Delft University of Technology

Adopting social network theory to understand how information flows during the different phases of the design process in inter-organizational projects

A case study

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by

K. Stroumpoulis

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TU Delft

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Preface

This report serves as the thesis for my graduation and concludes my Master of Science studies in Construction Management and Engineering at the Delft University of Technology. This research was supported by Delft University of Technology and Count & Cooper, a managing contractor firm which allowed me to apply my knowledge in one of their projects and collect the necessary data.

Having graduated as a civil engineer specialized in structural engineering from University of Thessaly in Greece I discovered that other things fascinate me the most. So I decided to pursue a master in Construction Management and Engineering at Delft University of Technology. There I chose the specialization of projects and people because I do believe that people play an important role in the management of projects and this is often forgotten. Thus, understanding the social nature that is hidden in the projects inspired me to undertake this research.

I was fortunate and honored to have an inspirational committee oversee my study. First and foremost, I would like to express my gratitude to prof. dr. Paul Chan for our insightful conversations. I would also like to thank my principal supervisor Ir. Leon Hombergen for being the first person who trusted my abilities and was willing to get on board to guide me throughout my thesis. In addition I would like to thank Dr. ir Leonie Koops for providing me with the right feedback which enhanced the quality of my research. Furthermore, I could not forget to thank my company supervisors Drs. ing. Jasper Blaauw and Drs. Dirk van Uffelen. Both of them were very supportive and motivating from the beginning. They believed in me and they taught me a lot regarding how to behave professionally in an organizational setting.

Last but not least, I would like to express my deep gratitude to my family for their unconditional love and for the sacrifices they made in order for me to obtain this degree. They are those who made it possible for me to broaden my horizons and build on unique skills. How could I not thank my friends? They are those who made this journey unforgettable by carving out priceless moments. Thank you all for that!

These last two years were one of the greatest chapters in my life no matter how intense they have been. The lessons I took from the people I interacted with and especially from my committee will be proved extremely valuable for becoming who I wish to be.

K. Stroumpoulis
Delft, October 2022

Executive Summary

Introduction

Projects are becoming larger and more complex, resulting in work being done more in a team environment. Among other industries, the construction industry is project-based as well. For the successful completion of construction projects, inter-organizational teams consisting of representatives from the owner, designer, contractors and other stakeholders need to cooperate. Due to the numerous relationships between the various organizations, construction management faces great challenges. One of these challenges is the encouragement of information sharing. Thus, information sharing in inter-organizational projects has already concerned academia for a long time. Studies have so far emphasized what motivates and hinders organizations from forming inter-organizational ventures and exchanging information, which factors contribute to their success and the impacts of successful information sharing between organizations. More recently, several researchers have investigated the power of social networks in shaping information-sharing practices in general. However, knowledge of how information flows during the design life-cycle is still limited, and no study has been found to examine that by using social network analysis. Therefore, the main research question formed to investigate the topic mentioned above is as follows:

"How is information exchanged in inter-organizational projects during the design life cycle?"

This study concerns the information sharing of inter-organizational teams in various design phases by adopting social network theory in a particular case study. It has been carried out for graduation purpose and it is supported by Delft University of Technology and Count & Cooper. Thus, the problem associated with this research lays in the execution of a big infrastructure project. To successfully deliver the project a consortium has been formed consisting of representatives from various organizations. Experts identified that the internal project communication needs to be improved which eventually sparked the interest for this research.

Research methodology

To answer the main research question, the researcher performed four research activities and tested three research propositions based on what the literature said and what he was expecting to find out at the start of the research. First, by carrying out an extensive literature review, he started exploring the concept of information sharing in the construction industry in general and then zoomed into the concept of inter-organizational information sharing, followed by the application of the social network theory in the construction industry and its relevance to the information sharing.

Then two other research activities were executed in parallel. One concerned the survey distribution, while the other was related to participant observations. After gathering the data from the survey, the researcher performed Social Network Analysis (SNA) to map the communication network of the inter-organizational venture for the three phases of design that have been executed in the applied case study. Besides that, the researcher also extracted some other statistics from the survey. Participant observations were carried out to add a more qualitative character to the survey's results. They comprised of personal notes, observations from participating in weekly organizational stand-ups and comparisons between the topology of the departments, the organizational relationships and the communities that have been identified by running the modularity analysis in the software used for the SNA.

