns. On the other hand, messy talk is geared towards the communication of tacit knowledge and information. Messy talk is grounded in the idea that participants are not consciously aware of what they want and need to know. In other words, messy talk supports participants in establishing unknown knowns and unknown unknowns. In a project, both explicit and tacit knowledge are required. Thus, BIM and messy talk have a purpose in the problem-solving cycle. Ideally, BIM and messy talk should be used together throughout the design process. Herein lies the crux of the matter. The communicative potential in a BECP is defined as the ability of a project team to effectively communicate with each other, knowing which methods to employ depending on the required type of knowledge, be it tacit or explicit. Consequently, it is necessary to know when messy talked is needed and for which type of tasks.

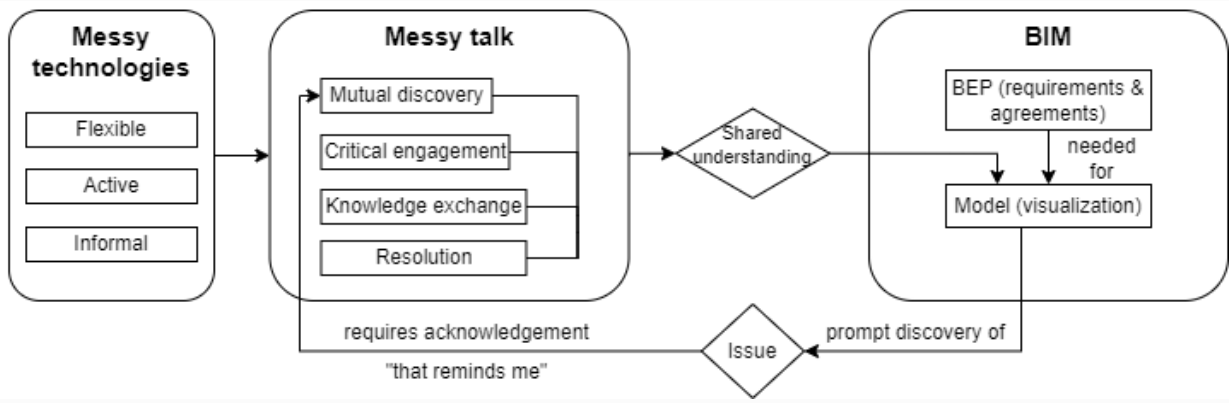

Figure 9 Theoretical relationship BIM-messy talk

In theory, BIM and messy talk can be complementary. According to the theory of messy talk and what is known about BIM, figure 9 describes how these two concepts could theoretically work together to achieve knowledge sharing and consequently generating new information. In this model, the discovery of an issue is prompted by the visualization power of BIM. For this issue to be solved by means of a messy talk interaction, the issue has to be acknowledged by a team member. If this occurs, the messy talk interaction is started by the mutual discovery of the issue. Once all four elements of the messy talk interaction have occurred, there is a possibility that the interaction leads to a shared understanding. This shared understanding can then be used as input for the BIM model. BIM has been designed for the capturing and exchange of explicit information, which can be used as an input for problem-solving and decision-making. The outcomes from the problem-solving and decision-making processes can also be recaptured in BIM. However, the process of getting to this outcome, which in some cases is more interesting than the outcome itself, cannot easily be captured in BIM. The theoretical relationship between BIM and messy talk is described as the potential of BIM and messy talk and as such forms the research proposition. This research proposition will be researched by analyzing empirical data through activity theory.

4 Theoretical underpinning

In the previous chapter, the communicative potential on a BIM-enabled construction project was introduced. However, it also highlighted that, in most cases, the communicative potential is exactly that – a potential. Project teams are not able to effectively communicate in BECP. To deepen the understanding of this topic, a human-computer interaction approach has been applied. The results from the activity theory analysis will be used in answering sub-research question three. First, a brief history of activity theory is given, introducing the terminology used. Following this, the terminology will be further explained in terms of the main principles of activity theory, the elements of the activity system and how analysis using activity theory can provide insights in the contradictions and mediations in the activity system.

4.1 The background of activity theory

Activity theory is the basis of an analysis method used for understanding human activity in a collective context (Yamagata-Lynch, 2010). In this section, the development of activity theory will be explained, concluding in the latest understanding of activity theory, which will be used as the basis of analysis in this research.

4.1.1 First generation activity theory

Activity theory, in full Cultural Historical Activity Theory (CHAT), originates in Russian works in the field of psychology. Initial CHAT research was done by Lev Vygotsky, who was interested in the methods that could be used to objectively study and explain human activity. The concept of mediated action was introduced by Vygotsky to "explain the process of the development of human consciousness through tools, artifacts and social others" (Yamagata-Lynch, 2010). These three elements, subject, object and mediating action or tool, make up the mediated action triangle which forms the basis of activity theory which can be seen in figure 10.

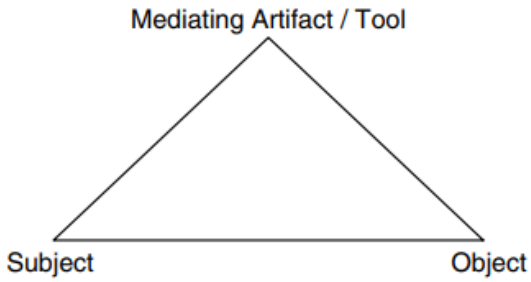

Figure 10 Vygotsky's basic mediated action triangle (Yamagata-Lynch, 2010)

The subject in this graphic is the individual or individuals engaged in the activity. The mediating tool can include artifacts, social others, and prior knowledge that contribute to the subject's mediated action experiences within the activity. The object is the goal of the activity. Signs are not represented in the basic triangle but are assumed to be an artifact of the mediated action process. This triangular representation of mediated action was Vygotsky's attempt to explain human consciousness development in a manner that did not rely on dualistic stimulus–response associations. (Yamagata-Lynch, 2010) The notion of mediated action is an important characteristic of the unit of analysis. The unit of analysis must have mediated action so that activity theory, or activity system analysis, can be applied.

4.1.2 Second generation activity theory

Work on activity theory was extended by Leontiev, who defined object-oriented activity as the unit of analysis that is of interest to activity theorists. It is important to note the difference between goal-directed actions and object-oriented activity. Goal-directed actions have a temporary nature and constitute the steps that subject take "in the process of participating in an

object-oriented activity" (Yamagata-Lynch, 2010). In other words, an object-oriented activity is made up of a number of goal-directed actions. An object is what drives an activity system, as it gives actions their ultimate continuity and meaning, even though the object of the action does not always line up with the object of the activity system (Engeström, 2000).

4.1.3 Third generation activity theory

Engeström further developed analytical method for activity theory and introduced the concept activity systems analysis. In activity systems analysis, the unit of analysis is the object-oriented activity. Engeström's activity system is based on Vygotsky's basic mediated action triangle, which has been extended by two additional triangles as can be seen in figure 11. The elements of the activity system will be elaborated in section 4.3.

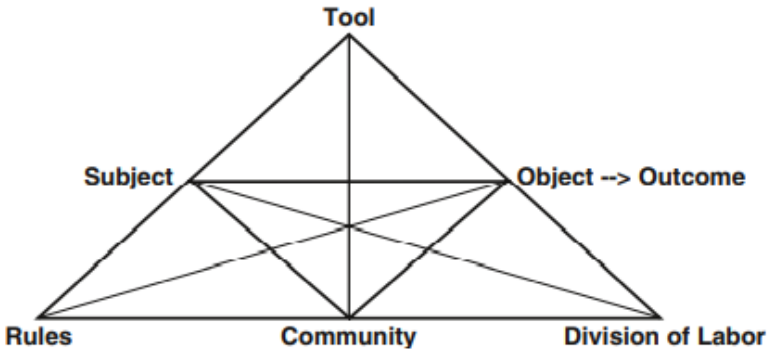

Figure 11 Engeström's Activity system (Yamagata-Lynch, 2010)

Systemic contradictions in the activity system can cause tensions. In other words, the conditions of the activity can lead to situations preventing the subject from reaching the object. These tensions can be triggered by human activity. The concept of systemic contradictions will be elaborated in section 4.4.

4.2 Principles of activity theory

There are five basic principles at the heart of activity theory for understanding human activities: (1) activity system as unit of analysis, (2) multi-voicedness of activity, (3) historicity of activity, (4) contradictions as driving force of change in activity, and (5) expansive cycles as a possible form of transformation in activity (Engeström, 2001).

The first basic principle defines the unit of analysis as an activity system, meaning it is collective, tool-mediated, and object-oriented, seen in a "network of relations to other activity systems" (Engeström, 2001). The second basic principle, the multi-voicedness of activity, describes an activity as "a community of multiple points of view, traditions and interests", stemming from the fact that each participant, with their individual histories, has a different position due to the division of labor. (Engeström, 2001). The very nature of collective work practices is contradictory, the objects of the activity cannot be considered to be harmonious. The third basic principle, historicity of activity, details how an activity system takes shape and transforms over time. The unique history of an activity system forms the basis to understanding the complications and possibilities created in the activity system. The fourth basic principle describes contradictions in the activity system as the main driver of development in the activity system. The concept of contradictions will be explained further in section 4.4. The fifth and final basic principle is that of expansive transformation. As the contradictions in an activity system increase, either in amount or intensity, individuals that are part of the activity system might begin to question the established norms. This has to the potential to set a change process in motion. If this change process, the

expansive transformation, is completed the object and motive of the activity are redefined to include a broader scope than the initial activity system. (Engeström, 2001)

4.3 The activity system

In activity theory, the activity system is used as an analytical framework and unit of analysis for "the analysis of the social- and time-dependent context of human activities and their enhancement" (Weeger et al., 2021). The current understanding of an activity system was developed by Engeström and is made up of seven interdependent elements (see figure 11). The elements of the activity system will be described and illustrated using a simple case.

An activity system is constructed around the object of the activity. The object is seen as a "project under construction", either physical or cognitive, moving from a problematic system to an outcome (Engeström, 1999). An object can be considered to be the goal of the activity and as such is the driver of the collective activity. The outcome of the activity system is the final result of the activity.

The subjects of the activity systems are those involved in the collective activity, who are trying to achieve this transformation to reach the intended outcome. The subject can be an individual as well as a group of individuals. The other elements in the activity system are in support of the subject in order to achieve the object and thereby the outcome. Tools are used by the subject to facilitate outcome of the activity. Multiple tools can be involved in an activity, these can be physical as well as conceptual. Tools can be a "social other" or artifacts. The community of an activity system consists of other individuals or groups which share similar knowledge and interests but also have the same stakes and goals related to the activity. The division of labor describes the way the work is divided by the community in the activity. Finally, the rules detail the laws, norms, standards, conventions, agreements, and customs that the community has, implicitly or explicitly, agreed to follow in the activity. (Yamagata-Lynch, 2010)

4.4 Contradictions and mediation

Activity system analysis is a method for analyzing the development of an activity system. This is based on the concept of contradictions and mediation. A disturbance in the activity system is leads to a contradiction in the activity system. Contradictions are systemic tensions that have accumulated throughout the history of the activity system. Several types of contradictions can occur in an activity system. Consequently, the activity system evolves to relieve the contradictions in the activity system. Tools, rules, and division of labor are so-called mediating elements. Primary mediation is mediation happens through a mediating element, for example when a tool mediates between the subject and object or when rules mediate between the subject and the community (the subject mediates the community through rules). Secondary mediation occurs when the mediating element is not between the two elements, for example when rules mediate between community and object (Lu et al., 2018).

There are four orders of contradictions in an activity system that can be defined. However, not all of these orders will be used in this research. Therefore, only first and second order contradictions will be further explained. First order contradictions are contradictions that occur within the element. This type of contradiction can function as a driver for an element to re-establish a stable state through adapting. First order contradictions are visually represented by a lightning bolt shape arrow between two elements. Second order contradictions are contradictions that occur between two or more elements. This type of contradictions results in the introduction of new items to the activity system. Second order contradictions are visually represented by an open circular arrow next to a single element. Consequently, the activity system has to reconfigure and re-establish a new stable state.

5 Case study introduction

In this chapter, the case study used in this research will be introduced. The case study is used for collecting empirical data. The selection of this project for the case study is motivated in section 2.2. First, background information related to the project and the project team will be provided. Furthermore, the project phase of interest in this research, the design process, of the project is discussed in further detail.

5.1 The project

The case study was selected based on the selection criteria in table 3. In this table, it is detailed how this case study meets these selection criteria. It is important to note that the level of BIM reflects the intended level of BIM, as agreed in the BEP, rather than the actual level of BIM, as applied by the project team.

Table 3 Case study selection criteria

	Criteria	**OKA**
1	Multidisciplinary design project	Yes
2	Involvement of RHDHV	DO design, total engineering
3	Availability of relevant and varied interview candidates	Yes, several disciplines and levels of experience
4	Level of BIM	High

The Oosterweelverbinding project in located in Antwerp, Belgium and it is a major infrastructure project has the purpose of closing the Antwerp Ring (Lantis, 2023). Besides completing the Antwerp Ring, the project aims to increase the livability in the area by creating areas for recreation and bicycle connections on top of the tunnels.

To make the project manageable, it has been split up into several units. One of the major units of this project are the so-called channel tunnels. The client of the Oosterweelverbinding project is Lantis, a management company employed by the Flemish government. In turn, Lantis has employed ROCO, a consortium of several contractors, to deliver the channel tunnels. Subsequently, ROCO have employed Sturino, a partnership of three engineering firms, to deliver the design for channel tunnels. RHDHV is responsible for the design of OKA (Ondergrondse kruising Albertkanaal). The position of this sub-project in the bigger picture can be seen in figure 12.

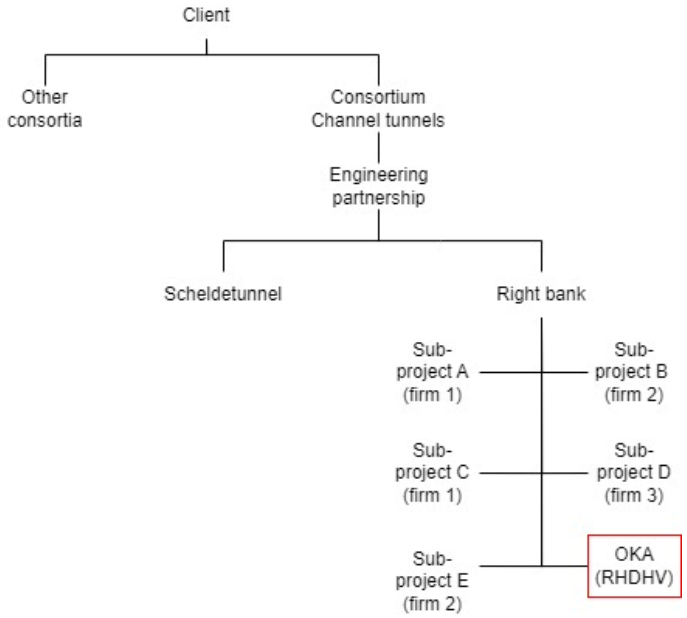

Figure 12 Organizational structure sub-projects

As OKA is still a large project, it has been split up into four sub-areas. Each of these sub-areas consists of team members from different disciplines, including geo-technical engineers, structural engineers, and a modeler, and is led by a team leader. Furthermore, there are two specialist teams responsible for the water management and the roads in the project. The remaining team members are responsible for the integral design and management of OKA. These team members include the project managers, the design leaders, discipline leaders, the BIM team, the interface coordinator, the systems engineer, and the contract manager. These team members are responsible for ensuring the coordination of the sub-units of the project and delivering an integral design for OKA. The organizational structure of OKA is visualized in figure 13.

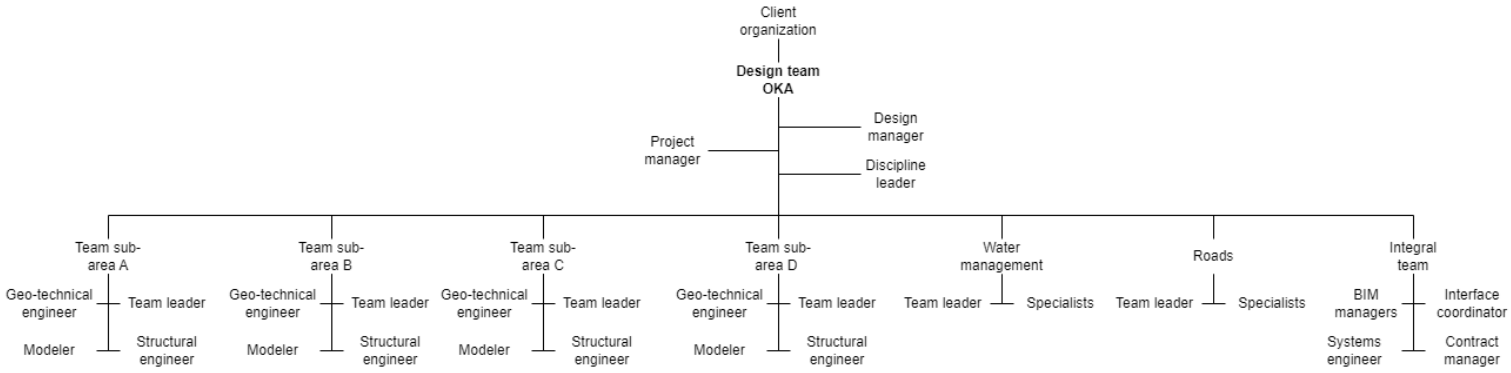

Figure 13 Organizational structure OKA (Adapted from Sturino Project Management Plan)

5.2 The design process

In this section, the design phase of the case study will be positioned in the general design process of a construction project, as described in section 3.1.1. The design stage of the project consists of several steps. In the first step, the focus is on defining areas that require attention, coming up with a solution for these areas and working the agreed solution out. Working out the solution consists of the following tasks: calculation, including preparations and execution, modelling/drawing, phasing, and finally reporting.

This initial design forms the input for the following step, internal review. In this step, the work is reviewed on technical and integral aspects. The design can either be sent back to the drawing table

for reconsideration or be internally improved. In the case of internal approval, the design and corresponding documentation is gathered and checked for completeness. Finally, the complete package consisting of the design and corresponding documents is sent to the client for external review. In this final step, the design can either be sent back to the drawing table for reconsideration or be externally improved. Once all designs have been externally approved, the DO design phase is complete.

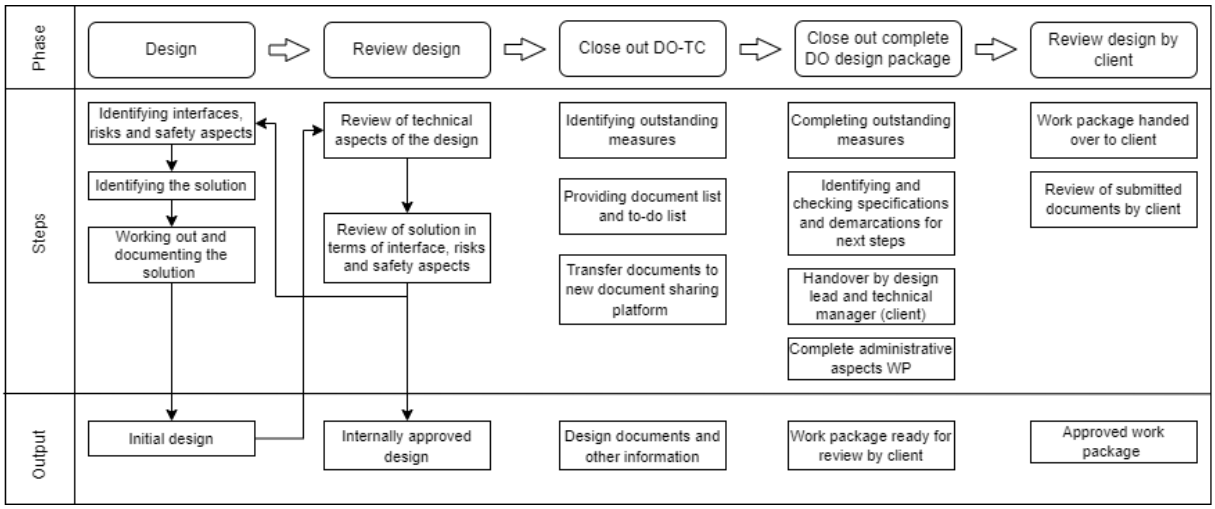

Figure 14 Design process of the case study (Adapted from Sturino Project Management Plan)

Some of these tasks require more creativity than others which require to be executed. This is due to the fact that some tasks have a clear intended result whereas other have a vaguely described intended result that can be approached in several ways. For some tasks, the explicitly available knowledge is enough, whereas for others you want or need tacit knowledge. So sometimes in the design process, there is a lot of discussion how to approach something and sometimes it is more focused on carrying out tasks.

6 Results empirical research

This chapter will combine empirical data, presented in the codebook, with activity theory to create an understanding of how the activity system of communication in a project team has developed as a result of implementing BIM on a project. Firstly, the identified occurrences of messy talk have been structured according to their purpose. The outcome of this analysis is used to determine scenarios which will be used as starting point for the activity system modelling. This will start with the motive leading to the implementation of BIM and describing the developments in the activity system stemming from this. Finally, the current communication practices identified in the data will be described. These elements will then all be combined to provide an answer to the third sub-question which reads *How has messy talk developed as a result of work in the BIM-enabled construction project?*

The analysis of the empirical data is done in three phases. The structure of the analysis is described in figure 15. First, the purpose of the observed messy talk interactions is identified. Consequently, the purposes are distinguished according to the contribution of BIM in the interaction, leading to two scenarios of problem-solving project team communication. In the second phase, the process surrounding the two scenarios is analyzed using activity theory. Finally, in the last phase, the results from the activity theory analysis are used to determine the impact of BIM and messy talk on a project team interaction in a BECP.

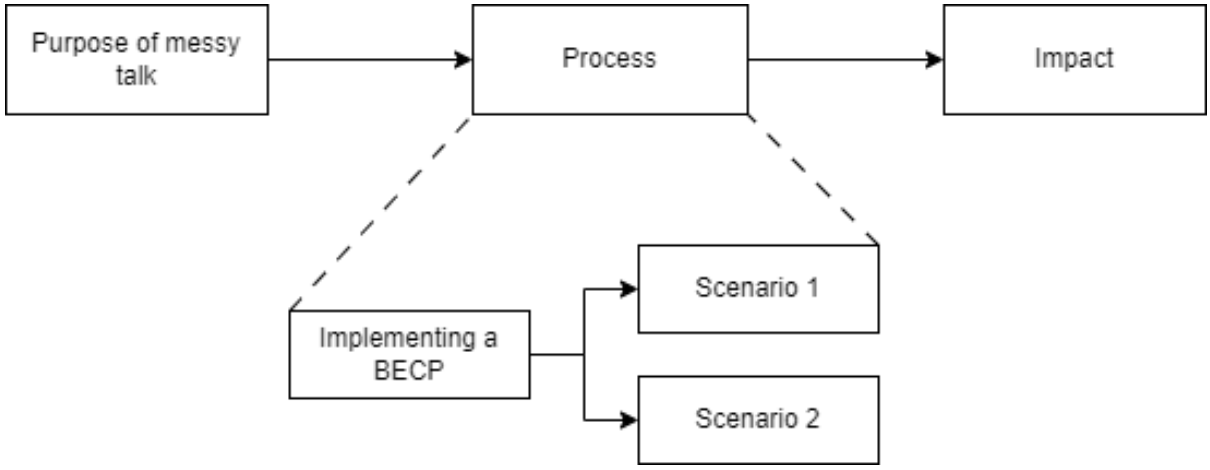

Figure 15 Structure of analysis

6.1 Purpose of messy talk

This research builds on the assumption that the messy talk characteristics unplanned, unforeseen, and unanticipated, relate to the total communicative process and not to the intentions of individuals (Mandhana, 2022). This assumption is critical when categorizing messy talk interactions according to their purpose. Although all elements of messy talk occur in these situations, they slightly differ from the definition by Dossick and Neff (2011) as they do not exclusively occur between or after formally organized agenda items. It is still messy talk because the interaction is unplanned, unforeseen, and unanticipated.

The setting in which the messy talk interactions occur can differ. The recorded occurrences of messy talk, following from both the interviews as well as the observations, were described to occur in a spontaneous interaction or in a pre-agreed meeting. For the most part, the recorded messy talk occurrences took place in a spontaneous setting. The structure of the observed meetings were similar. A meeting would start with a run through of the meeting agenda, this consisted of two main sections, firstly general project-wide updates that pertained to the sub-area and secondly task-specific updates by all project team members. The items of the agenda would be discussed in the meeting, although not exclusively in the initially determined sequence.

In the codebook, the third order construct represents the high-level purpose of the interaction in which messy talk occurs. Five purposes have been identified, these are: reviewing, revealing, reflecting, ruminating, and realizing. Messy talk with the purpose of reviewing occurs in situations in which the participants go over specific output critically and deliberately. The purpose of revealing includes situations in which the participants allow a look at or understanding of something hidden, with the outcome of uncovering something new or hidden. The purpose reflecting describes situations in which participants evaluate a series of actions and contemplate varied possibilities and options. Ruminating occurs in situations in which participants go over something repeatedly, often slowly, without any real outcome. Finally, realizing describes situations in which participants do not know how to proceed, so messy talk is needed to move forward or retreat. The second order constructs for each of these purposes were reached by asking the question "How do they 'R…'?" As such, the second order construct describes the more detailed purpose of the situation. An overview of these second order constructs, the definition thereof and a proof quote can be found in table 4. A complete overview of the proof quotes can be found in the codebook.

Table 4 Purpose of messy talk

3rd order code	**2nd order code**	**Definition**	**Proof quote**
Reviewing	Giving feedback	Spontaneous moments in which feedback is shared through messy talk	*"When I go through the model and I see something of a mistake, which I think the structural engineer should perhaps be asked a question about. Perhaps he had not seen it himself because he's so focused on his own work that he doesn't see the mistake. But since I can look at it now, I might be able to take out that error. So that way you also have an extra check or an extra pair of eyes that can spot errors."* (3)
	Checking	Standardized moments for checking work that result in messy talk	*"You can make that clear in this way. That also means, if you talk about installations with the constructor, is the hole for the pipe in the right place or is the hole too big or too small? And does the door fit properly, can I open or close the door properly? Will we fit the two-meter-twenty door into a two-meter frame? Yes, simple things like that, that can all be made transparent."* (3)
Revealing	What	Revealing that there is an issue	*"And by also seeing and naming it, especially in meetings where you go through the combined 3D model, people say things that you otherwise would not have seen if you had not looked at the 3D model together."* (4)
	Why	Revealing why there is an issue	*"Because in the past it was up to the person who was communicating how well do they know the construction? Some people did not understand 2D, how it looked in 3D. So no, you really have to explain that, yes, but I have a rejuvenation here in my bar and you cannot see that in a top view, that's a dotted line. And the*

			moment you have it in 3D you can rotate it and then you see hey there is a jump in my bar because of it. And in the past, you sometimes had to clearly indicate three times what it was like or you had to sketch that side view again so that they saw what it was like." (2)
Reflecting	Evaluating	Someone's (individual or group) actions are evaluated through messy talk	*"Which means that maybe two hours of sparring with someone, your output might be input for me."* (3)
	Contemplating	Different options are considered through messy talk	*"That is about something that someone sketched, then we discuss it. 'This, but not that'. And then you show a few examples on the screen 'Well, this is how I did it'."* (2)
Ruminating	Ruminating	Messy talk that does not lead to a change in the course of action	*Interaction in a team meeting that went through all messy talk steps and was resolved by concluding that it was a non-issue. (Team meeting 1)*
Realizing	Question	Realizing you need more information	*"You are discussing that sometimes. If one says, 'if we do it like this now' and then another says 'Yes, but it's not possible because my forces are different'. And then a design leader says, 'now I want it that way'. And sometimes it doesn't work out at once, then they first say, 'Would you like to see if you are going to work it out like this, how it will turn out and what is there then'. Sometimes a meeting is not enough."* (2)
	Task	Realizing how to proceed	*"But that still means that if you have a clash, you still have to discuss with each other 'Am I going to move my anchor or is the other going to move their anchor?' Or if there is an existing building that we eventually touch on, the existing building cannot go. So, then someone has to decide what will be the angle of that anchor or other things. Someone has to make the design decision and then say, 'We're going to fix it like this'."* (2)

The categories of purposes were analyzed in three ways. First, the data was analyzed according to the subject involved in the messy talk interaction. This did not lead to a generalizable pattern in the data, so the data was reconsidered. The second attempt at analysis was focused on the setting of the messy talk interaction, being either a meeting or in the workplace. Again, there was no conclusive pattern. Finally, the data was analyzed based on what prompted the messy talk interaction. In the final focus a pattern could be established. For each of the messy talk purposes, the prompt in the identified messy talk situations has been determined. For each messy talk situation, it was determined if BIM or something else prompted the interaction.

The purpose of messy talk is dichotomous. These two scenarios in which messy talk occurs will be used to discuss the process that has led to these possible outcomes and what their impact on the activity system is. In scenario one the messy talk interactions have the purpose of reflecting and realizing and were prompted by something other than an element of BIM. In this scenario ideas are shared to create a shared idea of how to proceed. The underlying question that is answered by the activity between the elements of the activity system in this scenario is *"There is a problem, how are we going to solve it?"*. In doing so, participants contribute to creating and thoroughly understanding a solution. Contrastingly, the messy talk in scenario two is prompted by an element of BIM. The purpose of the messy talk in this scenario includes revealing, reviewing, and ruminating. In this scenario, ideas are shared to create a shared idea that something will not suffice. The underlying question that is answered by the activity between the elements of the activity system in this scenario is *"Is this a problem? Why is this a problem?"*. Consequently, this results in the identification and clarification of the problem. The characteristics of the two scenarios are summarized in table 5.

Table 5 Scenarios of messy talk

	Scenario 1 – Solution ideation	**Scenario 2 – Problem identification**
Prompt	MT prompted by other	MT prompted BIM
Purpose	Reflecting & realizing	Revealing , reviewing, ruminating
Outcome	Working out how to approach the problem (sharing ideas to create a shared idea of how to go forward)	Realizing there is a problem (sharing ideas to create a shared idea that something will not suffice)

The scenarios will be analyzed using the same outline. Starting with the introduction, the changes in the activity system resulting from a new desired outcome are discussed. This is the same in both scenarios. Next, the activity systems of the respective scenarios respond to the implementation. Finally, the implications of the changes in the activity system are discussed. These last two steps are dependent upon the scenario, and thus differ.

6.2 Process

In this section, the process leading to the varying purposes of messy talk is explained using activity theory. The activity system model (ASM) is established using the codebook and other empirical data. The elements of the activity system, initially as well as during its evolution, are determined by using the eight-step-model created by Mwanza (2002) (table 6). This results in the initial activity system model in figure 16. The proof quotes for each of the elements of the initial ASM can be found in the codebook. This initial activity system is used as the basis for describing the development of the activity system as a whole. It allows for demonstration of what the impact is of the change drivers, problems and effects defined in the codebook, and where in the activity system this impact occurs.

Table 6 Eight-step-model (Adapted from Mwanza, 2002)

Identify the…		**Question to ask**
Step 1	Activity	What sort of activity am I interested in?
Step 2	Objective	Why is this activity taking place?
Step 3	Subjects	Who is involved in carrying out this activity?
Step 4	Tools	By what means are the subject carrying out this activity?
Step 5	Rules and norms	Are there any cultural norms, rules, and regulating governing the performance of the activity?
Step 6	Division of labor	Who is responsible for what when carrying out this activity and how are the roles organized?
Step 7	Community	What is the environment in which the activity is carried out?
Step 8	Outcome	What is the desired outcome from this activity?

As with any change, it does not come along without hiccups, meaning that several tensions have developed in this evolving activity system. In this section, the understanding of these tensions will be furthered. To answer the sub-research question, attentions will be focused on two relationships in the activity system. The relationship between members of the project team responsible for the design of a sub-area (Subject) and the objective (Object) of exchanging tacit and explicit knowledge for the purpose of design ideation is considered is the so-called relationship of interest. This relationship will be analyzed by focusing on the role of mediating elements within and between (first and second order contradictions) each sub-activity of the activity system. The outcome of the system has changed, from ad hoc design ideation to systematic design ideation, thereby bringing about changes to the mediating elements of the activity system.

Codebook

The process can be structured according to three main phases. Firstly, the change drivers define the driving factors in implementing a BECP. Secondly, there are problems that have come up in the activity system as a result of the implementation of BIM. Finally, the switch to a BECP has certain effects on the activity system. In this section, the codes defined in each section will be defined using quotes from the empirical data. The relationship between these codes will form the basis of the activity theory analysis.

Change drivers

The change drivers can be categorized based on the actors that are the driving force behind them. The first third order construct, Internal strategy, includes change introduced by the high-level management from within the organization. A so-called copycat situation has occurred, in which the switch to a BIM way of working has been motivated by the successes in other departments in the business, in terms of discipline as well as country, with the expectation that these can be extrapolated to civil engineering projects. This decision has been made by management. This is underlined in the following quote.

"The way I see it, it has been pushed into our civil world from buildings and industry, as well as from the English working field. But that does not go to say that it can immediately be introduced to our Dutch market or applied to our Dutch way of working. And then they say, you should do this, and you should to that, without entering into a discussion. Well maybe with a discussion, but with the wrong people." (3)

The organization has adapted its strategy to become more future proof and prepare for future needs of clients and potential changes in client demands. The decision for implementing BIM lies with management and is enforced top down. This is reflected in the following quotes.

"A lot of things that we are going to do, we will deliver to someone in the end. So, we have to make sure that it is somewhat future proof, so that they can also do something with it in the future." (6)

"And of course, it is also simply part of our digital transition program, which I also don't shape in its entirety. Of course, it what our CEO and such say, 'these are the things we are going to do go for in the coming years'." (1)

Table 7 Internal strategy

3rd order construct	2nd order construct	Definition	Proof quote
Internal strategy	Copycat	The system change has been introduced due to foreign influence	*"That is how we started, mostly influenced by our English colleagues because they started it much earlier. Because in England, clients made these things mandatory much earlier than in the Netherlands."* (9)
	Future proofing	The organization has adapted its strategy to become more future proof	*"We have to go along at the right speed, our clients are going along. The entire world around us is digitalizing, so we have to go along at the right speed."* (10)

The second third order construct, Industry needs, describes change drivers motivated by the AEC industry. Within the industry, there is a strong need for mutual understanding to enable collaboration between the parties. As many different parties work together on projects it is important to have structured and accessible information. This is reached by a uniform way or working.

"But because of all the knowledge of companies, at some point you start working together. But then you have to explain how to use it, so it reduces the time you have to explain it to someone. Because people are already familiar with a certain basis or a standard, you no longer have to explain it again specifically on the project, because I already have to get to know it from my own company." (5)

Table 8 Industry needs

3rd order construct	2nd order construct	Definition	***Proof quote***
Industry needs	Mutual understanding	Parties across the AEC industry understand each other through accessible, uniform information	*"And I find it very nice that when my colleagues from Arcadis are at the table, or maybe from a foreign party, that they also understand what you are talking about. That is also important, that it isn't only a RHDHV internal thing."* (8)

Finally, the last third order construct, Client push, described change drivers resulting from a pressure stemming from the client of a project. On the one hand, this stems from the described monetary benefits of implementing BIM. As projects increase in size and complexity, so do project costs. To limit unforeseen and unnecessary costs, responsible parties are looking for ways to better anticipate risks and avoid ad hoc re-work during the execution of a project. This is underlined in the following quotes.

"In the past, there may have been a lot of invisible repairs on site. But nowadays, the budgets and time no longer allow that. So, we actually have to make agreements with each other in advance about how we are going to do it." (1)

"But usually, it is the case that the output is important, the client asks for 2D drawings so those have to be good. But on a flat drawing, you can't really eliminate all the mistakes with that. A lot was solved during construction and that costs money." (8)

The manner in which BIM is introduced on a project, depends on the demands made by the client. The output of BIM is not limited to a model. Although, in larger projects the output generally is a

model. The demands made by clients vary in terms of extensiveness and clarity. This is underlined in the following quotes.

"This is also because there are more clients who want to do something with it and then perhaps don't even describe it very well. I mean, getting a full-fledged EIR on your desk almost never happens. But questions are asked, and you have to answer them. You have to think about what they are asking, what do they really want?" (8)

"We actually make structural 3D models. And it must contain the necessary information, in consultation with the client, but mainly for later management and maintenance." (7)

Table 9 Client push

3rd order construct	2nd order construct	Definition	Proof quote
Client push	Monetary motivation	Client push for implementing BIM is related to the monetary benefits attached to it	*"If you know of one another what the other is doing, that is more efficient. A uniform working method for reducing costs, reducing failure costs."* (1)
	Client demands	The use of BIM depends on the demands made by the client	*"Then we wouldn't have to say: 'we're doing it because we want to'. No, the client is asking for it as a deliverable. That would make the internal salability much easier if that were the case."* (1)

Problems

The second main category describes problems that have come up throughout the activity. The problems are found within the area the people, including external actors and the project team, the information system and the interface between people and information system. These problems form barriers to the desired outcome of the activity system.

The first third-order construct describes problems related to the people in the activity system, which can be actors as well as community members.

First of all, problems stem from the variation in personal skills among project participants. The introduction of BIM as a new way of working highlights several issues related to personal skills. Firstly, the ability to communicate is strongly tied to one's communication skills. The introduction of BIM has changed the way in which participants communicate, thus demanding different skills from participants.

"Everyone gets new skillsets and must communicate differently. For a project leader it may be that he has worked for years in a way that has always worked. And now suddenly he has to take some other steps or real steps: become visible, approve reviews, drawings and appoint the right people. Maybe he used to always read all the documents himself and just there also rely on people who read them and that he only had to go through the main points." (5)

As BIM is a way of working that all participants are expected to apply, this has made the varying levels of digital skills apparent. This leads to differing use of the system.

"Just like the average employee does not exist either. So that's why you see so many differences in level of skill with us, but I think in many other areas too." (8)

"I think you will be using more complex software. I think you need to check more, check on more aspects. I don't think that necessarily makes it all that much easier." (6)

Secondly, problems stem from unfamiliarity regarding the system among project participants. There is a difference in team members' understanding of what BIM entails, despite the agreed definition as given in ISO19650. As such, participants are unfamiliar with the elements of the system and how to use the system. Consequently, the system is not used at all or not used properly by the participants. This will be discussed in further detail in the section on coping mechanisms.

"So, you might be able to set up a project that fully complies with the ISO, which is very nice, but if nobody knows how to work with it, then you won't achieve the desired result. So, I always try to plan a project fit-for-purpose so that employees who will be involved with it can learn something but can also work in a somewhat familiar environment so that the learning curve is not too steep. Because you do notice that there are highflyers and that there a people who have held it off." (8)

Furthermore, BIM provides the same information to all participants, but if they make use of this depends on their willingness.

"So, I think that is also a bit of enrichment for the entire project team. If you want to see it, you can view it. You don't have to see it, if it doesn't interest you then you don't have to look at it, but the possibility is there." (3)

The willingness to accept and adapt to the new way of working differs among project participants. This is related to people stance towards the innovation, where some participants are eager to embrace a new technology, other participants are wary and prefer to remain working in the familiar way.

"But I still have the idea that some people are really very much part of BIM, and some people tell me Yes, I don't care, or I don't need it." (1)

The final code, non-alignment, includes the problems that stem from lack of alignment between the internal organization and the external actors. The abilities of collaboration parties in a project regarding information management differ. As such, information ends up being managed in such a way that it works for the party with the lowest level of abilities. Consequently, the interpretation of the agreements is often done internally and as such interpretations differ between the involved parties. If the organizations working on a project have not switched to the BIM way of working, the value added by BIM is low.

"And suppose you do everything, and it eventually comes to the operations and maintenance manager and the manager does not have a certain maturity level or he does not have a certain basic level, he then flattens all information again and says do all this in PDF and he saves it completely flat again. You actually want that information to continue and be reused and not be flattened in transition, for example by such a manager, who says yes, such a BIM model I cannot do anything with it, just send me drawings. Or a set of requirements in relatics because it is easy to edit, no, give me an Excel list because at least I can work with that. Each link is another sensitive point that the BIM process can fail." (1)

"In this company there is a sort of standard naming convention." (5)

Table 10 People

3rd order construct	2nd order construct	Definition	Proof quote
People	Personal skills	The implementation of BIM requires new and/or different personal skills from project team members	*"More, also personally, so that also requires other skills in that sense. Modelers are perhaps a bit more introverted, less strong in communication, so that means that we can no longer adopt a wait-and-see attitude but have to adopt a proactive attitude."* (5)
	Unfamiliarity	The basis of BIM is not yet clear to project participants	*"Because the roles, functions, are not clearly described, what is expected of everyone."* (5)
	Willingness	People have different stances towards accepting the new way of working and working with BIM	*"There are still some people from the old guard. But there are some people who really read a drawing the old way."* (2)
	Non-alignment	Problems due to a lack of industry broad coordination	*"But I am of the opinion that we make drawings for the reviewing organizations and work preparation. I think the people outside know how to make it in 3D for a long time already. And they find it much easier if we hand it to them in 3D."* (2)

The second third-order construct describes the problems related to the information system. The implementation of BIM has resulted in an increased number of activities, in terms of both input as well as output. For the desired outcome to result from BIM, the processes have to be precisely followed. This introduces new amount of administrative work, which costs time and is generally also not found enjoyable by project participants.

"I think an engineering firm such as this still functions in generally the same way as it did 20 years ago. I do think that there are more small sub-processes within BIM that may not have been there in the first place." (6)

"And what does it bring alongside it? A lot of information. But also, a lot of administration, administrative work. And if you ask an engineer if he enjoys administrative work, they will say no. They want to do things, work things through, engineering." (5)

Due to the implementation of BIM, the output created by the design team has increased considerably. The quality of this output has to be checked, but due to the increased amount of output the quality check systems have been adapted.

"It remains the same four eyes quality system. The only thing is, you need to check a little more, or consider a little more. Previously you only had a drawing output or just a paper drawing, and now you may have to check the model, the CAD file and both the drawing. You have amount of activity has increased." (5)

"We remain to check one another. Only now there are so many drawings and other things, it isn't checked three time. It is check once." (2)

The level of detail in the information system is also a source of issues. A certain level of information is needed for communication, too much or too little can result in issues. The level of information and detail in the system increases throughout the design processes, as design choices are added to BIM. At the start of the project, the level of detail in the model depends on the agreements made with the client.

"We have received models from the client. Then it must contain the information that we have agreed upon. And that must be clear and immediately visible to me." (7)

For the information system to have an added value, the information needs to be accurate and current. For this to occur, the agreements do need to be adhered to.

"But then you have to use it in the right way or in a way that serves the purpose. So, from top to bottom, you have to deliver the right things. It can be supportive, but then everyone has to contribute. And if somewhere in that series, someone only contributes to the end of his phase, then you cannot make a decision." (5)

Table 11 Information system

3rd order construct	**2nd order construct**	**Definition**	**Proof quote**
Information system	Increased activities	The number of activities has increased due to the implementation of the new system	*"Because a lot is coming at people these days, because they need to know something about safety ladders, they need to know about BIM, well, sustainability of all kinds. Well, at a certain point people are also just full in terms of what they can absorb, in terms of transition. That doesn't make it any easier."* (1)
	Level of detail	A certain level of information is needed to be useful in communication	*"Except, I think if you take it on in its entirety and use it as much as possible, then it adds something and that doesn't always happen here."* (6)

The third third-order construct entails problems that come from an imbalance between the people and the information system. This category includes problems that stem from the disbalance between the information system and the people. The balance between the information system and the people enables the system to reach its desired outcome.

System dependency describes situations in which project team members rely on the information system, BIM, to do communicate for them. BIM provides a certain ease in communicating findings, as issues can easily be detected and identified. This can lead to people relying on the system for communication and as such no longer communicate in person.

"Every visual, the moment you have a clash, you can freeze it and then at that moment it turns that situation into a 3D view, which it stores and that in turn is a means of communication with others. So, someone receives a notification and with that notification you can look directly into the model to see where it is and then we have to solve it again." (2)

Garbage in, garbage out stems from problems related to the quality of the information in the system. The BIM software has the ability of performing clash controls, in which the models are checked for any clashes between the elements. However, the software will simply do what is has been designed to do and cannot consider nuances. As such, the quality of the output from the

software depends fully on the quality of the input. Problems can occur due to some cases being deemed correct, while there are issues present that the system cannot detect, whereas other cases may be deemed erroneous, despite these errors not having consequences.

"Well, I made a clash model of that, determined the clashes, and it all worked everywhere. Meanwhile a structural engineer had found out that it was not sufficient for a certain cant. And then I had to measure in the model myself to see if it was indeed wrong. And that was right. So, the model I'm using now, and the clash program I'm running with, Navisworks, doesn't always give the right view. And I have to measure that myself. It's just a means to get there. It is not yet the utopia remedy." (7)

Information overload describes the situation in which users are overloaded with information and are unable to use the system effectively. The information overload stems from the introduction of BIM in a project concurrent with the use of other types of software that might be new to an individual. Consequently, people approach situations in their own way, thereby running the risk of creating more problems.

"Ultimately, you can throw everything you want into the BIM model, but then you also have too much information. And at some point, you lose the overview." (5)

"Ignorance, people don't know how to do something. And they have the pressure that they have to deliver it as quickly as possible, which makes them think I'll do it that way, because then it works. And it's not precise work." (2)

Information overload stems from the lack of guidance before and throughout use offered to users of the system. The occurrence of information overload can also be linked to unfamiliarity with the system and lack of willingness to learn.

"I think that it is a bit of the guidance of BIM or a bit of the introduction of BIM, that is desired. And that sometimes it is not fairly considered that people do have to understand what is being asked of them." (3)

"In my opinion, we really should have started from scratch. And then we can actually share things directly and explain how it all works, so that everyone works in a uniform way. And that is now happening bit by bit, which means that not everyone is immediately aware of what is going on. And that's also because not everyone does the same." (7)

Island thinking describes the situation in which participants are isolated and do not communicate with other project participants. In projects, project team members are assigned to a specific part of the work. The benefit of this is that the responsibilities among team members are clear, however this is also described as a limiting factor for thinking out of the box.

"Knowing who, but at the same time you put people in boxes and isolate them without them being able to think out-of-the-box." (5)

In discouraging creative thinking, people are less prone to critically consider input and as such run the risk of building onto existing mistakes. Thus, island thinking can be linked to garbage in, garbage out.

"Bad communication is people just not reporting, putting in work and then saying this is my drawing. And the moment they see something could go wrong here, that they don't signal that, that they think this is what I was told, I'm just going to do it like this." (2)

"When there are changes, it is often not or poorly communicated. You may know about it, but I don't, and I'll move on. Then I might run into problems that you might have foreseen." (3)

Island thinking is enabled by digitalization, as this allows people to isolate themselves physically, as this provides the opportunity to work remotely. Working in the digital age has moved the discussion media, such as drawings, online thereby moving communication to the online environment.

"People are behind their screen more. So, people are more concerned with their own world. With their things and everything, communicating digitally. While we used to spend much more time behind the drawing board, that is of course in the 2D drawing time." (2)

Follow-up problems result from the interpretation of agreements and the system (elements). Despite agreements regarding the way of working being made, these are not always followed up by the team.

"I do hear from others that a BEP is written, but that no one actually does anything with it. It's written because it needs to be written. I have not really experienced it myself within projects, but I think it does happen because for some it remains a must. Here you have your BEP, it is ready and then it disappears in a drawer and a completely different way working is used." (4)

When team members do not follow the agreements made, this results in individual interpretations regarding the use of the system. Consequently, the quality and consistency of the output cannot be guaranteed. For example, several versions of a documents exists, where it is unsure which document has the complete or correct information. Or certain assumptions have been made in a certain step resulting in data that cannot be used for the desired purpose.

"And it's not working precisely. And that is also the agreements you make in advance, of what should the output be? Because you can imagine that if you mix all those categories or you do a floor as a wall, you will want the quantities of the walls later and that it will say I only have three walls, while you have a lot of walls . But that is modeled as a floor. Then it won't work. You have to agree in advance what they will do with the model later." (2)

Problems related to time pressure stem from two types of time pressure in the activity. First of all, developments in the digital way of working have moved fast over the past decades. As such, project participants have had to constantly adapt and learn new skills. The resulting digital way of working has ensured that physical distance between actors in the project no longer causes time delays.

"So, what used to be drawn by a draftsman or what a designer could do, you can now present that much faster to the customer at a distance or, however. Those steps have progressed a lot in the last few years." (3)

This, in combination with tighter planning and limited budgets, has led to an overall time pressure on the project. This enhances the occurrence of other problems related to BIM as well as communication. In terms of BIM, project team members can be limited in their abilities to learn due to constant pressure on the project. As such, certain shortcuts might be taken to reach a desired outcome, despite that this goes against the agreements.

"A lot of people are busy; people have all kinds of reasons. But this is often the first thing that is neglected." (1)

"Of course, these are all things that we basically don't want. But if we don't facilitate it properly, people will do it anyway. People are under project pressure, 'it has to be finished by Friday'." (1)

The time pressure on the project also leads to problems with communication. This is further enhanced by the ability to share work digitally. As a result, there is a risk that project team members to not update one another.

"And what usually what happens is that we don't inform each other about it. The previous situation was I have completed this document, here is my signature. Here's my document, you can continue with it. There was a conscious moment of communication. And now that's about the first thing that fails to happen so many things are happening at the same time." (1)

Table 12 Imbalance in system

3rd order construct	**2nd order construct**	**Definition**	**Proof quote**
Imbalance in system	System dependency	People depend on the system for communication	*"And that we might be leaning too much on the systems that help us with that. That we think okay communication isn't necessary anymore because you can see that I have uploaded that file and that it says version three instead of version two."* (1)
	Garbage in, garbage out	The software will simply do what you tell it to, the quality of the output depends on the quality of the input information	*"But the tools you work with. So, the laziness of such a clash report, you still have to look through it yourself, but it is much more provided that you can continue with without having to look at everything yourself."* (4)
	Information overload	There is a large amount of information that project participants have to familiarize themselves with at the beginning and throughout the project	*"That people don't read the agreements. And at a certain point there is too much information available, so that you cannot see the forest for the trees."* (5)
	Island thinking	Everybody has their own role on the project, they can be prone to working on their own island and not collaborate	*"Bad communication is that people simply don't signal, do their job and then say, "this is my drawing". And at the moment that they see that something might not be going right, that they don't signal it. That they think "this is what I was told to do, I am just going to do it"."* (2)
	Follow-up	Problems resulting from different understandings regarding the follow-up of agreements	*"Let me put it like this, if they make use of BIM, then I think it will help. But not everybody makes us of it, despite that it is implemented on a project." (6)*
	Time pressure	Time pressure on the project participants stemming from the overall tight project planning, but also the new role definition and	*"But usually, you do because you are under pressure of time and you are also faced with the execution, which is also waiting. But officially that is not how it should go."* (7)

		information requirements of a project team members	

Coping mechanisms

The system has come up with ways to cope with the problems that occur throughout the activity. These copings mechanisms enable the activity system to reach its desired outcome. Three third-order constructs have been identified. The first third-order construct describes workarounds in the system. This are cases in which the other elements of the activity system are used to bypass the problem in another way than they were originally intended, which is somewhere in between the new way of working and the old way of working.