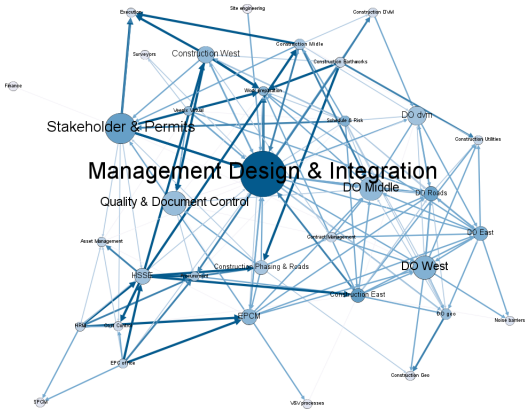
Lastly, the researcher organized an expert panel workshop session where he invited some experts to enrich and validate the results of the two previous research activities. This activity occurred in two rounds. In the first round, the researcher aimed to enrich his observations by asking the experts to express their opinion about the results, while in the second round, he gave them to validate the concluding statements to identify the stronger ones and come up with valuable recommendations to the organization.

Results

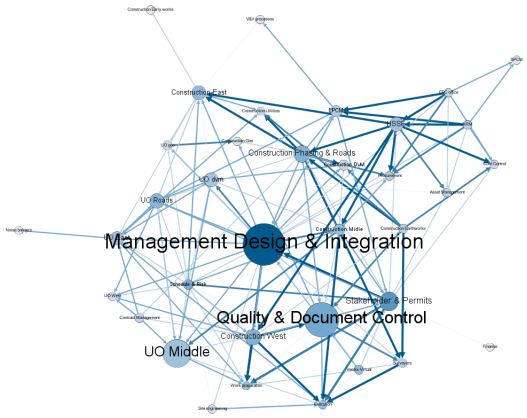
By performing an extensive literature review, there was an effort to understand the theoretical context of this research. Through the literature review the importance of knowledge exchange among employees in inter-organizational construction projects is highlighted. Several barriers have been identified to prevent organizations from sharing information among them but the motives to share information and exchange knowledge between them could act as drivers to the organizations that wish to achieve high-performing outcomes. Additionally, some of the impacts of successful information and knowledge exchange between the organizations were also discussed with a specific emphasis on enhancing team performance. To conclude the literature review, the researcher explored the power of social networks in fostering information-sharing behaviour.

The survey was distributed to the whole organization via email, and an acceptable response rate equal to 26.2% was achieved. Forty-four teams/departments have been identified, but not all appeared in each design phase. Network densities varied from 16.9% to 27.1%, with the highest achieved in the definitive design phase (DO). All the networks have been visualized by using ***Gephi***, a social network application and they are presented in Figure 6.1.

(a) Communication network of the inter-organizational venture in predesign phase (VO)



(b) Communication network of the inter-organizational venture in definitive design phase (DO)



(c) Communication network of the inter-organizational venture in execution-ready design phase (UO)

Figure 1: Communication networks of the inter-organizational venture in every design phase

In general, it appeared that the communication network in the definitive design phase was the one closest to reality. In contrast, the experts did not agree that the communication network results in the predesign and execution-ready design to represent reality. Team Stakeholder & Permits were among the most influential nodes in all design phases, playing a dominant role in the predesign phase (VO). Team Management Design & Integration undoubtedly had the control over the flow of information both in the definitive design phase (DO) and execution-ready design phase (UO), but the possibilities of running into the risk of being a bottleneck were high in both the design phases. During the execution-ready design phase, construction-related teams started participating more actively in information-sharing activities. They also appeared to have more frequent lines of communication than the rest of the teams. Teams Cost Control and Work Preparation were found to be the thorns of information sharing since they were either very disengaged from the network or just visible figures having no impact on sharing information. For the Cost Control team, this was also confirmed by the experts. However, regarding team Work Preparation, even though the SNA did not indicate it, experts explicitly stated that it contributed significantly to the execution-ready design phase.

The contract format, the technologies that employees had in hand, the divergence of individual and organizational goals, the teams not consisting of members from various organizations and some habits of the employees were found to have significantly impacted how information flowed in this specific inter-organizational venture.

Discussion - Conclusions

This research contributes to the body of knowledge related to inter-organizational information sharing by investigating how information flows in a specific case in the various design phases. It also contributes to the studies that have adopted Social Network Analysis (SNA) in construction projects. Additionally, the methods that the student adopted to approach the research may contribute to the existing knowledge since participant observations, and an expert panel workshop session were performed to enrich the primary data collected through a survey. The results of this research support that information sharing in inter-organizational ventures has logically concerned academia. Even though much is already known in the literature, inter-organizational information sharing still appears to be a problem. Thus, these results matter to the organization as it can take advantage of them and create structures that will result in effective information sharing and successful project delivery. However, the limitations that this study was subjected to should also be taken into account. These concern the theory, the scope, the methodology and the analysis of the results, and they played a major role in the interpretation of the results.

Regarding the three research propositions that have been formed at the beginning of this research, they were either wholly or partly confirmed based on the results. Regarding research proposition one, the part that more central positions will be acquired by the teams that have access to information provided by the client was confirmed, whereas the part stating that a lot of interactions between the departments will exist did not. Research proposition two was fully supported since the position of team Management Design & Integration in the network was confirmed from all the research activities. As far as research proposition three is concerned, it can be confirmed that construction-related departments were more engaged during this phase, but it cannot be completely confirmed that they acted as a link for transferring information to the rest of the organization.

This research concluded that in the predesign phase, there should have been more involvement from teams that were generating valuable information to balance the control that the most influential team, according to the SNA, had over the flow of information. The different design teams should have had the same degree centrality and probably the same betweenness centrality. However, it may also be the case that one area is more complex and more information-dependent, thus ranking higher in terms of influence in the network. In the definitive design phase, team Management Design & Integration should control the flow of information. However, other teams should also support it since being the only one to have control may become a bottleneck or even a single point of failure. Such teams could be teams of the same subculture regarding their roles and responsibilities in the organization. In the execution-ready design phase, many central figures concerning the construction-related teams exist in the network since many activities take place. There are multiple sources of information; thus, team Management Design & Integration should be able to absorb all of it. Attention must be paid to the various barriers that have been found to impact how information flows. Especially in how the information is being communicated and how to motivate employees to use the various technological developments

available since they found to enhance information sharing.

Since no studies were found to investigate how information flows during the different phases of the design process in inter-organizational projects by adopting social network theory, the results of this research will be of value both for the scientific community and the practice.

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1 Introduction

This report concerns the information sharing of inter-organizational teams in various design phases in a particular case study by adopting social network theory. First, the scientific context is introduced in section 1.1, and then the problem that the researcher aims to solve is discussed in section 1.2. This leads to formulating the research objective and the research questions, which are mentioned in section 1.3. Lastly, a reference to the thesis outline is made in section 1.4.

1.1. Scientific context

Projects tend to become larger and more complex (Y. Li et al., 2019; Park & Han, 2012; Son & Rojas, 2011) and a single company does not acquire the expertise to carry out the whole project by itself (Son & Rojas, 2011). Since the complexity has been increased, both technically and organizationally (S. Pryke et al., 2018), a wide range of skills across disciplinary boundaries is required, resulting in work to be done more in a team environment (Bygballe & Swärd, 2019; Dyer Jr et al., 2013; Edmondson & Lei, 2014). The construction industry is project-based, and people from various organizations and disciplines need to work together towards the same goal (Fong & Lung, 2007). Thus, inter-organizational project teams are formed. These teams are temporary (Solis et al., 2013), and they consist of representatives from the owner, designer, contractors, and other relevant stakeholders for the completion of the project (Albanese, 1994; Fong & Lung, 2007; Solis et al., 2013).

There has been longstanding concern about information sharing in inter-organizational projects. The construction industry has recognized the importance of information sharing to team outcomes, but it struggles to facilitate it when it is most needed (Mesmer-Magnus & DeChurch, 2009). A significant concern is that shortfalls in project performance are attributed to inter-organizational collaboration (Memon et al., 2021; Suprapto et al., 2015), and in order to deliver the projects successfully, integration of knowledge and more coordination between experts is deemed necessary (J. Koolwijk, 2022). As such, it should be a top priority for project managers to be aware of how to promote knowledge transfer between project participants (Zhou et al., 2022). This is because organizations rely on their employees to generate, share and utilize knowledge since they cannot create knowledge on their own (P. Zhang & Ng, 2012).