The first workaround is a fallback on analogue methods, describing the situation where, in certain problem-solving situations, analogue methods are used rather than the digital methods that have been introduced with the implementation of BIM.

"People are still, especially on this project, very inclined to look at drawings. Everyone wants drawings to gain a good insight into the construction." (7)

"Actually, the model was not used in that. Often the architect or structural engineer came up with a solution and then it was discussed and then the draftsman will work it out afterwards. So not that we actually did, we were together with the model, but you didn't immediately solve in 3D. A sketch was made. Just like you did on paper, we did it digitally back then because we were in a team solution. But then it was sketched out what it would look like, and the modeler then went to work with it." (4)

The second workaround is leaning. This describes situations in which team members that are unable to use BIM and thus rely on team members who can or on methods they do understand, to achieve their information goal. This workaround can be explained by the problems in the people-area as well as time pressure in the activity system.

"Well, we have coordination models, they can see for themselves how the construction works. Usually, they eventually ask for a drawing with the cross-sections in it, while you can also view that in the 3D model. Somehow that is not clear yet." (7)

"Yes, BIM has a single source of truth as its goal. So, if you are looking for something, from a thickness of a pile or an end of the foundation pile, you have to be able to search for it in some way and not be able to get that answer via via via." (5)

The final workaround is auxiliary. This describes the role of BIM in problem solving situations. The output of BIM plays a role in prompting detection and identification as it offers an integral understanding of the work. However, this is limited to a supporting role, as human interpretation is needed for this prompt to trigger action.

"You used to be a road designer and then you would simply throw it over the fence for someone else to see. And now there is a much more, more integrated view." (3)

"That is often still just sitting around the table and talking about it. That's the first step. And then you use BIM again to see if it has been solved. But I don't really see the tools I use for BIM as a tool to solve it." (4)

"I think you use the images of BIM to guide your conversations, to provide a guideline through the design, you use BIM as a tool, as data to be able to have those conversations." (6)

Table 13 Workarounds

3rd order construct	2nd order construct	Definition	Proof quote
Work-around	Fallback on analogue methods	Analogue methods are used rather than digital (BIM) methods	*"In reality that doesn't happen, sketching in always done in 2D. It is always drawn in 2D and in the end it is drawn in 3D. So only once people are completely confident or content with the solution, that is when the model is adapted."* (7)
	Leaning	Relying on technology savvy team members	*"And then you have to prepare the right views so that they can see that too, because they cannot yet see everything that we do not prepare."* (2)
	Auxiliary	The role of BIM in solution ideation	*"But I don't see the tools that I use for BIM as an instrument to solve it."*(4)

The second third-order construct includes the boundary conditions of the activity system. These are elements that have been proven to be required due to the evolved activity system.

An open team culture is described as a boundary condition for problem solving, as it enables communication. Team members need to know who to approach, based on how responsibilities are allocated, meaning that the lines between project members need to be clear. The implementation of BIM is said to enable this by keeping these lines short.

"Well, then you go to the relevant person, responsible person. And then you basically have a discussion about what the nature of the problem is. And then you come back to your responsibilities, what of the responsibilities lies with you? What can you or can't you do?" (5)

"Sure, you're getting closer together. We actually have four teams, and we want all four teams to do the same thing within [the project]. So, there is a lot of communication and interaction between each other. It will become stronger as the process progresses. But that is different from before. In the past you were alone on your own island, then you were only making reinforcement drawings, and then you had nothing to do with anyone else, which is also fine. But now you seek each other out more and try to get a little more clarity together." (7)

Furthermore, a critical mindset is needed in problem solving. Firstly, a critical mindset is needed in reviewing the output created, either in BIM or in any other form. As garbage in, garbage out, among others, is a risk people cannot solely rely on the output.

"When I go through the model and I see something of a mistake, which I think the structural engineer should perhaps be asked a question about. Maybe he didn't see it himself because he's so focused on his own work that he doesn't see the mistake." (3)

Secondly, a critical mindset has to be taken on while creating input. Creating too much input can contribute to problems in the area of the information system.

"Because it is so easy to add a detail in 3D, it is immediately accepted as true. I still think that… it is certainly a good development, but you have to think carefully every time about which phase of the project are we in now and how true is what is in the model." (4)

The third boundary condition is regulating. Regulating is defined as formally recording decisions and discovered issues. This can be done with help of the information system or older methods. On the one hand, this boundary condition is helpful in dealing with problems related to level of detail and garbage in, garbage out and island thinking, but on the other hand it adds to the problem of information overload.

"But this week we have a meeting about those recesses and then it is coordinated, next week I have included it. Well, that's good. We include that in relatics of now clash number is as much as it is good next week will process the action list there or next week to see if it has been resolved. Is it resolved, check the box and you're done. Or not, then we say how is that possible? Yes, that is still a bit difficult, we have not been able to solve it yet. Move on to next time and you make a decision. What are we going to do with it? And that will remain on the agenda until it is satisfactorily resolved." (8)

"It is useful to record that because otherwise you do it your way and Pietje does it his way. Then it is done in two ways, you don't want that either. So, it is also best to record those kinds of agreements." (3)

Table 14 Boundary conditions

3rd order construct	**2nd order construct**	**Definition**	**Proof quote**
Boundary conditions	Open team culture	In an open team culture, project team members can approach one another with ease	*"If I have a problem, I go straight to the other side, and we discuss." (5)*
	Critical mindset	A critical mindset is needed to filter information and carefully review work	*"Only now you are capable of checking much more. You can do your work much more thoroughly."* (6) *"We remain to review each other. Except, there are so many drawings and other things now, it isn't reviewed three times. It is reviewed once"* (2)
	Formalize	Decisions made and issues discovered in the project need to be or can be recorded in a uniform manner	*"And you record that with a BIM plan. So that you have a standard way of working, a standard testing method, a standard recording with the folders, the exchanges."* (3)

The final third-order construct entails management techniques that have been applied in the activity system. This is where elements of the activity system are adapted through management techniques.

The first management technique that is applied is involvement. Involvement is used as a tactic to include team members in the process of making agreements early on, to encourage them to adhere to these agreements in a later stage of the project.

"So, I think you get people to work in the right way more easily without having to go back from oh this you should have done this or that, by pointing out to them from the start on the way of working within the project and also so that you can fall back on it." (4)

The management technique lead describes a situation in which a clear example is set regarding the way of working.

"We now also want to try, for example, to get those project managers who are enthusiastic about this to tell their story because they are part of the club. Not that I or anyone else from semi-external comes to tell them how to do it. Because it feels a bit like 'Wij van WC eend vinden WC een de beste'." (1)

The final management technique is task allocation. Each team member has a specific knowledge and responsibilities. This goes hand in hand with the boundary condition of open team culture. The task allocation enables structured communication. The BIM agreements also play a role in the responsibilities of certain roles.

"It's not just about the modeler, it's about the whole team you put together. So, the geo-technical engineer, the structural engineer, the modeler, the design leader, the interface manager, everyone can influence the process." (4)

"Of course, you have the structural engineers, who ultimately just want to make a design that meets the requirements. Well, they coordinate with geo-technical engineer. They use cross-sections, which come from our models. They coordinate with modelers to implement changes, but they always do so based on the BIM model." (6)

Table 15 Management techniques

3rd order construct	**2nd order construct**	**Definition**	**Proof quote**
Management techniques	Involve	Using involvement as a tactic to encourage team members to perform specific tasks	*"Well, as far as I'm concerned, the most effective way is that the whole project works with it in the way we agreed. Not just me, who writes the BIM-plan, puts it on a drive somewhere, so that it can be ticked off on the to-do list."* (8)
	Lead	Team formation is done based on the willingness of the team	*"While it is actually also part of the managers responsibility to put together the right team that wants to comply."* (5)
	Task allocation	Specific team members are responsible for the BIM aspects of a task	*"And I also notice that designers or design leaders or constructors don't always see what we are doing."* (2)

6.2.1 Introducing BIM

The change in the activity system is initiated by a change in the desired outcome. The new desired outcome is defined as systematic design ideation rather than the previous ad hoc design ideation method. The new desired outcome is driven by three main factors: the organization itself, the client, and the industry as a whole. Following the wider organization, the infrastructure division of the organization has adapted its internal strategy to include modernization and as such prepare itself for the future. The methods for this strategy have in part been copied from other organizational divisions. Project clients are too looking to the future and as such are more demanding in terms of information management requirements. Furthermore, clients provide a financial stimulus to project plans that are finished within the set time and budget. Consequently, organizations are stimulated to take on a more systematic approach. Additionally, the systematic approach is encouraged through the industry. As the organization works together with a many different partners from the industry a structured approach is desired, in which one "language" is spoken and there is mutual understanding among one another. Consequently, the object is adapted to systematic problem-solving. These so-called change drivers lead to status 0.1.

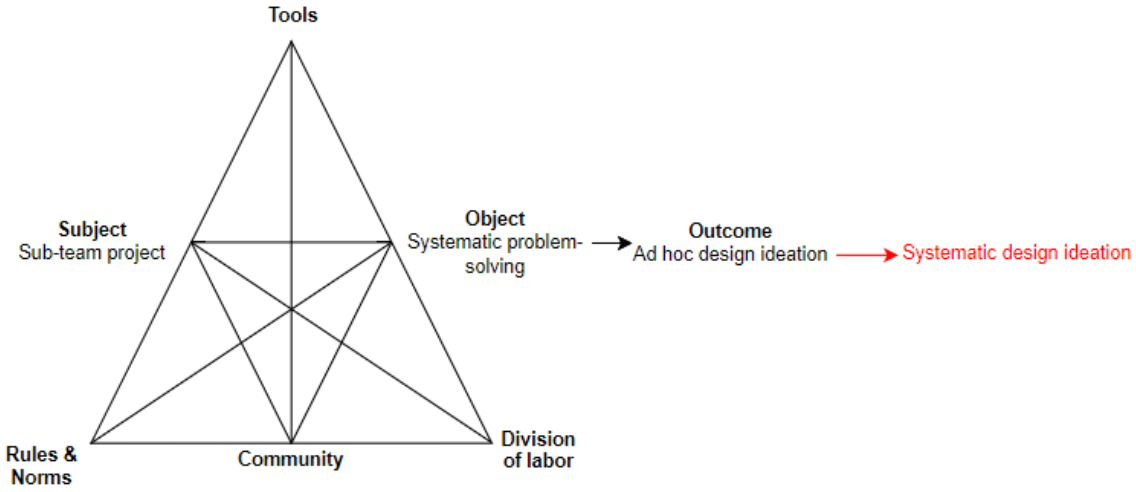

Figure 16 Status 0.1

The current activity system is deemed unfit for achieving the new object of systematic problem-solving, as such a second order contradiction arises between the tools and the object. BIM is introduced in the activity system as a method for coping with this tension. The following quote reflects the introduction of BIM as a manner of created a more systematic approach to problem-solving.

"Yes, that is what I understand as the basis of BIM, bringing back structure." (Interviewee 5)

The implementation of BIM on a project introduces new tools, BIM software, as well as new rules, the BEP and ISO19650. The BIM software allows for the visualization and recording on project information. The BEP and the ISO19650 specify how the visualization and recording of project information should be done, in terms of the process, people and tools involved. As implied by the change drivers, the choice for the implementation of BIM lies with the client and the project management and as such is enforced top down. On the project so-called BIM specialists have been introduced as low-level bureaucrats. The BIM specialists are responsible for managing the information system. The changes to the activity system result in status 0.2, which can be seen in figure 17.

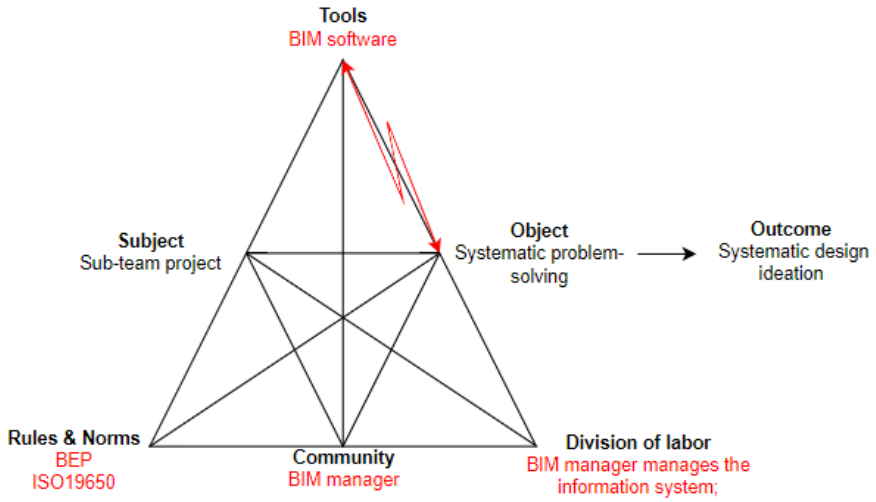

Figure 17 Status 0.2

Simply implementing the elements of BIM does not lead to it immediately being taken up by the subjects in the activity system. As the new way of working has been introduced top-down, not all subjects react positively to the implementation. A second order contradiction arises between the BIM team (community) and the sub-project team (subjects), stemming from the difficulty of convincing colleagues of value added through the use of BIM.

"If you want us to progress and come closer to the methods as they are described in the standards, you will have to take people by the hand a bit more. And if people have the idea that it's of no use to them or that it only costs them time, they will dig their heels in." (Interviewee 8)

Besides the willingness among subjects, the new systematic way of working is also hindered by the abilities of the subjects. There is a lack of understanding as to what BIM exactly is and how it can be used. The new systematic way of working, involving BIM, requires new processes and skills. In combination with the variation in willingness, this lack of understanding among subjects creates barrier to the receptiveness of the subjects to BIM.

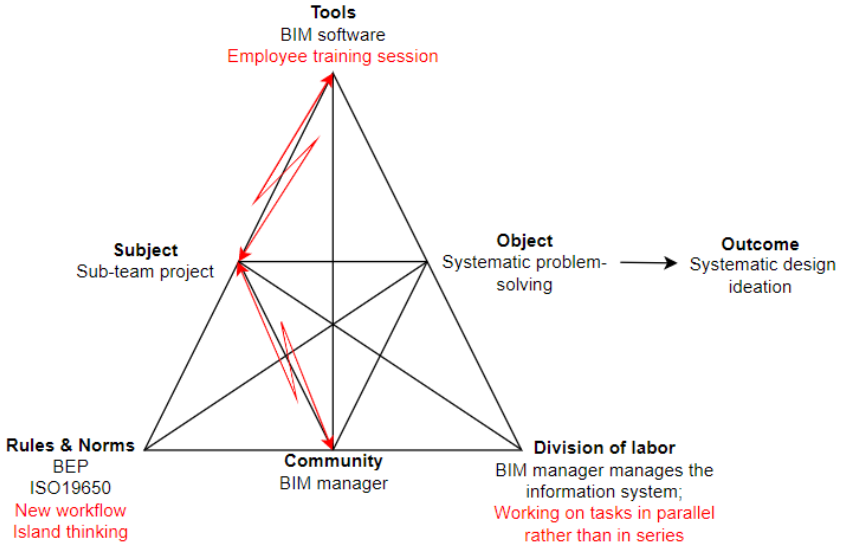

Figure 18 Status 0.3

In response to these contradictions, new workflows are introduced, as well as a voluntary training program for employees to learn new skills related to the use of BIM and the related software. The implementation of BIM results in the need for project team members to boost their personal skills. The need for these new personal skills is underlined in the following quote:

"Everybody gains new skillsets and has to communicate differently. For a project leader that could be that they have always worked in a certain way and that has always worked for them. And now suddenly, they have to take different steps or steps that he has to execute. Become visible, reviews, approve drawings and appoint the right people. Maybe they used to read all the documents themselves and now they have to trust that other people read the documents thoroughly and just scan them themselves." (Interviewee 5)

The training program is set up to enable all employees, and thus project team members, to be able to start working according to this new method. However, participation in the training program is voluntary, and as such is up to one's willingness, which has been linked to personal and external factors, to follow the program and actively learn. The importance of participation in the training program is highlighted in the following quotes:

"And on a project like this, who is expected to work with BIM? Everybody!" (Interviewee 5)

"I think that it provides more involvement within the project that is approached in a BIM manner." (Interviewee 4)

A shift has taken place in the allocation of tasks, the so-called path among which information is exchanges has changed. Where parties used to work in sequence, due to the fact that they had to wait for one party to be done with a certain task to get specific information, the implementation of BIM offers the ability to work on tasks is parallel, as multiple parties have access to the same information at the same time. This is reflected in the following quote.

"In the past it was the case that once one person was done, the other could get started with that as their input. And now we have a sort of live environment in which we can do thing together." (Interviewee 5)

In this activity system, where there is the opportunity for actors (subjects and community) to be always connected, subjects are likely to stay on "their own island", and simply do what they have been instructed to. This is reflected in the following quote:

"People indeed often work in silos. And thinking beyond those silos, not everybody does that. Of course, there are certain roles that you can expect that will do that. But most people are happy they can produce what is expected of them within their silo. Never mind looking beyond it." (Interviewee 1)

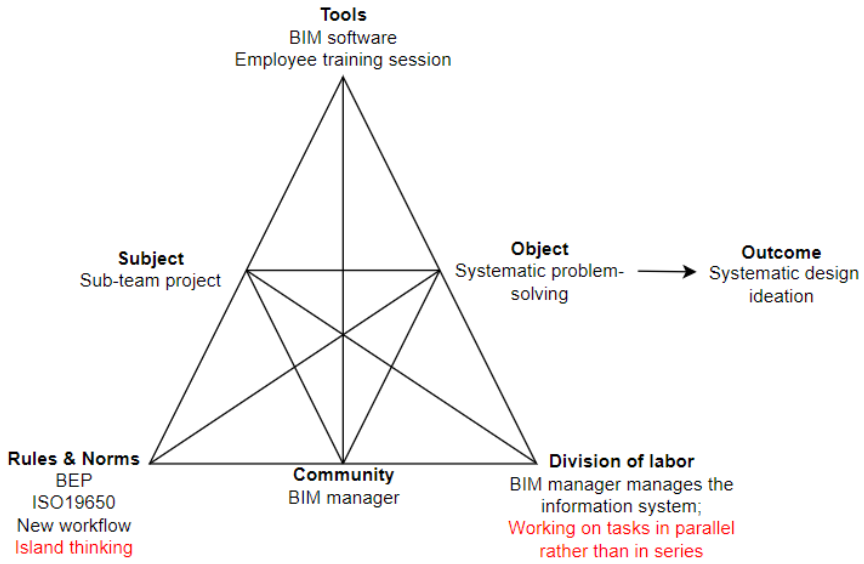

Figure 19 Status 0.4

The activity system in figure 19 will be used as a basis for the further analysis. In this further analysis, the two scenarios in which messy talk occurs will be analyzed with the goal of understanding how the implementation of BIM plays a role in communication practices for problem-solving. The two scenarios both reflect a specific step in the problem-solving cycle, scenario one describes solution ideation, whereas scenario two describes problem identification. The implementation of BIM expands the possibilities of digital communication, as it offers a new platform via which actors can interact. At the same time, older tools such as e-mail and MS Teams are still an option for digital communication. The immediate changes due to the implementation of BIM have occurred mostly in the mediating elements of the activity system (tools, rules, division of labor). Although the system has evolved in response to the contradictions that come up due to the implementation, certain contradictions and implementation issues remain unresolved. The contradictions in the activity system that remain due to the implementation of BIM are felt by the subjects of the activity system. In the following section, the two previously identified communication scenarios will be linked to the ASM development due to the implementation of BIM to create an understanding of the development of messy talk in the design phase of a BECP.

6.2.2 Scenario 1

For the BIM model to have an added value, it must contain a certain level of information. While executing a task, a subject or multiple subjects can run into the issue that this level of information does not meet their needs. This issue cannot be solved independently. There is a need to interact with other subjects and potentially also community members. Situations where people discuss are prompted due to the fact that the discoverer needs information to continue their work. Subjects have a strong focus on their own task and are prone to staying on their own so-called island, thereby hampering collaboration.

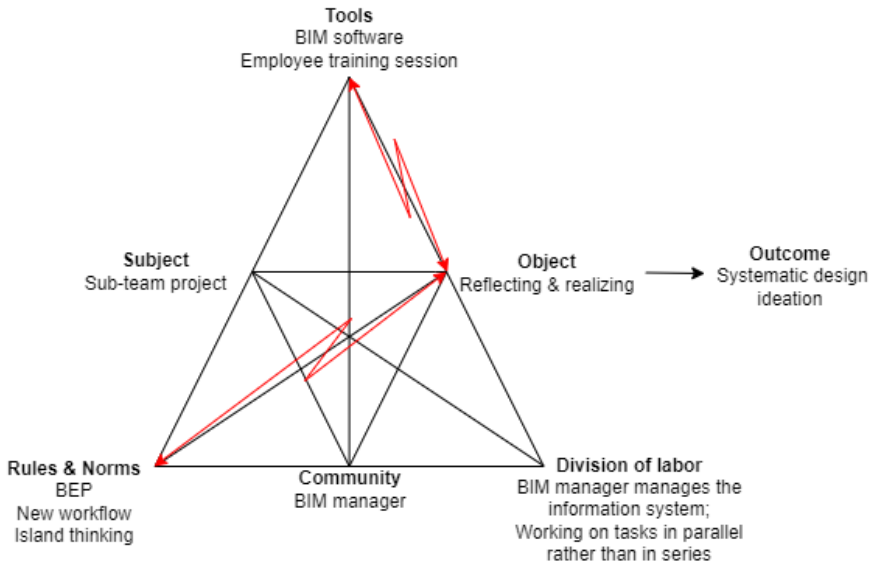

Figure 20 Status 1.1

To cope with the problems related to the lack of detail in the project and the norm of island thinking interaction between subjects is required. Interactions in the workplace occur between two or more colleagues and are spontaneous meetings in which project team members discuss an aspect of the work. In these discussions, issues can come up, either prompted by the verbal discussion or the other team member sees something in their work while they are 'looking over their shoulder', while initially discussing something else. These interactions require an open team culture in which subjects are encouraged to discuss topics with other team members freely, thereby exchanging the information that they need, among themselves and with the community.

The type of issues that are considered in this activity system include those falling inside the scope of the contractual agreements. In the case of an issue that seemingly falls outside of the contractual scope, a design leader or even the project manager is involved. Technical-related issues fall outside of the scope of this activity system. In this scenario, it is not up for discussion if there is an issue, rather the focus is on solving the issue. Other colleagues can join the conversation, either by invitation or independently. The choice for approaching a particular colleague is made based on authority and experience, usually a colleague with more seniority in the same discipline is approached. For the interaction to continue, the issue that the subject is dealing with has to be acknowledged by the colleague team member (MD) and has to have been given an initial response (CE).

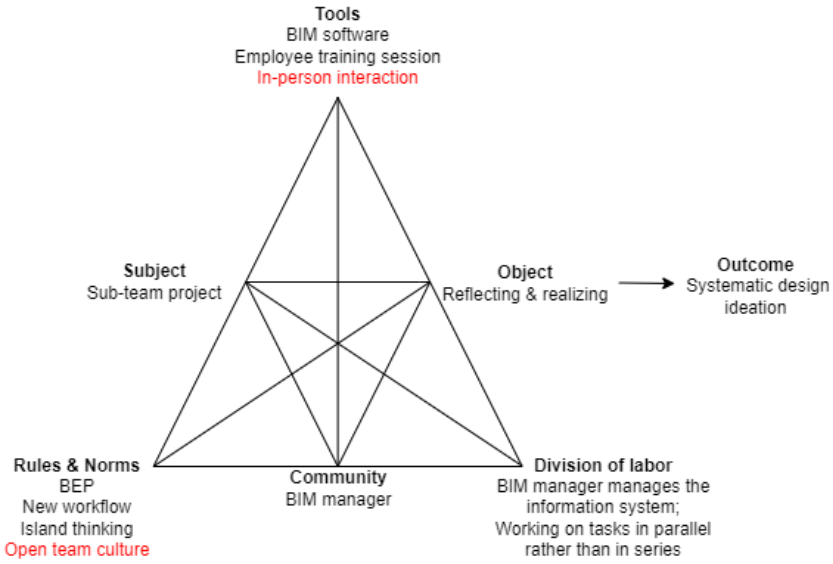

Figure 21 Status 1.2

The tools in the activity system are not flexible enough as a discussion medium, and as such do not lend themselves to knowledge exchange. This leads to a second order contradiction between the subject and object mediated by the tools, as the subject cannot reach the object in the current activity system using the current tools. BIM is given an auxiliary role here. The unresolved, and thus underlying, tension between subjects and BIM also plays a role in discussing potential solutions. The underlying time pressure on the activity system prevents subjects from being able to learn at their own speed. As such, the subjects do not have adequate skill in using BIM as a tool for trying out potential solutions. Consequently, subjects fall back on older methods that they have experience with, such as digital or analogue sketches, to as a medium for exchanging information. Having the right tools is necessary for knowledge exchange.

Besides the subjects' difficulties with working with BIM, the client and contractor's (community) BIM maturity also affect the use of BIM. Several aspects of the process, including how meetings are set up as well as aspects of BIM, are introduced and adapted throughout the life cycle of the project. As projects are done in collaboration between multiple actors, these parties need to agree on a uniform way of working. When the subject and community are not aligned in terms of BIM, the project team agrees on, for example, their own naming conventions, with the idea to be able to change to the actual naming convention once this has been determined.

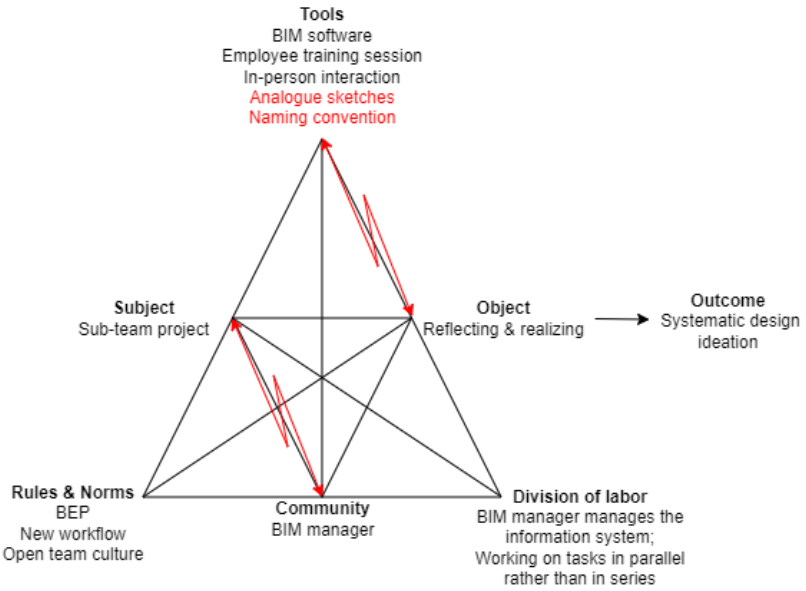

Figure 22 Status 1.3

The analogue methods and internal agreements are used by the project team in knowledge exchange. The subjects and community members involved in the discussion related to the discovered issue come to a solution as to how to solve the issue. Once a solution has been decided on, it needs to be incorporated in the BIM-model according to BEP agreements to ensure consistent information and avoid two sources of information. Until the solution has been incorporated in BIM, there is a primary contradiction in the tools, as the information in the sketches do not necessarily comply with BIM, the model as well as the BEP. If the explicit information is not being recorded properly in the system in the system, project team members run the risk of using different, perhaps even contradictory, information.

To incorporate the solution in the BIM model, the responsibly subjects have to provide the correct information. This requires understanding what is asked of them in the BEP. There is a risk of an information overload concerning information related to the new way of working as well as project specific information. Project team members need to become familiar the with the new way of working. At the same time, there are substantial amounts of project related information, due to the size and the complexity of the project, that team members needs to become familiar with. Project team members becoming familiar with either BIM or general project information after the project start are at risk of an information overload.

Furthermore, the administration tasks involved in BIM are met with some resistance by the team members, as it is not how they would preferably be spending their time. The BEP is made but not always lived up to by the project team. For BIM to be effective, working according to the agreements in the BEP is essential. BIM is said to offer a decrease of work over the whole project life cycle, but in the design phase, project team members feel that the amount of work has actually increased. Subjects are expected to deliver input for the BIM model, thus resulting in an increase of tasks for the subject. It seems like a small number of tasks that are added to what a member of the project team has to do to work according to BIM, but this is experienced as a burden because it means that they cannot spend time on the 'fun' things.

The resistance in the project team stems from the limitations in terms of willingness as well as familiarity. Information overload too can be linked to the limited familiarity of the project team. The limited willingness is tackled by leading the project team in a BIM-minded way, thereby creating a certain pressure to comply. Limited familiarity with BIM and the related agreements is

tackled by involving project team members from the beginning of the project and throughout, inviting them to provide input for potential changes to the BEP.

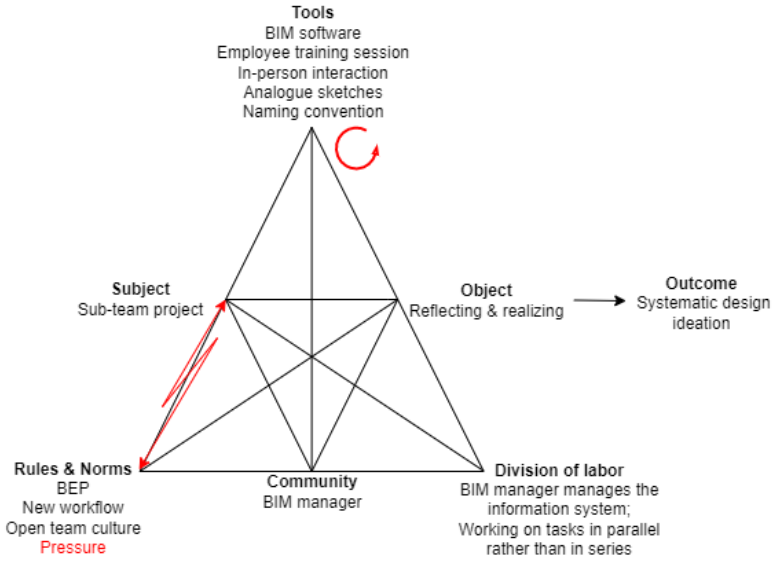

Figure 23 Status 1.4

Recording the solution according to the BEP provides the means for being able to evaluate the solution with the surroundings, to check if the solution also works in terms of the interfaces. Consequently, the division of labor is further defined by the role of a project team member as the civil engineers come up with solution, which is used as input by the BIM coordinator (community) to create the BIM model and check the solution in the bigger picture. With this clear task allocation, there is the risk that modelers are only involved at the end of the messy talk interaction, thereby feeding the separation of processes and thus island thinking.

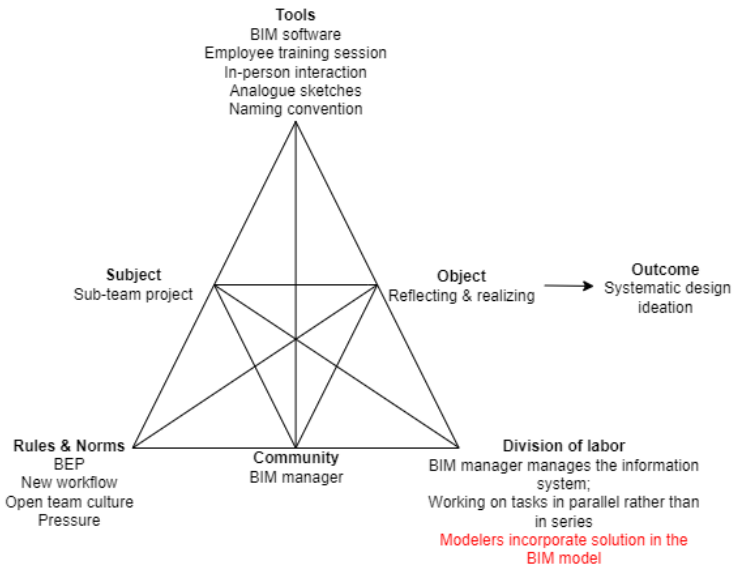

Figure 24 Status 1.5

6.2.3 Scenario 2

In discussing certain aspects of the project, often the interfaces, a high level of understanding of the project and overall experience is needed. These interfaces could be on system boundaries of the total scope of the project, or of a smaller scope on boundaries where sub-areas of the project meet. Visualization, in particular 3D visualization, can offer support in cases like this. Some issues are much more easily discovered with the support of the BIM model visualization. These types of issues can be discovered with clash detection tools, which is a part of BIM, or when the models are used as a talking point. This requires that subjects have a basic understanding of BIM and its functionalities. With BIM, the detection of potential problems is brought to an earlier stage in the overall project life cycle.

"I think, when you apply BIM, you can control much more, so naturally you run into more issues. So yeah, you run into more issues when you use BIM because you are trying to catch everything" (Interviewee 6)

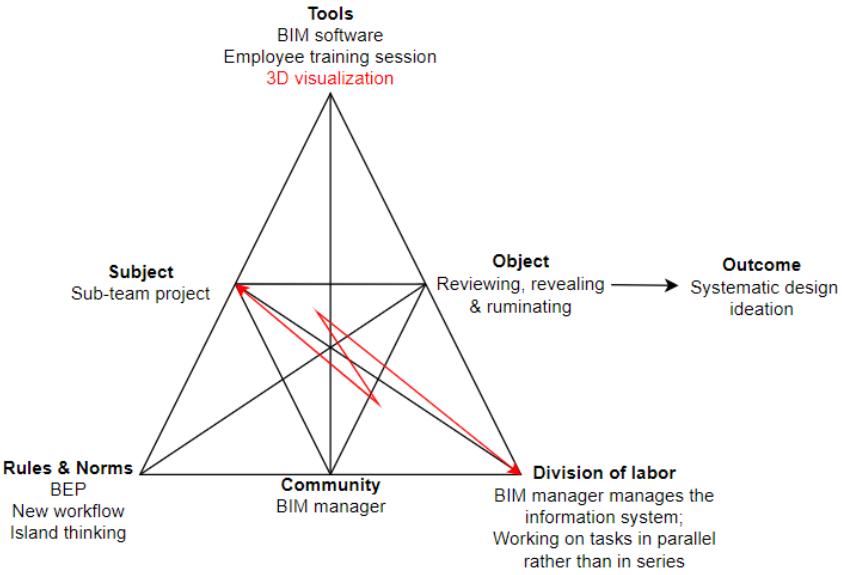

Figure 25 Status 2.1

Despite the efforts to engage employees in the new way of working, contradictions remain. Firstly, a first order contradiction between the subjects and the community remains. New specialist knowledge is required for understanding what BIM is and how to use it, which is offered to project team members in the form of the voluntary training program. However, since it is up to oneself if they partake in the training program, there is the risk of a split in the project team based on BIM abilities. Consequently, some project team members are unable to work with BIM and thus do not use it properly or use it at all, whereas other project team members are able to work with BIM. Adapting to the change in the way of working has been linked to personal traits by several interviewees. Personal differences are also reflected in the capability of people to use the BIM-environment. Here, age is mentioned as an important factor. It is often mentioned that the older generation has a more challenging time with it than the younger generation. This makes sense as younger people are so-called digital natives, who have grown up in the digital age and as such are comfortable working in digital environments. Furthermore, due to the task allocation, some team members come in to contact with BIM more readily, whereas others can execute their work with little interaction with BIM. Subjects who cannot work with BIM lean on their colleagues, either sub-team members or BIM team members (community), who are capable of working with BIM. Consequently, there is a shift in the division of labor.

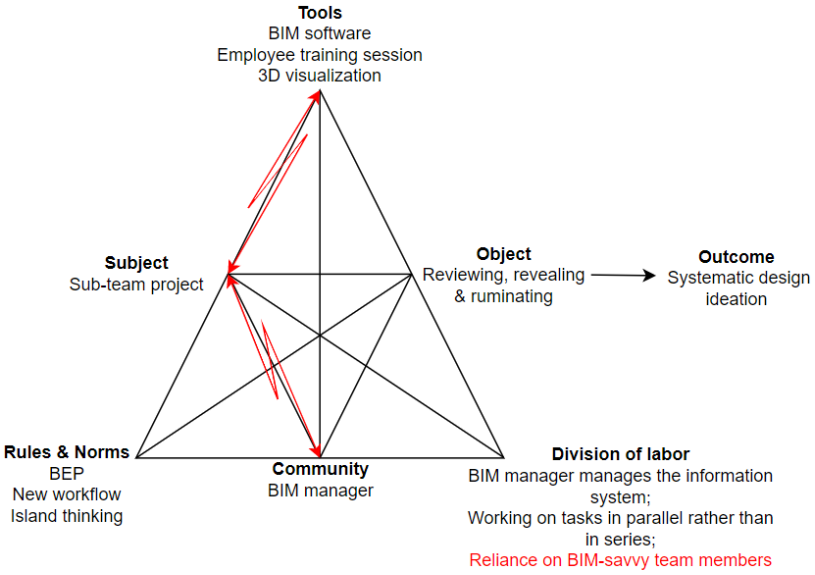

Figure 26 Status 2.2

The possibility for clash detection using BIM software has simplified the review process for the work. The so-called four eyes principle is still applied, meaning that at least one other project team member has to review the work before it is sent out for external review. This process of internal review used to involve more project team members, but now tools are used in this process too. In the DO phase, the input in the model initially comes from another organization in the project. However, as the output from the model strongly depends on the input, the so-called garbage in, garbage out concept applies here. Thus, when using the BIM model as a tool in reviewing the work, team members must be wary of fully relying in the output from model. Moreover, in relying on BIM too much and not staying naturally curious, team members run the risk of missing problems that did not show up in BIM but actually should have been seen. Thus, it is important that subjects stay critical and rely on their own experience when an issue is identified using BIM. While BIM can help identify and locate issues through visualization, it is still up to the people involved in the issue to decide that something is a serious enough issue that it has to be dealt with and when it has to be dealt with. The capability of the person who finds the issue to bring it to light is essential for the identification to lead to mutual discovery. To diminish the risk of garbage in, garbage out, subjects are strongly encouraged to formally record decisions and issues in BIM, according to the agreements in BEP.

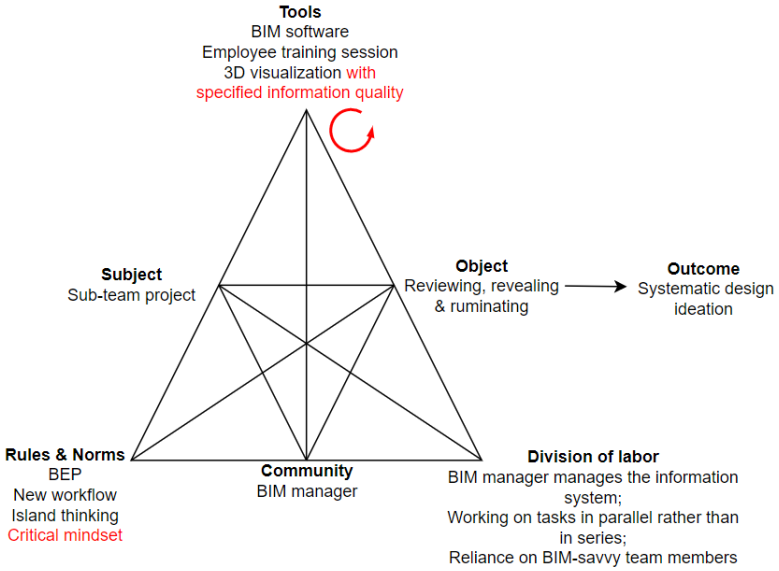

Figure 27 Status 2.3

The shift to working behind screens and still have the option to communicate with others creates the risk of system dependency. A certain ease has been creating by the ability to comment something instead of discussing it in-person. Similarly, when depending on the system, team members rely on another team member to notice a change in, for example, the document name and expecting them to check the new document based on this. The communication patterns described above are grounded in the idea that people go to each other when they see a problem. A subject's personal communication skills play a role here. An open team culture is needed to cope with this risk. This encourages team members to talk to each other and help each other out. The in-person interaction leads to messy talk situations in which issues are studied and discussed using the BIM model as a background.

The problems related to screens represent a tension between different development phases of the activity system. On the one hand, team members need to spend time behind their screen to prevent garbage in, garbage out and to record findings and potentially decisions. However, the screens also offer an easy way of communicating as team members can tick off tasks on their to-do list, thereby promoting system dependency.

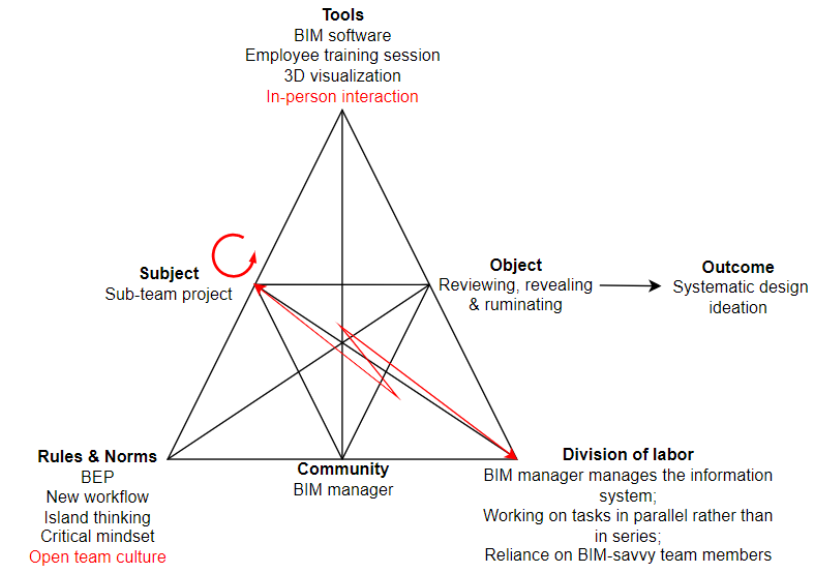

Figure 28 Status 2.4

As the first three elements of messy talk, mutual discovery, critical engagement, and knowledge exchange, have occurred, the final step is taking a decision to resolve the issue. In the case of problem identification, the resolution becomes 'parking' the issue to be further discussed at a later moment, by either turning it into an agenda item for a following team meeting or taking it to a person with a higher level of authority. This is because the solving of the identified issue does not necessarily have to occur in this exact moment or because the responsibility for further action does not lie with the subjects involved in the identification of the problem. An exception to this is messy talk with the purpose of ruminating, as the outcome of ruminating does not lead to a change in the course of action. These further problem-solving practices are no longer messy talk because the interaction will no longer qualify as unplanned.

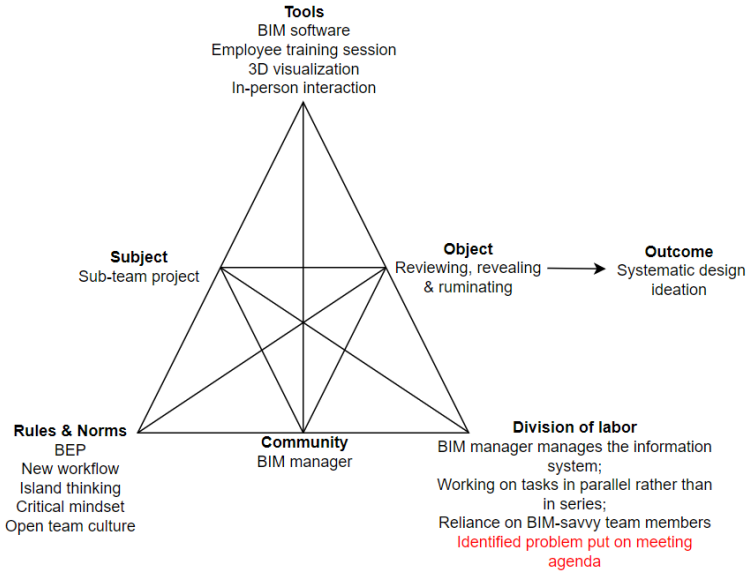

Figure 29 Status 2.5

6.3 Impact

In this section, the impact that the different instances of messy talk and contribution of BIM in the two scenarios will be discussed. The implementation of BIM reflects a focus on the explicit knowledge needs. On the other hand, messy talk is a valuable method for exchanging implicit knowledge. In both scenarios of problem-solving, both information needs play a role. So-called coping mechanisms have developed due to the struggle in the system that comes from trying to become more structured through BIM but at the same time remain messy. Implementing BIM has consequences for the way in which a project team communicates, some of which have an effect on messy talk. Although these consequences do not explicitly prevent messy talk, some do discourage messy talk. On the other hand, messy talk can distract project teams from BIM. Both messy talk and BIM are beneficial when it comes to project team communication, therefore it is recommended that the application of either should be balanced.

The five basic principles of activity theory, defined in section 4.2, are reflected in the activity system in this research. The first basic principle of activity theory is represented by the activity system being collective, tool-mediated, and object-oriented as it describes a collective activity of communication in which actions are mediated by the tools in the activity system. Moreover, the activity in the activity system is considered to be object-oriented. Despite the goal-directedness of some actions in the activity system that do not line up with the object of the activity system, the activity system is successful in reaching its goal. The analyzed activity system of communication practices in a BECP can be placed in a network of relations to other activity systems with other collaboration-oriented objects. Furthermore, the activity system describes a community of varied perspectives, in which participants with similar individual histories have their own position due to the division of labor. In addition to this, the activity system adheres to the third basic principle

of historicity of activity as the specific history of the activity system can be used to explain the tensions created in the activity system and opportunities that stem from them. This ties in to the fourth basic principle, as the development of the activity systems are powered by the contradictions that can be found. Finally, traces of the fifth basic principle, describing expansive transformation, can also be found in the activity system. If the contradictions in the activity system are not sufficiently addressed by the suggested management interventions, it falls within reason that subjects might start to question the norms upheld by the activity system. Consequently, this might lead to expanding the scope of the current object and motive of the activity.

6.3.1 Problem-solving cycle

In analyzing the two scenarios, it was found that the scenarios reflect different aspects of the problem-solving cycle. Messy talk with the purpose of revealing and reviewing can be placed at the beginning of the problem-solving cycle. These messy talk interactions start with the discovery of something that might be an issue and are resolved by determining that it is indeed an issue which needs to be solved and why it is an issue. In these cases, the solution is to "park" the issue, where the issue will be taken up in a meeting dedicated to the technical solution or where the issue will be introduced to someone with a higher hierarchical ranking. Messy talk with the purpose of reflecting and realizing can be placed at the middle and end of the problem-solving cycle. The messy talk interaction starts with the knowledge that something is an issue and quickly moves on to how to solve it. The issue is resolved by settling on a solution, which could be in the form of a content-related task or a decision to 'escalate' the issue to a higher level of management. This leads to the conclusion that the two scenarios can create input for one another and as such build on each other.

It is important to note that it is the intended outcome of the activity system, rather than of the subjects. Although the outcome is intended, because the intention is that of the activity system and not of the subject, the situation adheres to the messy talk characteristic of being unplanned, unanticipated, and unforeseen. In scenario one, the goal of the activity system is to determine and agree on how to go about an issue, leading to the outcome of an approach for this aspect of the project. On the other hand, the outcome of scenario two is an identified issue that has been formalized by putting it on a meeting agenda or taking it to an actor with more authority. Although the two scenarios both have different type of desired object in each of the scenarios, they are still both in line with the new desired outcome and both types of messy talk.

6.3.2 Prompts

As defined in this research, BIM consists of two main aspects: the process and the model. Both of these aspects of BIM play a different role in the two scenarios of problem-solving. When considering the consequences of the implementation of BIM on the activity system, certain conclusions can be made about the relationship this has with the occurrence of messy talk. Messy talk is predominantly enabled through the elements and applications of the BIM model. Alternately, the processual aspects of BIM, such as the BEP, are mostly barriers to the occurrence of messy talk. Some of the problems in the system are not directly linkable to BIM, but more so to the systematization of the system as whole, which BIM is a symptom of. The information in BIM is considered to be a given and to be correct. However, the occurrences of workarounds challenge this, as these workarounds introduce issues into the model that are not necessarily so-called hard clashes that can be detected by system. Furthermore, in the DO, the project team is dependent on information provided by actors involved in previous design steps of the project. While the BEP is in place to ensure a uniform way of working, this has proven to be challenging in reality. BIM has an added value here, but because of these workarounds it is not yet foolproof. Messy talk is not replaceable in these types of situations. Therefore, it is desirable to facilitate messy talk in the design phase of a construction project. At the same time, for messy talk to have added value, the people on the project need to have a feeling for when to engage in it and when to rely on another

form of communication. Furthermore, problems which are less concrete and cannot necessarily be seen in a visualization do not lend themselves to detection through BIM very well.

In comparing the two scenarios, the prompt of the messy talk as well as the intended outcome of the activity system differs. BIM can either be instrumental or the outcome of an interaction depending on the purpose of the messy talk. In scenario one, the messy talk is prompted in a way similar to that described in previous research, which will be referred to as "classic" messy talk. This is messy talk in which the topic is prompted by a discussion on a different topic, thus leading to mutual discovery. In this scenario, the absence of information in BIM led to project team members directly communicating with one another, thereby facilitating messy talk. During the messy talk interaction, the agreed naming convention comes in handy when referring to parts of the project. The use of BIM is limited in the messy talk interaction, as it does not offer the flexibility and activeness needed from a discussion medium (Dossick and Neff, 2011). This does not make BIM a barrier to the occurrence of messy talk, but at the same time it is not enabling messy talk either. In this scenario, BIM is used for recording, reviewing, and communicating the determined solution. In this scenario, it can be concluded that the occurrence of messy talk prompts the use of BIM.

Contrastingly, in scenario two, BIM acts as a prompt for messy talk, be it the visualization or the clash detection software. However, human reaction is required to actually initiate the messy talk interaction. This type of messy talk starts with critical engagement, as the initial discoverer engages critically with the issue and together with a team member comes to a mutual discovery. Messy talk prevents wasteful problem-solving. This is highlighted by scenario two. Due to the messy talk in the scenario, subjects can avoid the BIM-induced issues of 'garbage in, garbage out' that occur because of earlier workarounds or shortcuts taken. The occurrence of messy talk ensures that the outcome (formalized issue for agenda) is an actual problem that requires a technical solution and should therefore be a formalized agenda item. The messy talk, rather than for example troubleshooting, allows the participants to get to the root of the issue through critical engagement and knowledge exchange. Messy talk prevents the sole reliance on the capability of BIM to detect an issue. The prompt to 'start' messy talk interaction does not have to be real-time in the interaction, it can also be before, thus creating delayed messy talk, or after, where one messy talk interaction acts as input for another. So far, research has operationalized the elements of messy talk but has not yet determined if these elements occur in a fixed sequence. The results from the analysis show that the elements that kicks off the messy talk is guided by the purpose of the interaction. The sequence of mutual discovery and critical engagement are interchangeable in terms of which marks the beginning of the messy talk interaction.

6.3.3 Risks and requirements

While the implementation of BIM offers a multitude of benefits to a project, especially over the life cycle of the project, it also brings risk within terms of project team communication. This is illustrated in scenario two. BIM provides a so-called communication shortcut, as it provides the opportunity to rely on BIM for the exchange information, thereby pushing the project team away from messy talk interactions. On the other hand, the people-related barriers to BIM implementation, in the shape of tensions in the activity system due to the variation of capabilities and willingness in terms of BIM, pushes team members towards messy talk interactions. Both scenarios reflect the need for project team members with a critical mindset and a project team with an open team culture. The changes in the division of labor can be influential on the project team culture, as regulated responsibilities can encourage team members to remain on their own so-called islands. Furthermore, both scenarios speak to the risks that might occur when people communicate indirectly, via MS Teams, e-mail, telephone or BIM, discussions are often limited to what was planned. As such, there is less of a stimulant to bring up another topic and potentially trigger a messy talk interaction. Similarly, there is a risk that messy talk becomes dependent on

the personality of the team members, as it generally occurs when people interact in-person. Messy talk offers the benefit of providing the project with an outcome that was not known to be needed. The information overload and increase in activities makes the team members unwilling to work according to BIM but feeling of pressure makes them do it anyway. The application of coercive tactics should be used sparingly as this counteracts the benefits brought about by open team culture.

Messy talk proves to be useful in situations where subjects do not have the full authority for decision-making regarding solutions but do have the knowledge and experience to take a step in the problem-solving cycle. In situations of problem identification, authority is not required during the messy talk interaction, but might come into play after resolution, when a decision needs to be made if the problem requires action. The analysis reflects that for BIM to be advantageous, a certain level of cooperation and use is required. When it comes to following the BEP and providing input for the model, this is not optional. Project team members have to adhere to the agreements and requirements recorded in the BEP. Based on the described way in which the model can be used as a prompt for messy talk, not adhering to these agreements could get in the way of the occurrence of problem identification. However, the use of the output the BIM model is much more optional. Team members can opt to use the visualization power of the model to their advantage, but they are not obliged to do so. There is little encouragement to urge conservatives towards the use of BIM. The conservative team members can manage their work by using other mediums for communication, namely older systems that are still in place, such as drawings, or leaning on the early adapters, these are team members who do understand and work according to BIM.

Although the empirical data did not reflect any specific requirements in terms the setting in space of the scenarios, the activity system analysis provides insight into which settings lend themselves to the two types of messy talk. Two general settings are considered, namely co-location, where all communicating parties are present in the same location, and hybrid, where communicating parties are not all in the same location thus requiring a digital communication channel such as MS Teams. As solution ideation, scenario one, is prompted by conversations between project team members, team members need to feel the flexibility and time to bring up topics in a conversation but also to join in conversations they might overhear and feel enticed to join. Furthermore, flexible mediums play a key role in this type of messy talk. Although there are digital drawing boards available, sketching on paper was more commonly mentioned as a flexible medium in the empirical data. As such, co-location is considered to be most conducive to this type of messy talk. On the other hand, problem ideation, scenario two, is generally prompted by the digital visualization provided by BIM. In this scenario too, project team members have a need to contact a specific team member. As the initial step of this messy talk interaction, critical engagement, has taken place between a team member and the computer, both a hybrid setting as well as co-location lend themselves to this scenario.

7 Operationalization and validation

This section discusses finding a balance in messy talk and structed communication and as such finding an answer to sub-question four, which reads *Which management interventions can be identified to enable effective communication in the project team context?* Following this, the results and the operationalization will be validated to prove their relevance and robustness. Based on the validation, the operationalization will be amended.

7.1 Operationalization

Messy talk and BIM have been shown to both have a value added in problem-solving communication practices. Thus, it is necessary to find a balance between the messiness and informality of messy talk and structure and formality of BIM. This section proposes a strategy for enabling effective project team communication in a BIM-enabled construction project. This is done using the results from the activity system analysis in the previous chapter. First, the timing of the interventions is determined. Then, the tensions occurring in the two scenarios that have to be considered are identified. Subsequently, management interventions for dealing with these tensions and who they should be employed by are distinguished. Finally, these three elements are encapsulated in the proposed enabling strategy.

7.1.1 Strategy determination

To design an effective enabling strategy, the management interventions have to be placed such that they are most effective. As such, a strategy outline has been created based on the outcome of the analysis. In order to fill in this strategy outline, management interventions have to be determined. To determine these management interventions, the existing elements of tensions have to be analyzed and categorized according to the relationship with either BIM, messy talk, or both. Next, these elements of tension are linked to so-called areas of attention. These areas of attention are used to establish specific management interventions. Finally, it is established in which settings these management interventions could be employed, and who is involved in their employment.

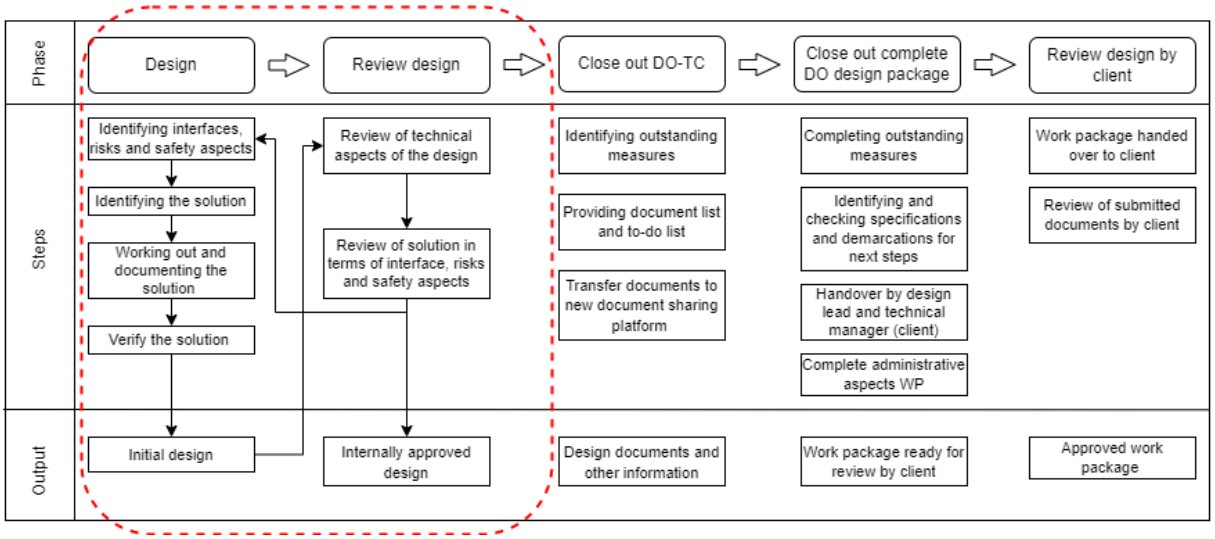

Figure 30 Focus of enabling strategy (Adapted from Sturino Project Management Plan)

The differences between the two problem-solving scenarios can be explained by placing them in a specific step in the design phase. Scenario one, solution ideation, is more likely to occur in the first step of the design phase. Although this might seem counterintuitive, this makes sense when considering the context of the scenario. The lack of detail in the BIM model can be explained by the fact that the design phase has only just begun. Messy talk with the purpose of reflecting and realizing is needed so that team members are on the same page concerning the course of action.

At the same time, the output of this messy talk is recorded with BIM thereby progressing the level of detail in the BIM model. This can be used as input for other problem-solving situation, be it messy talk or another approach to problem-solving. Scenario two, problem identification, can be placed in the first as well as the second step of the design phase. The level of information is already somewhat developed here as solutions are in the process of being worked out and documented, thus explaining the possibility of BIM to prompt messy talk. There is still room for messy talk with the purpose of reviewing, revealing, and ruminating, as the design is not yet finalized and still has room to improve.

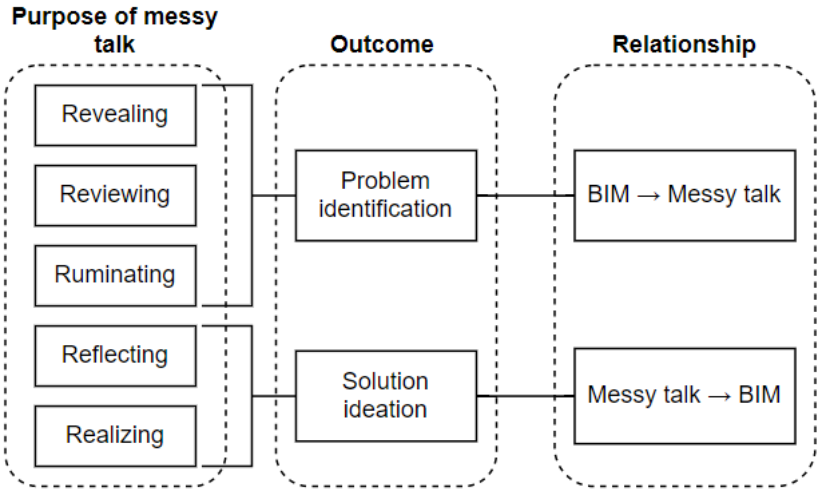

Figure 31 Summarized outcome of the analysis

The outcome of the analysis has been summarized in figure 31. This is used in determining the approach for developing the enabling strategy. As scenario one is likely to occur first in the design phase, this will be taken as a starting point in the enabling strategy. Seeing as messy talk prompts the use of BIM, the barriers and enablers related to messy talk in this scenario will be the first to be included in the enabling strategy. After this, the barriers and enablers to the use of BIM will be included. Moving on, the barriers and enablers in scenario two will be incorporated in the enabling strategy. As here it is BIM prompting messy talk, the barriers and enablers not yet included by the enabling strategy in the previous step will be incorporated. Finally, the barriers and enablers to messy talk in this scenario, which have not yet been included, will be now introduced in the enabling strategy.

7.1.2 Areas of attention

In both scenarios of messy talk, contradictions arise between the elements of the activity system. Whereas several contradictions are tackled in the evolving activity system, others become latent and appear again in later stages of the activity. Based on the description of current communication practices in the two scenarios that can be described after the implementation of BIM certain barriers and enablers of effective communication can be identified in the activity system. The concepts are described below.

Screens

The digitalization of the workplace allows flexibility in terms of workplace. Employees no longer have to be at the office every day as they can rely on digital communication channels to stay in contact with their colleagues. The information management systems that have developed in the digitalization age allow subjects to depend on the system to communicate for them rather than doing it themselves. At the same time, employees are encouraged to spend more time behind their screens in an effort to upkeep the information management system. This can be discouraging the direct interaction between people.

Authority
Having authority is vital to decision-making. However, not having authority does not mean that certain elements of the problem-solving cycle cannot be fulfilled. If a decision falls outside a subject's scope of work and authority, it can either be escalated horizontally, for example to other project team members, or vertically, to a higher level of management.

Personal communication skills
A subject's personal communication skills has a significant effect on the occurrence of messy talk. Subjects that are inclined towards synchronous, in-person communication will be more likely to engage in messy talk, whereas subjects who are inclined towards asynchronous or indirect communication are more dependent on others to engage in messy talk.

Island thinking
Situations in which subjects stay on their own island, meaning they stick to executing the work that has been assigned to them and to not confer with colleagues, are not conducive to messy talk. The introduction of a digital information system comes with a large amount of additional information, in some cases leading to an information overload. In combination with specific task allocation, this can encourage further island thinking.

Open team culture
In an open team culture, team members feel comfortable in approaching colleagues both horizontally and vertically in the organizational hierarchy. Open team culture allows project participants to engage in conversations from which messy talk can flow.

Experience and knowledge
The experience of team members is vital to their work as it provides them with insights and knowledge they need on a daily basis. Furthermore, it encourages their critical mindset which creates a basis for gaining more knowledge. Experience can encourage the development of personal skills but also nurture the willingness of team members, in both a positive as well as a negative way.

Agreements
Agreements, such as a naming convention, provides uniformity for certain elements of a project. This not only forms the basis of BIM but is also provides structure to messy talk interactions as team members have a mutual understanding of project elements. Conversely, the lack of agreements can cause issues and situations of incoordination, especially between the project team and other parties involved in the project, such as the client or contractor.

Administration
The implementation of a new information system brings administrative changes with it. The increasing amount of project information can be overwhelming to team members. At the same time, team members are expected to do more administrative tasks to ensure the relevance of the information in the information system. Time pressure is a constant underlying, systemic tension in both of the activity systems. The additional administration in combination with time pressure creates a strain on the occurrence of messy talk.

Personal stance towards digitalization
There is a divide in the personal stance of team members towards digitalization, or the subsequent changes. On the one hand, so-called conservatives can be identified who oppose the changes due to digitalization. On the other hand, the so-called early adapters embrace these changes. This is not a strict, dichotomous divide, there are also team members with more nuanced opinions. The stance towards digitalization can be described on a spectrum, ranging from early adapters to conservatives.

In creating the enabling strategy, a balance has to be found in terms of messy talk and structured communication by means of BIM. An overview of the barriers and enablers of effective communication, categorized by their influence on BIM or messy talk, is given in figure 32. In some cases, a barrier to either messy talk or BIM can be an enabler for the other.

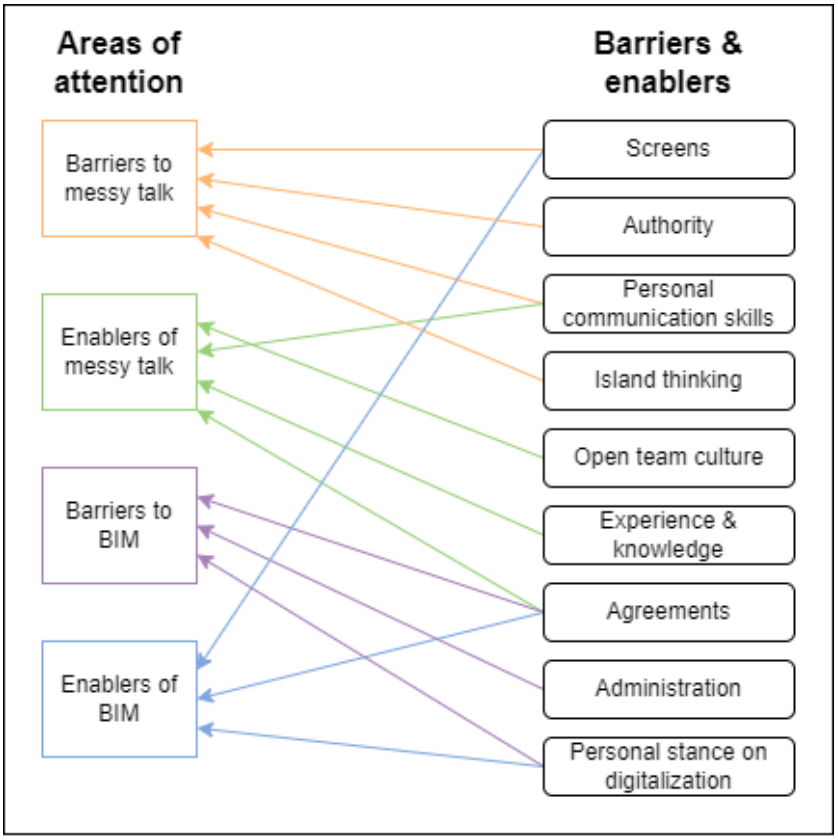

Figure 32 Relation between barriers/enablers and BIM and messy talk

7.1.3 Management interventions

The identified barriers and enablers can be linked to four main categories. These four categories demarcate areas of attention in which need to be accounted for in the proposed enabling strategy. It is important to underline that these are areas of attention rather than areas of improvement. The difference in the concepts "attention" and "improvement" is nuanced yet is important in terms of interpreting the proposed enabling strategy. The concept "improvement" implies that a change has to be made and that this change will lead to a better result, whereas the concept "attention" implies that the barriers and enablers must be considered while constructing the enabling strategy. The four areas of attention are the team, instruments, leadership, and external organizations.

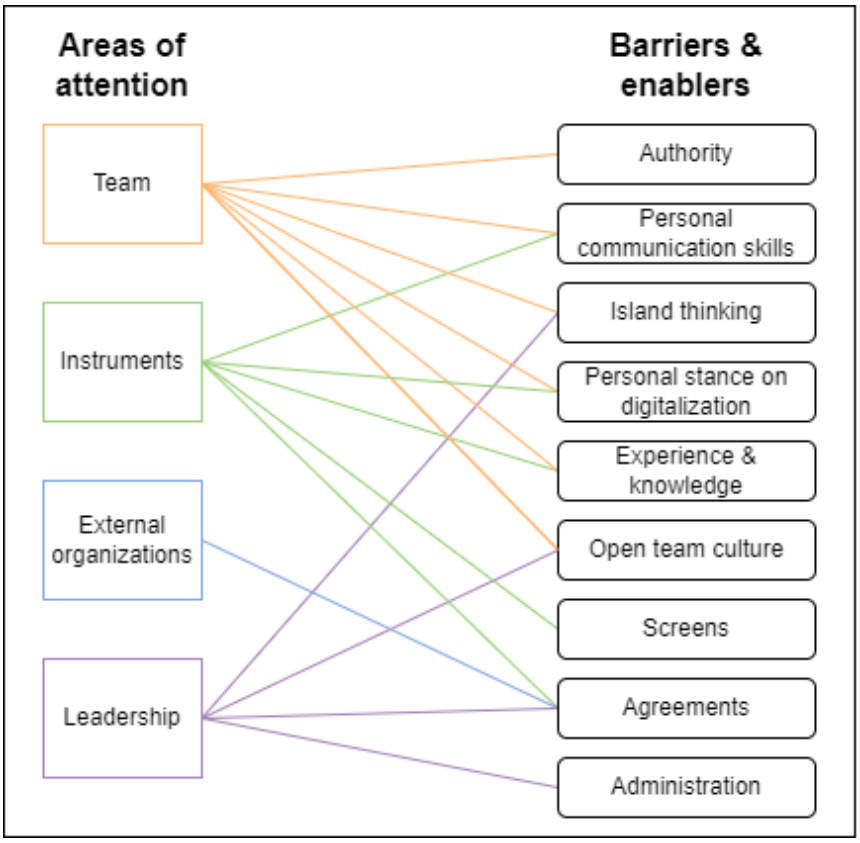

Figure 33 Areas of attention

Using the areas of attention, general requirements can be identified. These general requirements are used to guide the elaboration of specific management interventions. The management interventions are formulated as instruments for project managers and team leaders to apply to an intra-organizational project team working on a BIM-enabled construction project. The project manager plays an important role in fostering collaboration in a BECP. Previous research has shown that enabling a bottom-up approach is beneficial in BIM-enabled construction projects, as it provides practitioners with tools to be employed as they see fit (Hartmann et al., 2012). The requirements are assertiveness, coordination, employed instruments and active leadership (see figure 33).

The barriers and enablers in the category Team requires assertiveness to be respectively tackled and encouraged. Assertiveness is defined as knowing when and how to act. As such, a certain level of transparency concerning processes, expectations and information is needed.

The barriers and enablers in the category External organizations require coordination to be respectively tackled and enabled. As barriers and enablers in the category Team and in the

category External organization are both related to people, these requirements have been combined.

The barriers and enablers in the category Instruments require employed instruments to be respectively tackled and encouraged. Employed instruments is defined as the understanding and proper use of the instruments that play a role in the respective scenarios.

The barriers and enablers in the category Leadership require active leadership to be respectively tackled and enabled. Active leadership is defined as knowing when and how to steer the project team. Leadership is found on several hierarchical layers, including but not limited to, the project manager and the design leader.

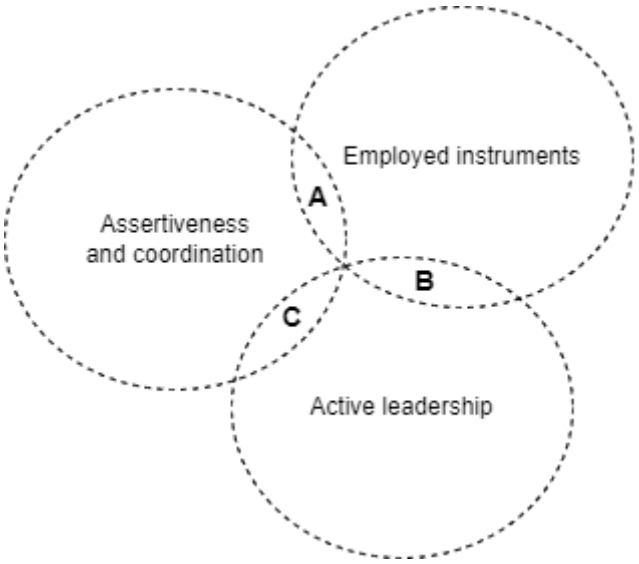

Figure 34 General requirements

Several specific management interventions have been identified to enable the project team to meet the defined requirements. Several currently employed management interventions can be identified among the coping mechanisms that occur in the activity system. Further management interventions are based on the researchers understanding from empirical data collection, including the interviews and observation rounds.

The management interventions have been designed with the purpose of meeting a requirement, or a combination of requirements. The overlapping areas have been given labels for ease of reference. These labels are included in figure 34. In table 16, the link between the management intervention and requirement(s) is shown. As can be seen in the table, the majority of the management interviews meets a combination of the requirements. The management interventions have been purposely designed as such, so that the number of interventions done can be minimalized.

Table 16 Linking management interventions to the requirements

Requirement	Management intervention
Active leadership	Open door policy
	Revoking 'Any other business' as meeting agenda item
Employed instruments	Sketch modeling
A	BIM training
	Open iRoom
	Interaction meetings
B	Model as agenda
C	Messy talk awareness
	Workplace management
	"Ask why out loud" campaign
	Team building and personal training

The management interventions are explained in detail below. This explanation includes how the management intervention will meet the necessary requirement and as such which barriers and enablers will be tackled through this intervention. A visual overview of the relationship between the management interventions and the barriers and enablers can be found in appendix D.

Team building & awareness for personality
Project teams are made up of a broad selection of team members, some of which already know each other, for example from a previous project, whereas others have never worked together before. Team building activities in the project team encourages bonding among team members, which can help lower the threshold of approaching a team member. A subject's awareness of their personality, and that of their team members, can help in understanding why team members make certain communication choices and can be considered when making decisions regarding communication. This intervention has been designed with the purpose of encouraging personal communication skills and open team culture and discouraging island thinking.

"Ask why out loud" campaign
By encouraging team members to ask themselves and other why aloud when they run into an issue, critical questioning becomes a standard practice. This is necessary for tackling island thinking. At the same time, this intervention is designed to encourage team members to develop their personal communication skills.

Regular BIM training & demonstration
As working with BIM is a relatively new concept for team members, it is important to facilitate team members to learn about what it entails and how it can be used in their work. These trainings should be short and limited to a small component of BIM. This has the purpose of relieving the information overload without adding on to it by providing too much information at once, thus increasing team members familiarity with agreements regarding BIM. By employing regular, role specific trainings, this management intervention aims to gradually increase experience and knowledge with BIM and its application. Although the process of administration is not decreased by this intervention, it does offer insight in the process thereby alleviating the barrier of administration.

Workplace management
Workplace management is defined as the enforcement of (semi-)mandatory office days & flex workplaces This offers the opportunity for people to listen in on other interactions and potentially join in, which might lead them to topics they were not necessarily aware they needed to discuss.

Furthermore, by encouraging office days, team members are provided with the opportunity for informal interaction. As such, the focus created by island thinking can be broken up.

Model as agenda
This intervention suggests using the BIM model as a visual meeting agenda rather than a classic written meeting agenda with the aim of promoting the visualization power of BIM for prompting messy talk interactions. This management intervention has been designed with the purpose of increasing the experience of applying BIM. This intervention aims to show the added value of BIM to team members by making use of BIM output in a common task, with the result of creating understanding for the change in administrative aspects of the work.

Awareness of messy talk among design leaders
This management intervention is at team members in leadership positions, for example design leaders or discipline leaders. It is included as a heed for the pitfalls of efficient processes. The results from the analysis show the added value of messy talk to interactions. By making leaders aware of messy talk, leaders can encourage messy talk by allowing room for it in meetings and other group interactions.

Interaction meetings
These are held to promote interaction with team members from other parts of the project, such as team members from other sub-areas or disciplines, that an individual might be apprehensive to approach or not normally come into contact with. This management interventions has been designed to encourage a critical mindset, mitigate island thinking, and enable a subject to expand their experience.

Revoking 'Any other business' as meeting agenda item
The item 'any other business' is a common final item on a meeting agenda, in which attendees at presented with the opportunity to bring up points of attention that they want to discuss. However, as this item is placed at the end of the meeting, there is often little time left for it. This management interventions has the intention of promoting interaction, with the potential of messy talk, during a meeting, rather than waiting until the end to bring up possibly interesting points of attention. This management intervention has been designed with the intention of encouraging an open team culture.

Open iRoom
An iRoom is a multi-screen meeting room, used at RHDHV to present and discuss projects with stakeholders. The goal of the open iRoom is to introduce a so-called discussion station to the project, which is a stimulating and enabling setting where team members can come together to discuss their work, thereby using the qualities of the barrier 'screens' to enable messy talk. This offers the opportunity for people to listen in on other interactions and potentially join in, which might lead them to topics they were not necessarily aware they needed to discuss. This intervention attempts to avoid system dependency and island thinking. Simultaneously it aims to encourage BIM learning in an accessible way for increasing experience and knowledge, both related to BIM as well as to the project in general. By showing the value added of BIM and messy talk, the personal stance that might initially form a barrier to messy talk can be employed as an enabler.

Open door policy
An open-door policy is aimed at the higher management on a project. This encourages these managers to keep their doors open, thus lowering the threshold for team members to approach them. This intervention attempts to deal with the issues related to authority.

Sketch modeling
Sketch modeling, which is defined as fast, rough modeling, promotes the use of BIM to more quickly evaluate the solution thought of in a messy talk interaction. It is important that team members are wary of the issues garbage in, garbage out and two sources of information. To mitigate this, a team member is appointed as the responsible party for solution incorporation, testing and feedback. Ideally, a review buddy would be appointed.

Two settings where management interventions could take place have been identified. These are meetings and the open workplace. Meetings are mostly used to discuss updates, task related as well as project wide, and assign and confirm the division of labor in a sub-area project team. Meetings are structured by a meeting agenda, which consists of main discussion points, to keep the meeting concise and to the point. Resulting, individual members of the project team are aware of the specific tasks that they carry the responsibility for. Every so often, some meeting time is allocated to BIM, be it a training on the use of BIM or the model used as a discussion point. Contrarily, the workplace provides a much more flexible setting for interaction. Interactions in the workplace are varied in their purpose and are not bounded by an explicit agenda. The involvement of team members is also flexible and can be fluctuate throughout the interaction as team members can join and leave an interaction more easily. Team members can be involved in an interaction either by their own initiative or by request. An overview of the characteristics of the two settings is provided in table 17.

Table 17 Characteristics of settings

Characteristic	**Meeting**	**Workplace**
Purpose	Preconceived ideas, as to what the purpose of the interaction is, are a limiting factor to the occurrence of messy talk	Multitude of purposes for these type of interaction
Agenda	Fixed agenda	Open “agenda”
Involvement	Sub-area team (fixed) – risk of too many people	Whomever is initially approached and team members that join later
Time	Constrained by set time – some room for runover	Possibly constrained by later engagements but otherwise flexible
Hierarchy	Clearly defined hierarchy	Mixed hierarchy, depending on who is involved
Instruments	Digital information, sketches	Drawings (printed), digital information, sketches (hand-drawn)

Some of the management interventions have been designed for a specific setting, whereas others are unbounded and could be applied in either setting. An overview of intended setting of a management intervention is provided in table 18.

Table 18 Management interventions in setting

Setting	Intervention
Unbounded	Team building & awareness for personality
	"Ask why out loud" campaign
	Regular BIM training & demonstration
	Workplace management
Meetings	Model as agenda
	Messy talk awareness
	Interaction meetings
	Revoking 'Any other business' as meeting agenda item
Workplace	Open iRoom
	Open door policy
	Sketch modeling

7.1.4 Enabling strategy

The enabling strategy has been developed by considering the theoretically defined tasks in the design phase and combining this with the results from the empirical analysis. The previous sections have explained the design of the management interventions and the theory behind the structure of the enabling strategy. Combining this information leads to a proposed enabling strategy for effective communication in a BIM-enabled project team.

The purpose of the enabling strategy is to create opportunity for the identified types of messy talk and facilitate effective communication in the project team of a BIM-enabled construction project. While instinctively, the first reaction would be to implement a strategy that avoids the coping mechanisms, the strategy embraces them and recognizes their role in the communication practices. The relationship between messy talk and BIM is recognized in the different scenarios, and as such the interventions are geared towards strengthening this relationship rather than pushing the communication practices more towards either BIM or messy talk.

In an effort to keep the enabling strategy readable and concise, the management interventions have been number. The numbers mentioned in figure 35 correspond to specific management interventions, as can be seen in table 19.

Table 19 Numbered management interventions

Nr.	Intervention
1	Team building & awareness for personality
2	"Ask why out loud" campaign
3	Regular BIM training & demonstration
4	Workplace management
5	Model as agenda
6	Messy talk awareness
7	Interaction meetings
8	Revoking 'Any other business' as meeting agenda item
9	Open iRoom
10	Open door policy
11	Sketch modeling

The proposed enabling strategy, visualized in figure 35, shows where the management interventions might be done in the early steps of the design phase. The arrows between the steps indicate the forward flow of the work. The dashed arrows represent the feedback loops in the design phase. These feedback loops represent learning cycles, in which the output of a later task

forms input for an earlier task. The results from the empirical data underline the importance of involving the project team from the beginning. This has been incorporated into the strategy by suggesting management interventions that can be done from the very beginning of the project, and how management interventions can continue throughout the project.

There are two possible placements of the management interventions. Management interventions placed inside a particular step are intended to be applied in that particular task. Contrarily, management interventions placed between an arrow between two steps are intended to be applied in the step both ahead of the arrow as well as after it. As several management interventions have an added value in terms of solution ideation as well as problem identification, these interventions can be employed in either of these steps or, if desired, in both.

Finally, it should be noted that the proposed enabling strategy has been designed in such a way that not all management interventions have to be employed to reach the intended outcome. It is up to the project manager, design leader or other team member in a management role to decide which management interventions to entertain. In making this choice, one should take heed of the focus of the management interventions, being either BIM, messy talk, or both. This is important as intervening more with the BIM aspect or the messy talk of the communication practices might bring the practice is disbalance, thereby steering the project team too much towards BIM or messy talk and away from the effectiveness of their combination. In doing so, the proposed enabling strategy can be tailored to the needs of a specific project. To aid the manager in this, the management interventions have been color coded according to their focus. Management interventions that are more likely to steer towards more and improved BIM are yellow, whereas management interventions that are more likely to steer towards messy talk are purple. Management interventions designed to steer towards improved BIM and messy talk are red. Finally, management interventions that do not specifically gravitate towards either are white.

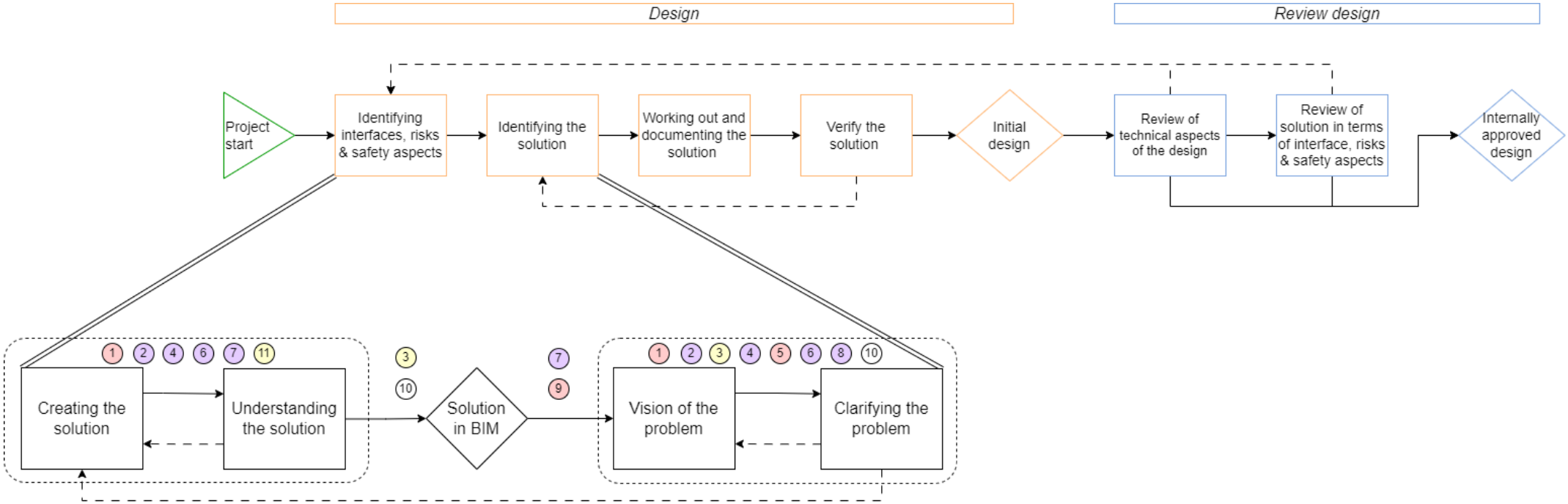

Figure 35 Proposed enabling strategy for effective problem-solving communication

7.2 Validation

Validation is done to ensure the robustness of the results. This is especially important in qualitative research, where there is a risk of researcher bias (Johnson and Jehn, 2009). In this research, validation is done in two ways. The first goal of the validation is to validate the results of the activity system analysis. Secondly, the recommendations are validated by holding expert validation sessions. As the recommendations stem from the analysis results, the expert validation sessions also serve the secondary purpose of validating the results of the activity system analysis. This is especially important as the results are influenced by the interpretation of the researcher, which is a common issue with qualitative data analysis.

7.2.1 Set-up

In this section, these methods and the set-up of the validation will be discussed. As the validation has two goals, two methods will be applied.

The validity of the results of the activity system will be underpinned by validating the codes used for the activity system analysis. In research performed by a research group, the reliability of the coding is established by multiple coders. However, since this research has been performed by a single researcher, a different method for establishing reliability has been sought out. The coding is validated by means of cross referencing the number of proof quotes for the codes with the number of unique interviews that the proof quotes originate from. Ideally, there is a high number of proof quotes and the number of unique interviews providing proof quotes for a code is equal to the number of proof quotes for a code. As it expected that there are codes where the number of unique interviews is lower than the number of quotes, an acceptable margin is set at 50%. This implies that a code where the number of proof quotes is made up by 50% or more individual interviews. If a code does not reach this acceptable margin, an in-depth examination of the situation will be done.

The management interventions cannot be validated using activity theory, as activity theory is a descriptive theory rather than a predictive theory. Therefore, a different method has been chosen to validate the management interventions, namely expert validation. The goal of the expert validation sessions is to validate the content and timing of the management interventions. Rather than hosting a group validation session, private validation sessions were held with a number of experts. This was done in an effort to prevent groupthink.

The validation session has several goals. The first goal is to ensure that the outcomes of the activity system analysis are correct. This is especially important because of the qualitative nature of the research. Qualitative research is subject to the interpretation of the researcher, so by validating the outcomes of the activity system analysis, this interpretation bias is minimalized. Secondly, the management interventions, based on the outcomes of the activity system analysis, will be validated to ensure their practical relevance. The relevance of the individual management interventions will be discussed in terms of the effectiveness and feasibility. The relevance of the combined management interventions will be discussed in terms of completeness.

To ensure robustness of the results, the participants of the validation sessions are different to the participants of the semi-structured interviews. Similarly, to ensure that the management interventions were relevant and feasible, the participants of the validation sessions had different roles in project, ranging from a leadership role to an engineering role. The participants role and years of experience are included in table 20. Open-ended questions were asked in order to encourage the participants of the expert validation sessions to share their vision and professional opinion.

Table 20 Participants of expert validation session

Nr.	Role	Years of experience
1	Design leader infrastructure	9
2	Design leader infrastructure	4
3	Design leader infrastructure	25
4	BIM coordinator	19
5	Structural engineer	10
6	Structural engineer	18

7.2.2 Validation results

Overall, it was established that the codes are reliable. The complete overview of the cross-referenced codes can be found in appendix D. However, it has become evident that there are a few codes that are substantiated by a limited amount of proof quotes. This can be explained by the fact that these were topics that came up that were not a part of the interview questions. This was able to occur due to the semi-structured nature of the interviews. Regardless of the lower number of proof quotes, these codes were deemed to be indispensable in analyzing the activity system and were therefore included in the codebook. This demonstrates that reliability cannot be established solely through quantitation.

As defined in the validation set-up, the management interventions will be validated based on their effectiveness, feasibility, and completeness. Overall, the experts were in agreement with one another. The identified management interventions were deemed to be complete, no recommendations for additional interventions were given. The feedback and suggested amendments regarding the effectiveness and feasibility of the specific management interventions will be discussed below. The results from the expert validation sessions reflected a need for development to ensure the feasibility and effectiveness of the management interventions. Interventions not explicitly mentioned in the discussion were considered to be effective and feasible but are left out of the discussion as no striking amendments were suggested.

Regarding the intervention to use the BIM model as a meeting agenda, experts generally agreed that this would add an interesting dimension to the meeting and would encourage participants of the meeting to actively engage in discussion. However, the feasibility was questioned. It was noted by an expert that this would require exceptional BIM capabilities from the design leader, or other team member leading the meeting. Furthermore, there was a concern that this intervention would spark so much discussion amongst meeting participants that the purpose of the meeting would easily be overridden. In order to manage this, it was suggested to define a scope of discussion.

The intervention messy talk awareness was also well received by the experts, as this was regarding to be a feasible intervention. The importance of taking minutes was pointed out as an improvement to this intervention in order to increase its effectiveness. It was mentioned that besides messy talk awareness, it is necessary to be able to anticipate if the messy talk has added value in the place and time is occurs in.

While the intervention of introducing sketch modeling as a tool for messy talk sparked the interest of the experts, the feasibility of this was questioned due to the strict input requirements of the BIM model. Software development is necessary for this to become a feasible intervention. This also speaks to the feasibility of the open iRoom as an on-site discussion platform. It was suggested to add a whiteboard, or similar medium conducive to messy talk, to this discussion platform. Additionally, experts pointed out that analogue methods, such as drawings, remained to be valuable despite the availability of a 3D-visualizatoin. It was agreed that combining a medium for prompting messy talk with a medium for messy talk itself could be beneficial. By offering both the

drawings and the 3D visualization as a medium for prompting, it is believed that team members will slowly get more familiar with working with BIM and appreciate its value added. The feasibility of this intervention was considered to be dependent on the facilities provided at the organizational level.

The intervention team building was considered to be both effective and feasible. This intervention was considered to be a simple yet effective manner of lowering the threshold and encouraging interaction between formally agreed moments with the result of speeding up the problem-solving process. The experts suggested two points of attention. First of all, the importance of team building on both the project level as well as the lower levels was pointed out. Furthermore, it was observed that team building activities did not solely have to take place in the shape of actual activities but could also be included in everyday work practices in which team members can bond. Such undertakings could simultaneously function as a possible prompt for messy talk. Additionally, it was noted that workplace management ties in with this second, lowkey form of team building which might be more accurately referred to as team bonding. Consequently, several experts were of the firm opinion that workplace management should be more strictly than was initially suggested. Rather than semi-mandatory days at the office, these experts called for at least three mandatory days at the office. On a final note, several experts mentioned that the awareness of personalities should be combined with techniques to deal with colleagues' personalities. These experts were of the opinion that without this addition, the awareness of personalities could be used as a defense mechanism.

Moreover, the suggested intervention of interaction meetings were also regarded to be effective provided that both teams have similar goals. The feasibility was suggested to be improved by not limiting it to meetings but expanding this intervention to the workplace. This could be done in one of two ways. First of all, a buddy system could be established where junior team members are linked to senior team members that they might not otherwise be in regular contact with, such as senior team member from another sub-area. The benefit of doing this is that the buddy does not only have the experience to share but can offer a different perspective while having a base level understanding of the work done in another sub-team. The second possibility is to appoint a so-called linking pin. This is a senior team member who is appointed as the central person in a, for example, discipline specific network. In this way, the linking pin can link team members together that might be able to help one another out. In the designation of a linking pin, it does need to be considered that this may not create too much extra work for the linking pin up to the extent where they can no longer focus on their own tasks.

The intervention calling for the revocation of the agenda item 'any other business' provoked different reactions. Although all experts agreed that this intervention would be feasible, the effectiveness was argued in two opposing ways. Several experts agreed that this intervention would be effective for encouraging interaction throughout meetings, thereby prompting messy talk. However, other experts doubted this, as they considered the active input of to be dependent on an individuals' personality. It was mentioned that for these individuals, the opportunity to mention something at the end of a meeting was a stimulant for bringing up a point of attention. As such, it is suggested that this management intervention is employed depending on the people present in a meeting. The decision to do so falls with the meeting leader, and thus depends on their ability to assess the personality of the meeting attendees.

Finally, the management intervention BIM training was well received by the experts. Several experts pointed out that this management intervention has a strong correlation with multiple other BIM-related management interventions. The feasibility of this intervention was said to be dependent on the availability of the trainer, most likely a BIM coordinator. The effectiveness was mentioned to be dependent upon two factors. Firstly, the topic and the regularity of the trainings.

The topic of the trainings was determined to have to be small, so that an in-depth explanation could be provided rather than scratching the topic. The regularity of the trainings was deemed to be a decisive factor in the effectiveness, as the trainings would have to be given at a very regular interval for progress to be made. In turn, this is dependent upon the availability of the trainees. Secondly, the effectiveness of this intervention was said to be dependent upon the application by the trainees. Thus, it is important that the topic of the training is aligned with the work of the trainee-group so that they can immediately apply it to their work.

To conclude, the effectiveness and feasibility of the management interventions has several boundary conditions. Firstly, technological developments of the BIM software is needed to be able to use the BIM model as a flexible medium. Secondly, organizational investments in facilities are needed to make advantage of the visualization power of BIM. On a project level, adaptiveness is needed to ensure continuous learning. Finally, looking forward, several interventions are expected to be able to be applicable in an intra-organizational project team, provided there is transparency between collaborating parties. Based on these boundary conditions, it can be concluded that several management interventions are more suitable to an organization with a higher BIM maturity whereas other management interventions are less dependent upon the BIM maturity of the organization. This provides another characteristic that an organization can use to tailor the proposed enabling strategy to their needs and abilities.

Table 21 BIM maturity for management interventions

Management intervention	**Suggested BIM maturity**
Team building & awareness for personality	Not applicable
"Ask why out loud" campaign	Not applicable
Regular BIM training & demonstration	Low-Medium
Workplace management	Not applicable
Model as agenda	Medium
Messy talk awareness	Not applicable
Interaction meetings	Not applicable
Revoking 'Any other business' as meeting agenda item	Not applicable
Open iRoom	Medium-High
Open door policy	Not applicable
Sketch modeling	Medium-High

Furthermore, some feedback was provided on points other than the management interventions. As these too are important to proving the validity of the results, they have been included. Scenario one is based the fact that the issues that come up fall within the authority of the project team. Thus, the concept of authority has been included as an area of attention. However, in the validation sessions it was mentioned that in some cases solutions are envisaged, using messy talk, for issues that require approval by higher management. This is done to speed up the process. Rather than asking higher management for a solution, one or two solutions are presented to an issue and simply need to be 'signed off' by higher management. Thus, authority does not appear to be a barrier to messy talk for solution ideation as initially thought, but rather messy talk is applied as a workaround to the potential requirement of authority.

The overall placement of the management interventions in terms of the phasing was considered to be most effective. The added value of messy talk was recognized by the experts in the validation sessions. The experts were of the opinion that the added value of messy talk is concentrated in the earlier design steps. Once consensus is reached, decisions should be considered final, and the focus should be on working this design out properly. An exception should be made for the discovery of errors in the design.

8 Discussion

In this chapter, the implications of the results (section 8.1), and the limitations of the research (section 8.2) will be discussed.

8.1 Discussion

Productivity in the AEC industry is lacking (Green, 2016). In response, the industry has been employing methods in an attempt to establish more structure in the design process. In this research, it has become clear that the ad-hoc approach to design ideation cannot be changed into a systematic approach by simply implementing an information management system. This is underlined by the need for messy talk throughout the process. The complex and dynamic nature of the industry and its projects does not allow for a fully systematic approach to design ideation. Messy talk brings the ability to enable participants to learn things they did not necessarily know they needed to know, the same cannot be said of BIM. Whereas messy talk enables participants to exchange tacit knowledge, BIM is well-suited to the exchange of explicit knowledge. As the attention in literature is currently often focused on the success of the implementation of BIM, this research aims to understand how the implementation of BIM has affected other forms of communication, in casu: messy talk.

This research contributes to science by extending the work by Dossick and Neff (2011) to further understand the conditions under which messy talk occurs in intra-organizational project teams working in BIM-enabled construction projects. The developments of the activity 'communication practices for problem-solving' following the implementation of BIM have been described using activity theory. Five purposes of a messy talk interaction have been identified. These were then grouped into two categories based on the contribution of BIM in the interaction, thereby leading to the differentiation of two scenarios. These scenarios, with differing use of both BIM and messy talk, have evolved in response to the implementation of BIM. The activity systems have reached a transitional equilibrium, in which several contradictions remain unresolved.

In project team communication for solving problems, the messy talk cycle does not have go through the complete problem-solving cycle, from problem identification to solution confirmation. Messy talk does not have to necessarily have to concern a huge problem that is solved in a very messy way, it is much more nuanced. The topic of messy talk can also concern a smaller aspect of the problem-solving cycle. The relationship BIM and messy talk can be described as a chicken-or-the-egg case, as the relationship between the two concepts is not fixed in a specific direction. The analysis results show that where BIM is a prompt to messy talk in problem identification, messy talk is a prompt for BIM in solution ideation. Both cases reflect the delicate balance between either process prompting the other or becoming a prevention. The contribution of BIM and messy talk to the scenarios reiterates the point made by Dossick and Neff (2011) that BIM and messy talk is not an either-or situation. Situations can be described along the spectrum described by Dossick and Neff, as there is always a balance of the two in each type of situation. The two scenarios have been placed on this spectrum based on the contribution of messy talk and BIM in either scenario. Although BIM is used in the scenario of solution ideation, this is done in preparation of the following step in the problem-solving cycle, namely solution confirmation. On the other hand, the role of BIM in the scenario problem identification is much more closely linked to the activity of identifying the problem, therefore this scenario is placed more towards the middle of the spectrum. It should be noted that the placement of the two scenarios is relative. If another scenario were to be identified and placed on the spectrum, the placement of these scenarios might change.

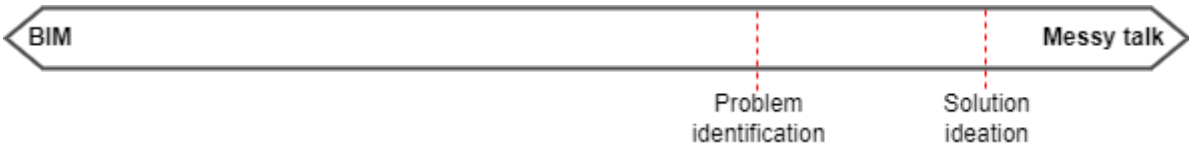

Figure 36 Spectrum BIM - messy talk

The results from the empirical research can be used to reflect on the research proposition describing the relationship between BIM and messy talk, as defined in section 3.4. Although the general outline of this framework holds truth, the practical situation has proven to be more complex. The research proposition has been updated with the results from this research, resulting in the framework visualized in figure 35. This framework includes both scenarios, with scenario one, solution ideation, represented by the orange arrows and scenario two, problem identification, represented by the blue arrows. The framework shows how the output from either scenario might be a form of input for the other scenario. The temporal aspect has been purposely left out of this framework.

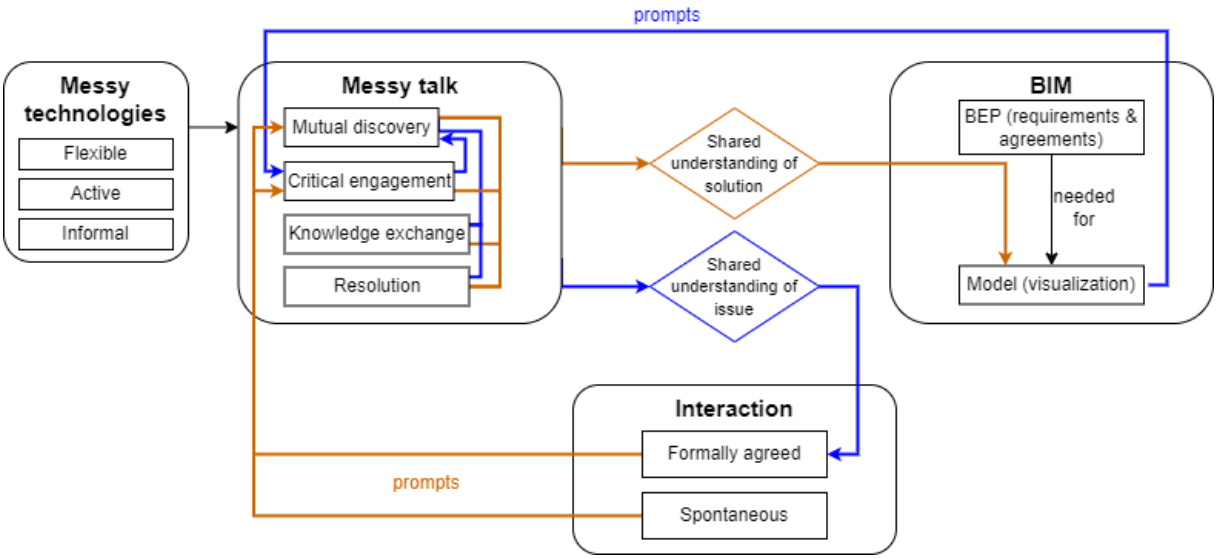

Figure 37 Updated conceptual framework

Dossick and Neff (2011) argue that BIM is used for determining an issue, whereas messy talk is used for determining the solution of the issue. While this may be true in a full-BIM project, where the maturity level is relatively high, the results in this research show that this is not necessarily the case in projects where the BIM implementation is still developing, and the maturity is progressing. In this type of project, BIM and messy talk both play a role in problem definition as well as problem solving. A distinction can be made between the two scenarios in terms of problem identification versus solution ideation, in terms of messy talk purpose and the contribution of BIM therein. This finding is in line with the expectation by Dossick et al. (2014) that "a variety of independent variables including industry experience, leadership, and tool usage may impact the emergence and quality of messy talk". Although this research does not provide a basis for claims regarding the quality of messy talk, it does show how the use BIM is related to the emergence of messy talk as interactions in which (BIM) models were actively used prompted occurrences of messy talk. The human-computer interaction (HCI) as the initial step in problem solving messy talk was a surprising finding of this research. This opens up the discussion on the active role of computers in messy talk, which is especially interesting in light of the paradigm of computer as social actors (Waddell et al., 2015).

In this research, it was found that engagement in messy talk is not only dependent on an individual's communication skills but also on other situational factors that can form an enabler or barrier to an individual engaging in messy talk. The results in this research demonstrate the role of people-related factors in terms of the engagement of messy talk as well as the use of BIM. These people-related factors include experience, knowledge, and willingness. This is in line with previous research towards the adoption of BIM by Gu and London (2010) who found that not only technical issues, but also human-centered issues are important when addressing BIM adoption. Where Mandhana (2021) stated the likeliness of messy talk to be higher in teams with higher technical expertise, this research has shown that this can only be said in the case of messy talk with the purpose of problem identification. Furthermore, it is expected that co-location, where team members work in the same environment at the same time, is generally more conducive to messy talk than hybrid interaction, as it provides an opportunity for informal approach and interaction. This is in line with previous research on the use of BIM in relationship to messy talk by Dossick et al. (2014), where messy talk interactions that place in an online, co-located setting were considered. Based on the contribution of BIM to messy talk interactions with a problem-identification purpose, a hybrid setting, in which team members are not continuously in a shared setting, might lend itself to this type of messy talk. However, this requires more research.

The differences in the relationship between BIM and messy talk, depending on the purpose of the messy talk, are in line with the paper by Harty and Whyte (2010) which states that newly implemented technologies "are incorporated into existing ecologies of practice". Where Harty and Whyte considered technology implementation in existing ecologies of practice on a larger scale, this research has focused on the implementation of BIM. BIM is taken up into existing practices, in this study messy talk, and applied in a way that suits the current practice of a team or an individual team member. A similar phenomenon was found by Lundberg et al. (2021) who found that users at different levels in the organization come to different understandings, perspectives, and knowledge according to their context of use. This offers an explanation as to why BIM implementation is not reaching the intended goals. These insights have provided input for establishing management interventions with the purpose of providing clarity on how BIM can be integrated with current communication practices and align the use of BIM and messy talk within the project team. Jacobsson and Linderoth (2012) and Davies and Harty (2013) underline the importance of aligning BIM implementation with current practices but also allowing room for BIM to transform these current practices. The inclusion of BIM in the current practices create a puzzle piece for explaining the slow transformation of the industry following the implementation of BIM. This is in line with Babič and Rebolj (2016) who found that not technical aspects, but rather culture and work practices were essential elements of the successful implementation of BIM.

8.2 Limitations

In this section, the limitations of this research are identified and discussed. In this research, two main types of limitations have been identified, these are: limitations due to the data collection methods and limitations due to the case study.

8.2.1 Limitations of data collection methods

The expectations regarding the spatial setting of messy talk were based on observations limited to in-person interactions. Online and hybrid interactions between two individuals were excluded from the scope of observation. The (partial) online nature of these types of interaction created a barrier for observation. Therefore, this research does not consider how BIM and messy talk are related in online or hybrid interaction, and how this might differ from in-person interactions.

The research was conducted using qualitative methods. In the interviews, there is a strong dependency on the description provided by project team members when determining if a

communicative practice can be deemed to be messy talk. Similarly, the data collected by means of observation is dependent upon the judgement of the researcher in terms of what they deemed to be important and relevant. Quantitative methods were not considered to understand the relationship between BIM and messy talk. The sole reliance on qualitative methods puts the research at risk of researcher bias. This risk was mitigated by expert validation.

The communication pattern was observed in terms of problem-solving. Interviews and observations were done with this approach. There are several types of scheduled meetings: team meetings (design meetings), interface meetings and discipline meetings. In this research, only team meetings were observed. This can create a limited view on the occurrences of messy talk. Time was a limiting factor throughout data collection in the research, especially when it came to observations. Due to limited time, the researcher was limited in terms of observations, and as such was dependent on the occurrence of specific communicative practices in the observation moments. This was mitigated by observing as many moments as possible in the specified time frame. Furthermore, the time limitations meant that observations were limited to a part of the design phase, rather than the complete design phase. As such, the researcher was unable to identify developments of messy talk and BIM use throughout the design phase.

The validation of the activity system analysis is currently limited to validating the coding through cross referencing. This could be elaborated by validating these codes using previous research and literature.

8.2.2 Limitations of case study

The case study was limited to the perspective of an engineering firm. Empirical data was collected solely with the aid of Royal HaskoningDHV employees. Employees from other engineering firms were not considered. As the company culture might differ between firms, the results might differ between firms. To determine if this is the case, and in which aspects results differ, broader research, considering multiple engineering firms is required. The team members in the project team studied in the case study all worked for Royal HaskoningDHV. As such, the results and proposed enabling strategy is limited to the perspective of an engineering firm. Empirical data from may provide additional insights, which can form an extension or addendum to the enabling strategy.

The case study studied was not completely BIM, simply because such projects do not yet occur within Royal HaskoningDHV. However, relatively speaking the case study was a high-level BIM project. The characteristics of a project play a role in the application of BIM on the project. In this research, the case study and additional examples from other projects discussed in the interviews are concerned large projects. Consequently, it cannot be concluded that these results are also applicable to smaller and medium sized projects or projects outside the infrastructure scope. Furthermore, the results in this research stem from empirical data collected from AEC participants active in the design phase of infrastructure projects. As such, the suggested management interventions are based on how these participants see, value, and use BIM. It falls within reason that the management interventions have to be reconsidered and adapted when looking to create an enabling strategy for another phase, especially phases that do not constitute one of the design phases such as the execution phase. The generalizability of the results of qualitative research is a highly disputed point (Osbecka and Antczak, 2021). It stands to reason that the conclusions from this analysis are not necessarily applicable to smaller projects. Therefore, it will not be claimed that the enabling strategy that has been developed in this research can be applied to all BIM-enabled construction projects, but the generalizability will be limited to large BIM-enabled construction projects in infrastructure.

The analysis method does not allow for hard conclusions on cause-effect relationship between BIM and the occurrence of messy talk in a project team. But that is not what the goal of the research is. The goal is to understand what communication practices, using BIM and messy talk, in a project team are, thereby creating insight in which areas of the activity of communication require attention and thus how project team communication might be enabled through relevant management interventions.

9 Evaluation

In this chapter, the answers to the sub questions will be reiterated and combined to form an answer to the main research question, which reads: *How can an organization enable effective project team context communication practices in BIM-enabled construction projects?* The answer to the main research question will be discussed in terms of the scientific as well as the societal value. Finally, recommendations for practice will be given and areas of interest for further research will be introduced.

9.1 Conclusion

In this section, the main research question will be answered. The main research question reads: *How can an organization enable effective project team context communication practices in BIM-enabled construction projects?*

The goal of this research question is to understand when and how project teams engage in effective project team communication in a BIM-enabled construction project and how this could be enabled by management interventions. The main research question is supported by four sub research question. Thus, the main research question will be determined by answering the four sub questions.

> **Sub-research question 1: What are the constituent elements of project team context communicative practices?**

This question was addressed by means of a literature review. In this research, the project team context communication practices were defined as BIM and messy talk. As these concepts form the basis of the rest of the research, a clear definition of both concepts is needed. Thus, the literature review studied these two concepts with the purpose of forming a definition of these elements.

As messy talk is a relatively new concept that has not yet been broadly researched, there is a general consensus in literature as to what the definition of messy talk is. Messy talk is defined as the processual construct of opening up a conceptual space in which knowledge sharing and synthesis between interdisciplinary project team members is possible (Mandhana, 2022). In other words, messy talk is a process in which ideas are shared among team members with the purpose of establishing a shared idea (Chan, 2023). For an interaction to be considered messy talk, it must be considered unplanned, unforeseen, and unanticipated (Dossick and Neff, 2011). Unplanned entails that the messy talk was not planned by the participants but rather came up spontaneously in an interaction or discussion with an alternative original topic. Thus, the topic that comes up in a messy talk interaction was unforeseen. Additionally, the outcome of the messy talk interaction has an unanticipated impact in terms of the topic. In order to ease the recognition of messy talk, the concept has been translated into four comprehensive elements. In no particular order, these elements are mutual discovery, critical engagement, knowledge exchange and resolution.

When it comes to BIM, there are several understandings of what can and cannot be considered to be BIM. In order to answer the following research questions, an unequivocal definition of BIM is needed. The acronym BIM has multiple definitions, the definition used in this research is Building Information Modelling (International Organization for Standardization, 2018). This is considered to be a more relevant understanding than the similar-sounding definition of Building Information Model. By defining the letter M in the acronym as modelling rather than model, the concept includes the process of the modelling rather than simply the output of the process, being the model. As such, BIM consists of two main elements, the technology, namely the BIM model and related software, and the process, namely the BIM execution plan (BEP). The first concept, the technology, provides users with the digital tools, such as software, for creating the BIM model. To ensure the value of the outcome, the modelling must be done according to the agreements made

in the BEP. The policies and processes that apply to modelling process are recorded in the BEP. These agreements are not fixed from the outset but can change throughout the course of the project. A BIM model can contain several layers of information, depending on the agreed dimension of the model. The information requirements and dimension of the model are recorded in the BEP.

Sub-research question 2: What is the communicative potential in the BIM-enabled construction project?

By defining both of the concepts, messy talk and BIM, as processes, their influence on one another can be studied rather than limiting the research to understanding the influence of one concept on the other conceptual process. The communicative potential is defined as the potential integration of the two communicative processes in the problem-solving cycle.

BIM is adept at "generating, storing, managing, exchanging, and sharing building information" (Haltulla et al., 2022). As such information involved in BIM must be codifiable, explicit information. However, this is not the only type of information needed in the problem-solving cycle. Tacit knowledge, which cannot be codified, plays a key role. The process of messy talk is a suitable method for exchanging this kind of knowledge. Furthermore, BIM relies on the fact that users are aware of what they want to know, suggesting that BIM is most suitable for identifying known knowns and known unknowns.

On the other hand, the unplanned, unforeseen, and unanticipated characteristics of messy talk state the messy talk is valuable in helping participants become aware of what they did not know they needed to. In other words, messy talk is helpful in making team members aware of unknown knowns and unknown unknowns. The theoretical relationship between BIM and messy talk, and how they might be integrated to add value in the problem-solving cycle, is visualized in figure 38.

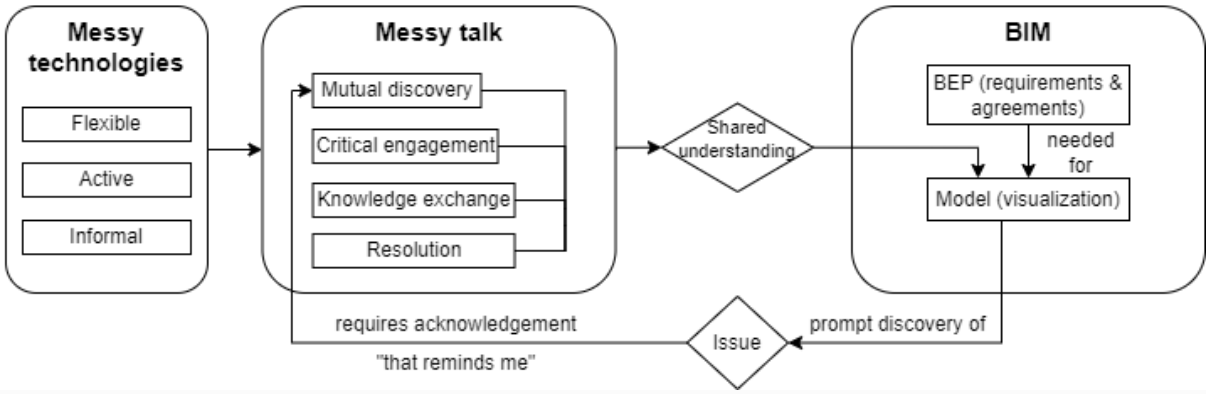

Figure 38 Theoretical relationship between BIM and messy talk

Sub-research question 3: How has messy talk developed as a result of working in a BIM-enabled construction project?

Answering this sub question consists of two phases. First, occurrences of messy talk in the case study were identified and analyzed in order to determine the characteristics of its occurrence. Second, the development of the messy talk occurrences was analyzed in order to explain the previously identified characteristics. In order to answer this sub question, empirical data was collected and qualitatively analyzed. This resulted in the following five categories of messy talk: reviewing, revealing, reflecting, ruminating, and realizing. The contribution of BIM in the identified interactions of messy talk was studied to establish if there was a pattern. Resulting, two categories of messy talk were identified: messy talk that is prompted by BIM and messy talk that is prompted by something other than BIM. It is important to note that a prompt does not to lead

to a messy talk interaction without a reaction by the initially involved team member. These categories led to the establishment of two scenarios in which messy talk occurs.

Scenario one includes messy talk situations with the purpose of reflecting and realizing. These messy talk interactions were prompted by something other than an element of BIM. The communication goal in this scenario is to work out how to approach a problem, meaning that ideas are shared to create a shared idea of how to proceed. As such, this scenario has been given the name "Solution Ideation". Although BIM does not prompt the messy talk in this scenario, this does not mean that BIM does not at all play a role. BIM played a role at the end of the messy talk in this scenario and served the purpose of recording the output of the messy talk interaction.

Scenario two, on the other hand, describes messy talk interactions that were prompted by an element of BIM. The purpose of the messy talk in this scenario includes revealing, reviewing, and ruminating. The goal of communication in this scenario is to realize that there is a problem, meaning that ideas are shared to create a shared idea that something will not suffice. This scenario has been given the name "Problem Identification". The two scenarios can be placed on a spectrum of BIM and messy talk, to visualize the contribution of these two processes in the scenarios. Although the BIM process and "normal" design process appear as two separate processes, they do interact and create input and output for one another. Both products of the respective processes have varying information needs. Explicit knowledge is needed as input for model ideation, whereas design ideation requires implicit knowledge as well as explicit knowledge.

The development of the communication scenarios has been analyzed using activity theory. Activity theory is used to map the development of the activity systems of the two scenarios, by establishing which tensions occur in the system and how these are solved by the activity system. Four categories of problems were identified, these were defined as problems related to the people in the activity system, problems related to the information system used in the activity system, and problems due to the imbalance between the people and information system in the activity system. Additionally, three types of coping mechanisms were identified which were defined as workarounds, boundary conditions and management techniques. When and how these problems and coping mechanisms came forward in the activity system, depends on when messy talk and BIM were employed in the activity system.

Finally, placing the scenario in a specific step in the design phase will help in understanding the contribution of BIM and messy talk to the scenario. Scenario one is placed at the beginning of the first design step, as the level of information at the beginning of the phase is relatively low and there is a need for identifying and determining a course of action. Scenario two is placed in the final tasks related to the first step and in the second step. The level of information has advanced and can now be used in identifying any problems that might have been missed in earlier steps. It can be concluded that in scenario one, messy talk was prompted by some other than BIM and functioned as a prompt for BIM once the interaction was completed. As such, there is a possibility that messy talk might prevent of challenge the use of BIM in this scenario. On the other hand, in scenario two, BIM prompted the messy talk interactions. In this scenario, improper use of BIM might prevent of challenge the occurrence of messy talk.

Sub-research question 4: Which management interventions can be identified to enable effective communication in the project team context?

In order to answer this final sub question, the tensions and coping mechanisms identified in the activity system analysis have been used to design specific management interventions. The management interventions have been designed to ease the tensions in the activity system in order to enable the effective communication practices as described in the activity systems. The

management interventions were designed to either enable messy talk, BIM, or both. Furthermore, management interventions were designed with a specific setting in mind. The setting for a management intervention can be a (team) meeting, a spontaneous workplace interaction, or unbounded. Based on their characteristics, these management interventions are used to establish a strategy for enabling effective communication in a BIM-enabled construction project.

The enabling strategy has been designed to fit the first two steps of the design phase. As such, the management interventions were dedicated to a specific task in the enabling strategy based on the placement of a scenario in the design phase. As several management interventions can be employed as a similar point the design phase, it is up to the manager to decide if they employ an intervention at that point and which of the interventions them employ. This can be based on a manager's judgement of the situation, resulting in a decision to steer it more towards BIM or more towards messy talk. Furthermore, based on the validation sessions, an overview of the suggested BIM maturity to ensure the feasibility of the management intervention is given. As such, the enabling strategy can be tailored to the needs of the project.

These management interventions have been validated in order to ensure that they are complete, effective and feasible to employ. However, it cannot be demonstrated how these management interventions might affect the activity system. Determining this would require more research.

9.2 Recommendations

The research has led to a more extensive understanding of the communicative potential of BIM and messy talk, and how this might be enabled. However, there is still much to be uncovered on this topic. This section will discuss avenues for further research that result from this research and provide recommendations for practice.

9.2.1 Recommendations for future research

Based on the results of this research, two main avenues for further research have been identified. These are messy talk and the enabling strategy. The possibilities will be further discussed below.

Research recommendations for messy talk

As messy talk has not yet been broadly researched, there are numerous possibilities for further research. In this research, the relationship between BIM and messy talk was further explored. In the empirical analysis, the purpose of the messy talk interactions were placed in two main categories, problem identification and solution ideation. These categories are part of the problem-solving cycle. The empirical data collected in this research does not offer insights in situations where both elements occur in one interaction. As such, this provides an opportunity for further research. There is reason to believe there are further elements in a project team that might influence the occurrence of messy talk. One of these elements is the culture in a project team, being either national, organizational, or otherwise. Another possible element influencing the occurrence of messy talk is the diversity in the disciplines involved in the interaction. This could be extended by considering the role of the contract in the division of labor. Furthermore, it could be interesting what the hierarchical and seniority levels in a project team mean for the occurrence of messy talk. Does a certain level of experience influence how much messy talk one engages in or how easily they prompt a messy talk interaction? Lastly, there is also need for research towards team members willingness, ability, or both to engage in messy talk and their personality. This could be 'measured' through a personality test such as Belbin or DISC. This could be a part of a larger research focusing on the question Do the characteristics of the people in the project team, or the combination thereof, influence the occurrence of messy talk?

Additionally, more research is necessary on the influence of BIM and messy talk in other phases of a BIM-enabled construction project. This research shows that the level of information available

in a specific step of the design phase can be linked to the messy talk prompt. As the level of information increases as a project progresses, it is worth researching if the relationship between BIM and messy talk transforms as well. As this research has focused on the relationship between BIM and messy talk, prompts of messy talk other than BIM have not been considered thoroughly. In the research, other prompts for messy talk were identified. These could be an interesting topic for further exploratory research. Furthermore, additional research on the occurrence and sequence of the operationalized elements is needed. This research has shown that messy talk interactions do not exclusively start with mutual discovery. However, further research is necessary to understand specific types of messy talk have a fixed sequence of the elements of messy talk. Based on a deeper understanding of the prompts of messy talk and the sequence of the elements of messy talk, the enabling strategy can be elaborated. Moreover, research is needed what determining factors the topic of a messy talk interaction are. Initially, the results in this research pointed to the scope of authority or contractual agreements as a steering factor in the discussion topic. However, in the validation sessions it turned out that authority is a limited steering factor, as messy talk is sometimes used as a workaround to the need for authority.

As previously stated, there are several types of scheduled meetings: (design) team meetings, interface meetings, discipline meetings. In this research, only team meetings were observed. However, there is reason to believe messy talk occurs in the other types of meetings too. It could be interesting to see how messy talk occurs in the types of meetings and use lessons from this for extending the recommendations for enabling messy talk in BIM projects. This research could be set up in a similar way to the research by Dossick et al. (2015) regarding the occurrence of messy talk in virtual teams. In this vein, the research could be extended by considering the disciplines of team members. This research provides strong indications that communication practices differ between disciplines. Problem solving is different depending on if it is an inter-disciplinary or intra-disciplinary dialogue or meeting. The occurrence of messy talk in these interactions can be argued two ways: intra-disciplinary interactions allow for a deeper level of knowledge exchange whereas inter-disciplinary interactions could potentially lead to more mutual discovery because of 'innocent questions' from team members who are not as specialized in a certain discipline but who do have enough general knowledge relating to the project (and related projects) that they do understand the general tendence. Consequently, further research could be oriented around the question: Is there is difference in the occurrence of messy talk between team members of the same discipline versus team members of different disciplines?

The differences in the identified purposes of messy talk reflect different areas of problem-solving, however these differences are nuanced, thus making it difficult to recognized what type of messy talk is occurring in the moment. This makes the application of several management interventions challenging. As such, more research is needed to understand if there are signals that indicate a specific type of messy talk, and if there are any, what these signals are.

Finally, the scope of this research was limited and as such only considered the role of BIM in messy talk situations. Consequently, the contribution of BIM in near messy talk situations, such as trouble shooting, has been disregarded. This research could be complemented by further research that does include these interactions. Furthermore, a more granular approach can be considered for studying the relationship between BIM and the operationalized elements of messy talk. This could be set up in a similar manner to this research, using activity theory as the unit of analysis.

Research recommendations for the enabling strategy

Further research efforts could also be done to enhance the enabling strategy. First of all, further research is needed to better understand the feasibility of the enabling strategy. Research might consider how to convey the enabling strategy to project managers and aid them in employing it.

An opportunity for achieving this could be a serious game. A serious game is a carefully designed game with an educational purpose (Breuer, 2010), and as such could be a useful tool in operationalizing and assessing the enabling strategy. As the effectiveness of the management interventions has only been validated through expert validation sessions, further research is needed to assess the effectiveness of the suggested management interventions in practice. Do they actually lead to effective communication? And does this effective communication lead to more creative or different results?

Efficiency does not always equal effectiveness. As such, it is important that the efficiency of communication and the effectiveness of communication are in balance. This research has a strong focus on the effectiveness of communication. The enabling strategy could be enhanced by aligning the management interventions with the results of further research on the enabling the efficiency of communication practices.

9.2.2 Recommendations for practice

Based on the results of this research, three main recommendations for practice can be done.

First of all, on the project level, it is recommended to establish the effectiveness of the management interventions in practice through trial-and-error. While a specific management intervention might generate positive results for one project team, it might be less beneficial to another. The proposed enabling strategy has been designed in such a way to aid managers and leaders in making an educated assumption as to which management intervention might generate the desirable results depending on the characteristics of the situation.

Furthermore, enabling effective communication is a continuous process. It is therefore recommended to employ the proposed enabling strategy in the early phase of the design process and adapt it as the project progresses. Doing so will avoid sudden changes to the way team members are encouraged to work and thereby hopefully limit resistance. Furthermore, this will give the manager or leader a better feel for what works for the team, thereby supporting the recommendation above.

Finally, on an organizational level, it is recommended to encourage the use of the proposed enabling strategy through setting an example. This is in line with the bottom-up approach incorporated in the enabling strategy. As such, it is recommended to start on a small scale, with projects with willing and accepting managers or leaders, and encourage others to employ the enabling strategy by proving its value added. Taking on this approach will avoid coercion and top-down pressure.

References

Abbasnejad, B., Nepal, M. P., Ahankoob, A., Nasirian, A., & Drogemuller, R. (2020). Building Information Modelling (BIM) adoption and implementation enablers in AEC firms: a systematic literature review. *Architectural Engineering and Design Management*, *17*(5–6), 411–433. https://doi.org/10.1080/17452007.2020.1793721

Adel, M., Cheng, Z., & Lei, Z. (2022). Integration of Building Information Modeling (BIM) and Virtual Design and Construction (VDC) with Stick-Built Construction to Implement Digital Construction: A Canadian General Contractor's Perspective. *Buildings*, *12*(9), 1337. https://doi.org/10.3390/buildings12091337

Akintola, A. A., Venkatachalam, S., & Root, D. E. (2020). Understanding BIM's impact on professional work practices using activity theory. *Construction Management and Economics*, *38*(5), 447–467. https://doi.org/10.1080/01446193.2018.1559338

Babič, N. Č., D. Rebolj. (2016, June 17). *Culture change in construction industry: from 2D toward BIM based construction*. http://www.itcon.org/2016/6

BNA & NLingenieurs. (2014). *Standaardtaakbeschrijving DNR-STB 2014: Toelichting*. IMAGO Printing. https://www.nlingenieurs.nl/assets/e4a75bb165/Standaardtaakbeschrijving-20141.pdf

Boktor, J., Hanna, A., & Menassa, C. C. (2014). State of Practice of Building Information Modeling in the Mechanical Construction Industry. *Journal of Management in Engineering*, *30*(1), 78–85. https://doi.org/10.1061/(asce)me.1943-5479.0000176

Borrmann, A., König, M., Koch, C., & Beetz, J. (2018). Building Information Modeling: Why? What? How? *Building Information Modeling*, 1–24. https://doi.org/10.1007/978-3-319-92862-3_1

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework. *International Journal of Project Management*, *29*(6), 728–739. https://doi.org/10.1016/j.ijproman.2010.07.008

Bouthillier, F., & Shearer, K. (2002). Understanding knowledge management and information management: the need for an empirical perspective. *Information Research*, *8*(1).

Bouwend Nederland. (n.d.). *Feiten en cijfers*. https://www.bouwendnederland.nl/service/feiten-en-cijfers

Breuer, J. (2010). *Why so serious? On the relation of serious games and learning*. https://hal.science/hal-00692052

Bronstein, L. R. (2003). A Model for Interdisciplinary Collaboration. *Social Work*, *48*(3), 297–306. https://doi.org/10.1093/sw/48.3.297

Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of Building Information Modelling (BIM). *International Journal of Project Management*, *31*(7), 971–980. https://doi.org/10.1016/j.ijproman.2012.12.001

Chan, P. W. C. (2023, January 12). *Personal correspondence*.

Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. *Journal of Building Engineering*, *19*, 242–257. https://doi.org/10.1016/j.jobe.2018.04.028

Chen, G., Chen, J., Tang, Y., Li, Q., & Luo, X. (2022). Identifying Effective Collaborative Behaviors in Building Information Modeling–Enabled Construction Projects. *Journal of the Construction Division and Management*, *148*(6). https://doi.org/10.1061/(asce)co.1943-7862.0002270

Communication. (2022). In *The Merriam-Webster.com Dictionary*. Retrieved January 6, 2023, from https://www.merriam-webster.com/dictionary/communication

Davies, R. J., & Harty, C. (2013). Measurement and exploration of individual beliefs about the consequences of building information modelling use. *Construction Management and Economics*, *31*(11), 1110–1127. https://doi.org/10.1080/01446193.2013.848994

Dossick, C. S., & Neff, G. (2010). Organizational Divisions in BIM-Enabled Commercial Construction. *Journal of the Construction Division and Management*, *136*(4), 459–467. https://doi.org/10.1061/(asce)co.1943-7862.0000109

Dossick, C. S., & Neff, G. (2011). Messy talk and clean technology: communication, problem-solving and collaboration using Building Information Modelling. *Engineering Project Organization Journal*, *1*(2), 83–93. https://doi.org/10.1080/21573727.2011.569929

Dossick, C. S., Anderson, A. J., Azari, R., Iorio, J., Neff, G., & Taylor, J. B. (2015). Messy Talk in Virtual Teams: Achieving Knowledge Synthesis through Shared Visualizations. *Journal of Management in Engineering*, *31*(1). https://doi.org/10.1061/(asce)me.1943-5479.0000301

Dowsett, R. M., & Harty, C. F. (2018). Assessing the implementation of BIM – an information systems approach. *Construction Management and Economics*, *37*(10), 551–566. https://doi.org/10.1080/01446193.2018.1476728\

Engeström, Y. (1999). Expansive Visibilization of Work: An Activity-Theoretical Perspective. *Computer Supported Cooperative Work (CSCW)*, *8*(1–2), 63–93. https://doi.org/10.1023/a:1008648532192

Engeström, Y. (2000). Activity theory as a framework for analyzing and redesigning work. *Ergonomics*, *43*(7), 960–974. https://doi.org/10.1080/001401300409143

Engeström, Y. (2001). Expansive Learning at Work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, *14*(1), 133–156. https://doi.org/10.1080/13639080020028747

Fox, S. (2014). Getting real about BIM: Critical realist descriptions as an alternative to the naive framing and multiple fallacies of hype. *International Journal of Managing Projects in Business*, *7*(3), 405–422. https://doi.org/10.1108/ijmpb-12-2013-0073

Fulford, R. S., & Standing, C. (2014). Construction industry productivity and the potential for collaborative practice. *International Journal of Project Management*, *32*(2), 315–326. https://doi.org/10.1016/j.ijproman.2013.05.007

Fürstenberg, D. (2020). Information Management in AEC Projects: A Study of Applied Research Approaches. *Lecture Notes in Civil Engineering*, 272–284. https://doi.org/10.1007/978-3-030-51295-8_20

Gamil, Y., & Rahman, I. A. (2018). Identification of Causes and Effects of Poor Communication in Construction Industry: A Theoretical Review. *Emerging Science Journal*, *1*(4). https://doi.org/10.28991/ijse-01121

Green, B. (2016). PRODUCTIVITY IN CONSTRUCTION: CREATING A FRAMEWORK FOR THE INDUSTRY TO THRIVE. In *CIOB*. Chartered Institute of Building. https://www.ciob.org/industry/research/Productivity-Construction-Creating-framework-industry-thrive

Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction*, *19*(8), 988–999. https://doi.org/10.1016/j.autcon.2010.09.002

Halttula, H., Haapasalo, H., & Silvola, R. (2020). Managing data flows in infrastructure projects - the lifecycle process model. *Journal of Information Technology in Construction*, *25*, 193–211. https://doi.org/10.36680/j.itcon.2020.012

Hartmann, T., Van Meerveld, H. J., Vossebeld, N., & Adriaanse, A. M. (2012). Aligning building information model tools and construction management methods. *Automation in Construction*, *22*, 605–613. https://doi.org/10.1016/j.autcon.2011.12.011

Harty, C., & Whyte, J. (2010). Emerging Hybrid Practices in Construction Design Work: Role of Mixed Media. *Journal of the Construction Division and Management*, *136*(4), 468–476. https://doi.org/10.1061/(asce)co.1943-7862.0000146

Hicks, B. (2007). Lean information management: Understanding and eliminating waste. *International Journal of Information Management*, *27*(4), 233–249. https://doi.org/10.1016/j.ijinfomgt.2006.12.001

International Organization for Standardization. (2018). *ISO 19650-1:2018(en) Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles*. https://www.iso.org/obp/ui/#iso:std:iso:19650:-1:ed-1:v1:en

Jacobsson, M., & Linderoth, H. (2012). User perceptions of ICT impacts in Swedish construction companies: 'it's fine, just as it is.' *Construction Management and Economics*, *30*(5), 339–357. https://doi.org/10.1080/01446193.2012.672757

Jonsen, K., & Jehn, K. A. (2009). Using triangulation to validate themes in qualitative studies. *Qualitative Research in Organizations and Management: An International Journal*, *4*(2), 123–150. https://doi.org/10.1108/17465640910978391

Kahn, A. Z., & Bokhari, R. H. (2018). Understanding ICT Enabled Organizational Transformation. *Abasyn Journal of Social Sciences*, *11*(1), 87–103. https://www.researchgate.net/profile/Abdul-Khan-21/publication/326558481_Understanding_ICT_Enabled_Organizational_Transformation/links/5b5741000f7e9b240f05497e/Understanding-ICT-Enabled-Organizational-Transformation.pdf

Koppenjan, J., Veeneman, W., van der Voort, H., ten Heuvelhof, E., & Leijten, M. (2011). Competing management approaches in large engineering projects: The Dutch RandstadRail project. *International Journal of Project Management*, *29*(6), 740–750. https://doi.org/10.1016/j.ijproman.2010.07.003

Koutamanis, A. (2022). *Building Information - Representation and Management Principles and Foundations for the Digital Era* [E-book]. TU Delft Open Textbooks. https://doi.org/10.5074/T.2022.001

Kunz, J. & Fischer, M. (2020). Virtual design and construction. *Construction Management and Economics*, *38*(4), 355–363. https://doi.org/10.1080/01446193.2020.1714068

Lantis. (2023). *Het project | De Oosterweelverbinding*. Oosterweelverbinding. https://www.oosterweelverbinding.be/het-project

Lauer, T. (2020). *Change Management: Fundamentals and Success Factors* (1st ed. 2021). Springer.

Liao, L., & Teo, E. A. L. (2018). Organizational Change Perspective on People Management in BIM Implementation in Building Projects. *Journal of Management in Engineering*, *34*(3). https://doi.org/10.1061/(asce)me.1943-5479.0000604

Linderoth, H., & Isaksson, A. (2016). What is the "Potential" of new ICT and how are Perceptions Shaped by Experience of Use and Practice? - The Case of Building Information Modelling. In *The 27th Australasian Conference on Information Systems*. https://research.chalmers.se/en/publication/512372

Liu, Y., van Nederveen, S., & Hertogh, M. (2017). Understanding effects of BIM on collaborative design and construction: An empirical study in China. *International Journal of Project Management*, *35*(4), 686–698. https://doi.org/10.1016/j.ijproman.2016.06.007

Lu, Q., Chen, L., Lee, S., & Zhao, X. (2018). Activity theory-based analysis of BIM implementation in building O&M and first response. *Automation in Construction*, *85*, 317–332. https://doi.org/10.1016/j.autcon.2017.10.017

Lundberg, O. H. M., Nylén, D., & Sandberg, J. K. (2021). Unpacking construction site digitalization: the role of incongruence and inconsistency in technological frames. *Construction Management and Economics*, *40*(11–12), 987–1002. https://doi.org/10.1080/01446193.2021.1980896

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

Mandhana, D. M. (2022). Messy talk: an unanticipated process of problem-solving and knowledge creation. *Journal of Communication Management*, *26*(3), 221–235. https://doi.org/10.1108/JCOM-04-2021-0039

Matthews, J., Love, P. E. D., Mewburn, J., Stobaus, C., & Ramanayaka, C. (2017). Building information modelling in construction: insights from collaboration and change management perspectives. *Production Planning & Control*, *29*(3), 202–216. https://doi.org/10.1080/09537287.2017.1407005

McKinsey & Company. (2022, June 6). *Building products in the digital age: It's hard to "get smart"* [Press release]. https://www.mckinsey.com/industries/engineering-construction-and-building-materials/our-insights/building-products-in-the-digital-age-its-hard-to-get-smart

Merriam-Webster. (n.d.). Collaborate. In Merriam-Webster.com dictionary. Retrieved February 9, 2023, from https://www.merriam-webster.com/dictionary/collaborate

Mithas, S., Ramasubbu N., & Sambamurthy, V. (2011). How Information Management Capability Influences Firm Performance. *MIS Quarterly*, *35*(1), 237. https://doi.org/10.2307/23043496

Mwanza, D. (2002). *Towards an activity-oriented design method for HCI research and practice* [PhD dissertation]. The Open University.

Nardi, B. A. (1995). Activity Theory and Human-Computer Interaction. In *Context and Consciousness: Activity Theory and Human-Computer Interaction*. The MIT Press. https://doi.org/10.7551/mitpress/2137.001.0001

Nesan, J. (2012). Factors Influencing Tacit Knowledge in Construction. *Construction Economics and Building*, *5*(1), 48–57. https://doi.org/10.5130/ajceb.v5i1.2943

Nightingale, D., & Srinivasan, J. (2011). *Beyond the Lean Revolution: Achieving Successful and Sustainable Enterprise Transformation* (Illustrated). AMACOM.

Oraee, M., Hosseini, M. R., Papadonikolaki, E., Palliyaguru, R., & Arashpour, M. (2017b). Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review. *International Journal of Project Management*, *35*(7), 1288–1301. https://doi.org/10.1016/j.ijproman.2017.07.001

Oraee, M., Hosseini, M., Banihashemi Namini, S., & Merschbrock, C. (2017a). Where the Gaps Lie: Ten Years of Research into Collaboration on BIM-Enabled Construction Projects. *Construction Economics and Building*, *17*(1), 121–139. https://doi.org/10.5130/ajceb.v17i1.5270

Osbeck, L. M., & Antczak, S. J. (2021). Generalizability and qualitative research: A new look at an ongoing controversy. *Qualitative Psychology*, *8*(1), 62–68. https://doi.org/10.1037/qup0000194

Poirier, E. A., Forgues, D., & Staub-French, S. (2017). Understanding the impact of BIM on collaboration: a Canadian case study. *Building Research &Amp; Information*, *45*(6), 681–695. https://doi.org/10.1080/09613218.2017.1324724

Project Management Institute. (2008). *A guide to the project management body of knowledge: (PMBOK guide)* (4th ed.).

Rezgui, Y., Beach, T., & Rana, O. (2013). A GOVERNANCE APPROACH FOR BIM MANAGEMENT ACROSS LIFECYCLE AND SUPPLY CHAINS USING MIXED-MODES OF INFORMATION DELIVERY. *Journal of Civil Engineering and Management*, *19*(2), 239–258. https://doi.org/10.3846/13923730.2012.760480

Ribiere, V., & Tuggle, F. D. (2007). The Influence of Organizational Trust on the Use of KM Systems and on the Success of KM Initiatives. *IGI Global EBooks*, 96–120. https://doi.org/10.4018/978-1-59904-261-9.ch007

Rodrigues De Almeida, P., Bühler, M., Gerbert, P., Castagnino, S., & Rothballer, C. (2016). Shaping the Future of Construction - A Breakthrough in Mindset and Technology. In *World Economic Forum*. World Economic Forum. https://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report.pdf

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). *Bim Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers* (3rd ed.) [E-book]. Wiley.

Sampaio de Melo, R. S. , Granja, A. D. & Ballard, G. (2013). Collaboration to Extend Target Costing to Non-Multi-Party Contracted Projects: Evidence From Literature. *Proc. of the 21st Annual Conference of the International Group for Lean Construction.* Fortaleza, Brazil.

Schöttle, A., Haghsheno S., & Gehbauer F. (2014) Proc. of the 22nd Annual Conference of the International Group for Lean Construction (IGLC).

Schrage, M. (1995). *No More Teams: Mastering the Dynamics of Creative Collaboration*. Crown.

Siebelink, S., Voordijk, H., Endedijk, M., & Adriaanse, A. (2020). Understanding barriers to BIM implementation: Their impact across organizational levels in relation to BIM maturity. *Frontiers of Engineering Management*, *8*(2), 236–257. https://doi.org/10.1007/s42524-019-0088-2

Snyder, J. S., & Lee-Partridge, J. E. (2013). Understanding communication channel choices in team knowledge sharing. *Corporate Communications: An International Journal*, *18*(4), 417–431. https://doi.org/10.1108/ccij-03-2012-0026

Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, *18*(3), 357–375. https://doi.org/10.1016/j.autcon.2008.10.003

Tulke, J. (2018). BIM-Based Design Coordination. *Building Information Modeling*, 317–327. https://doi.org/10.1007/978-3-319-92862-3_18

Ullah, K., Lill, I., & Witt, E. (2019). An Overview of BIM Adoption in the Construction Industry: Benefits and Barriers. In *Emerald reach proceedings series* (pp. 297–303). Emerald Publishing Limited. https://doi.org/10.1108/s2516-285320190000002052

Um, K. H., & Kim, S. M. (2019). The effects of supply chain collaboration on performance and transaction cost advantage: The moderation and nonlinear effects of governance mechanisms. *International Journal of Production Economics*, *217*, 97–111. https://doi.org/10.1016/j.ijpe.2018.03.025

Vass, S., & Gustavsson, T. K. (2017). Challenges when implementing BIM for industry change. *Construction Management and Economics*, *35*(10), 597–610. https://doi.org/10.1080/01446193.2017.1314519

Verschuren, P., Doorewaard, H., & Mellion, M. J. (2010). *Designing a Research Project*. Van Haren Publishing.

Vidal, L., & Marle, F. (2008). Understanding project complexity: implications on project management. *Kybernetes*, *37*(8), 1094–1110. https://doi.org/10.1108/03684920810884928

Waddell, T. K., Zhang, B., & Sundar, S. S. (2015). Human–Computer Interaction. *The International Encyclopedia of Interpersonal Communication*, 1–9. https://doi.org/10.1002/9781118540190.wbeic182

Wang, K., Zhang, C., Guo, F., & Guo, S. (2022). Toward an Efficient Construction Process: What Drives BIM Professionals to Collaborate in BIM-Enabled Projects. *Journal of Management in Engineering*, *38*(4). https://doi.org/10.1061/(asce)me.1943-5479.0001056

Weeger, A., Wagner, H. T., Gewald, H., & Weitzel, T. (2021). Contradictions and Interventions in Health IS. *Business & Information Systems Engineering*, *63*(6), 689–710. https://doi.org/10.1007/s12599-021-00697-w

Winfield, M. (2020). Construction 4.0 and ISO 19650: a panacea for the digital revolution? *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law*, *173*(4), 175–181. https://doi.org/10.1680/jmapl.19.00051

Wood, D. J., & Gray, B. (1991). Toward a Comprehensive Theory of Collaboration. *The Journal of Applied Behavioral Science*, *27*(2), 139–162. https://doi.org/10.1177/0021886391272001

Yamagata-Lynch, L. C. (2010). Activity Systems Analysis and Its Value. *Activity Systems Analysis Methods*, 1–11. https://doi.org/10.1007/978-1-4419-6321-5_1

Appendices

Appendix A – Interview set-up

The criteria were determined to ensure a variety of views and experiences, meaning these are not limited to experiences on one project. This will help create an understanding of the development. The following criteria were used to determine which interviewees to approach.

- Years of experience: >5 years
- Department: Infrastructure
- Role within the department: mix of roles and responsibilities

Table 22 Interviewee criteria

Nr.	Role	Experience [years]	Active in case study?
1	BIM lead; BIM manager	16	No
2	3D specialist	33	Yes
3	BIM coordinator; integral designer	17	Yes
4	Interface coordinator, design leader	20	Yes
5	Road designer; BIM coordinator	14	No
6	BIM coordinator; 3D modeler	5	Yes
7	BIM coordinator	19	Yes
8	BIM manager; structural engineer	14	No
9	Technical & innovations director	27	No
10	Director Business Unit	29	No

Interviewing process

The interviews were held in Dutch. This was done to ensure that the interviewee can properly express their thoughts, opinions, and experiences. Before starting the interview, the interviewee was asked for permission to record the interviewee (with the purpose of creating a transcript), ensuring them that the results would be anonymously processed. The interview was started by giving a short personal introduction and explaining the main goals of the interview. Then a brief explanation of the interview was provided, highlighting that explanations of experiences relating to projects are highly useful, there is no need to use the names of the projects, but a rough indication of size would be appreciated. Finally, the two concepts at the core of this research were introduced. More specifically, what will the researcher was looking for into is the appearance of messy talk in a BECP. The explanation is kept short and concise as to not steer the interviewees towards a certain direction, the focus remains on the interviewees' experiences.

Interview questions

The questions posed in the interview were formulated as open-ended questions as to encourage the interviewees to share their experiences. Due to the semi-structured nature of the interviews, the questions were asked in no particular order. If an interviewee touched on a topic that might be valuable to the research, this was entertained by asking follow-up questions. This topic list was used to ensure that all the topics had been covered in the interview. Per topic in the topic list, a few examples of questions that were asked, are given.

Use of BIM

- Why is BIM used on a project?
    - What is the goal in using BIM? What do you expect to achieve by using BIM?
- Who is expected to use BIM? Who actually uses BIM (for the purposes they are expected to)?
    - How do you use BIM in your job/work?
    - Do you think BIM has an added value in terms of how you communicate? When is it good or bad?
- What was the situation before BIM? [in terms of communication]
- What happened when BIM was introduced?
    - How do you experience working with BIM?
    - Has the introduction of BIM influenced your way of working?

Appearance of messy talk

- Do you feel that the dynamics of communication have changed as a result of introducing BIM?
- How do/did you overcome problems in the design process?
- How did you experience in the introduction of BIM in the design process?
- What forms of communication do you use in the design process?
    - Which colleagues (in terms of function) do you communicate most with and how?
    - How are decisions made in a project environment?
- What is good communication?
- What is bad communication?

Appendix B – Observation form

The observation form consists of two parts. Firstly, the matrix with observation requirements. The requirements are twofold, the topic of the interaction has to be related to the design and the interaction had to include all four operationalized elements of messy talk (as defined in section 3.2). If an interaction fulfilled these requirements, the researcher could move on to the second part. The second part of the observation consisted of follow-up questions. These questions were posed to participants of observed meetings.

Table 23 Observation form

Topic of interaction: design related?
Mutual discovery - An issue/problem related to the aspects of an assignment or existing in the response to that assignment, which a team member highlights but other members have not noticed. - A practical resolution that team members find to troubleshoot a technical problem.
Critical engagement - A statement to clarify a mutually discovered issue/problem, which is followed by a question or an opposing statement/explanation. - A question whose answer is challenged or supplemented. - A suggestion not accepted by the other which leads to reasoning by other. - A suggestion accepted by others but is complemented by other as well.
Knowledge exchange - A fact related to one aspect of the assignment. - A true statement sharing a personal experience or understanding.
Resolution - A solution suggested by a team member and agreed upon or not challenged by other, which solves a mutually discovered problem. - A resolution agreed upon by everyone to be followed in order to achieve a final solution.

Similar to the semi-structured interviews, this question list was used a control method to make sure that all questions were covered during the follow-up.

1) What do you expect to learn in a (team) meeting?
2) What do you expect to learn in a spontaneous workplace interaction?
3) Do you use any means or tools in this interaction? If yes, which ones?
4) When are you satisfied by the outcome of an interaction?
5) What leads you to ask a question in a meeting/in the workplace?
6) What do you understand BIM to include?
    a. How do you use BIM in your tasks?
    b. Does BIM support you in collecting the information you need?

The follow-ups were held with varied group of team members, in terms of both years of experience and roles. An overview of these respondents is provided in the table below.

Table 24 Follow-up respondents

Nr.	**Role**	**Years of experience**
1	Structural engineer	20
2	Structural engineer	18
3	Geo-technical engineer	5
4	Structural engineer	25
5	Geo-technical engineer	5

Appendix C – Codebook

Table 25 provides a concise overview of the codebook, structured according to the third and second order constructs. The complete codebook, including proof quotes, can be found in the corresponding file.

Table 25 Concise codebook

3rd order construct	2nd order construct	Code
Purpose	**Reviewing**	Giving feedback
		Checking
	Revealing	What
		Why
	Reflecting	Evaluating
		Contemplating
	Realizing	Question
		Task
	Ruminating	Ruminating
Change drivers	**Internal strategy**	Copycat
		Future proofing
	Industry needs	Mutual understanding
	Client push	Monetary motivation
		Client demands
Problems	**People**	Personal skills
		Unfamiliarity
		Willingness
		Non-alignment
	Information system	Increased activities
		Lacking level of detail
	Imbalance in system	System dependency
		Garbage in, garbage out
		Information overload
		Time pressure
		Island thinking
		Follow-up
Coping mechanisms	**Workaround**	Fallback on analogue methods
		Auxiliary
		Leaning
	Boundary conditions	Open team culture
		Critical mindset
		Formalize
	Management techniques	Involve
		Lead
		Task allocation

Appendix D – Management interventions

The relationship between the management interventions and the barriers and enablers is provided in table 28. This overview provides insight as to which management interventions can be employed based on the desired goal.

Table 26 Management interventions (numbered)

Nr.	Intervention
1	Team building & awareness for personality
2	"Ask why out loud" campaign
3	Regular BIM training & demonstration
4	Workplace management
5	Model as agenda
6	Messy talk awareness
7	Interaction meetings
8	Revoking 'Any other business' as meeting agenda item
9	Open iRoom
10	Open door policy
11	Sketch modeling

Table 27 Barriers and enablers (numbered)

Nr.	Barrier/enabler
A	Authority
B	Personal communication skills
C	Island thinking
D	Personal stance
E	Experience and knowledge
F	Open team culture
G	Screens
H	Agreements
I	Administration

Table 28 Relationship between management interventions and barriers/enablers

	A	B	C	D	E	F	G	H	I
1		x	x			x			
2		x	x						
3				x	x			x	x
4			x			x			
5					x				x
6	x								
7			x		x		x		
8						x			
9			x	x	x	x	x		
10	x								
11							x	x	

Appendix E – Reliability of coding

Table 29 provides an overview of the codebook, including the number of proof quotes per code and the number of interviews they originate from. The table also mentions if the quotes per code fall within the acceptable margin. The complete codebook, including proof quotes, can be found in the corresponding file.

Table 29 Code reliability

Code	Number of quotes	Number of interviews	Within acceptable margin?
Giving feedback	2	2	Yes
Checking	3	3	Yes
What	6	5	Yes
Why	4	3	Yes
Evaluating	5	5	Yes
Contemplating	5	4	Yes
Question	4	4	Yes
Task	4	3	Yes
Ruminating	3	3	Yes
Copycat	5	3	Yes
Future proofing	4	4	Yes
Mutual understanding	7	3	Yes
Monetary motivation	11	3	No
Client demands	11	5	Yes
Fallback on analogue methods	7	4	Yes
Auxiliary	18	5	No
Non-alignment	8	3	No
Garbage in, garbage out	6	5	Yes
Personal skills	13	6	Yes
Unfamiliarity	13	8	Yes
Willingness	6	3	Yes
Information overload	10	6	Yes
Time pressure	11	5	Yes
Follow-up	12	7	Yes
Increased activities	7	4	Yes
Leaning	4	3	Yes
System dependency	13	6	Yes
Island thinking	8	5	Yes
Level of detail	6	5	Yes
Involve	10	5	Yes
Open team culture	13	5	No
Critical mindset	10	6	Yes
Task allocation	13	7	Yes
Lead	4	2	Yes
Formalize	13	6	Yes

Appendix F – Expert validation session set-up

Before starting the validation session, the expert was asked for permission to record the interviewee (with the purpose of creating a transcript), ensuring them that the results would be anonymously processed. To start off the expert validation session, the purpose of the validation session was defined. The purpose is defined as: validating the research results by the professional vision and opinions of experts from practice.

The validation session consisted of three parts. Firstly, the introduction of the concepts of messy talk, BIM, and activity theory. Then, the discussion of the results from activity theory. In this part, experts were asked for their opinion regarding the accurateness of these results, as to limit researcher bias. Further, experts were asked if any elements of the activity systems were missing from the visualization or if they had any other additions. Finally, the validation session was wrapped up by discussing the identified management interventions. Regarding the recommendation it was noted that these are general recommendations, not specific to the case study. These were discussed in terms of their setting, the effectiveness of the individual interventions, the feasibility of the individual interventions and the completeness of the set of interventions.

- Effective? Do the recommendations achieve the desired results? Potential pitfalls?
- Feasible? Are the recommendations feasible within the project team?
- Complete? Are the recommendations complete, do you feel anything is missing?

Finally, the session was finalized with an opportunity for any further questions or recommendations.