Studies have so far emphasized that the adoption of a team working environment in most organizations has forced employees to perform effectively in them (Han et al., 2017), resulting in high productivity (Baiden & Price, 2011) and more effective problem solving (Van den Bossche et al., 2006), which can be attributed to the variable presence of skills. Bringing people together though, and assigning them to various teams guarantee neither efficient collaboration between them (Baiden & Price, 2011) nor an effective performance (Salas et al., 2000). If inter-organizational teams aim to increase performance, effective information sharing and knowledge exchange should be prioritized (Marlow et al., 2018). To ensure that, employees must exchange information and knowledge in and between groups (Ni et al., 2018). Thus, communication is paramount to team performance and project management success (Chiocchio, 2007).

If a company wishes to be competitive in this challenging world, it requires high-performing teams (Dyer Jr et al., 2013) which can achieve outstanding outcomes beyond the projects' expectations (P.

Chinowsky et al., 2008). Hence, circumstances have emerged the need to form high-performing teams (Y. Li et al., 2019). To achieve such results, a shift needs to be made from traditional project management practices to the management of projects as social collaborations (P. Chinowsky et al., 2008). Interpersonal interactions, such as those seen in social networks, must be considered as well (Lin, 2015). Social network theory could be constructive in mapping communication trends of various teams in construction projects (Malisiovas & Song, 2014). Still, only very recently the network analysis approach has received significant attention in the construction industry from researchers (P. S. Chinowsky et al., 2010; Lin, 2015; Park & Han, 2012; Wanberg et al., 2015; Zheng et al., 2016).

Furthermore, all this competition and complexities that exist in the construction industry make information and knowledge exchange difficult (Farshchi & Brown, 2011) and thus creates the need for the consideration of managing the projects as social networks in order to capture the knowledge that circulates among the employees from daily project work to past project experience (van Waveren et al., 2014). Fragmentation issues that beset the construction industry for years can be solved by forming networks which can help project teams operate more efficiently and communicate better (Abbsaian-Hosseini et al., 2019). If design and construction teams start collaborating early, the fragmentation issues of the construction industry can be addressed (Kent & Becerik-Gerber, 2010).

However, despite all of the attention put into effective communication and knowledge sharing among the project participants, the latter still appears to be an issue in practice (Pirzadeh & Lingard, 2017), especially between design and construction teams (Kwofie et al., 2020). Therefore, this research focuses on understanding how information flows during the different design phases of the design process in inter-organizational projects. By adopting social network theory, the researcher aims to grasp valuable insights into the communication patterns that evolve during the design life cycle between the various teams in an inter-organizational venture. By understanding how teams, projects and the construction industry, in general, can enhance the knowledge transfer among them, the construction processes can be improved, resulting in a more innovative industry (Farshchi & Brown, 2011). Besides, an attempt to map the organization's communication network will be made for possible bottlenecks be found. If they do, this will lead to the redesign of the communication network to be more effective. Such adaptations to the organization will be proposed to improve the communication and knowledge transfer between teams and departments.

1.2. Problem description and research gap

This research has been carried out for graduation purpose and it is supported by Delft University of Technology and Count & Cooper. Count & Cooper was founded the year 2013 and is located in Rotterdam. Count & Cooper is being characterized as a Managing Contractor firm which their main business is winning tenders and successfully delivering construction projects. One of the key focus areas of the firm is promoting teamwork trough their high-performing team practice.

For Count & Cooper, the problem associated with this research lies in the execution of a big infrastructure project in which collaboration is being measured for all types of teams (1 through 4), as depicted in Figure 1.1. This study examines information sharing in an inter-organizational venture from the private domain for clarification purposes. This clarification is essential because various types of inter-organizational projects exist, and Public Private Partnerships (PPPs) can also be characterized as inter-organizational teams. Additionally, inter-organizational relationships may exist on the public side itself as well. Thus, in this study, when there is a reference to the inter-organizational venture, this will be meant for the consortium partners that shape the inter-organizational venture, excluding the client.

Count & Cooper has implemented an Integrated Project Delivery method which, according to (Manata et al., 2018) such implementation is supposed to enhance team performance, remove barriers regarding information sharing in and between teams and, in general, improve the project outcomes. However, regardless of the benefits such a partnership could bring to the table, its impact on performance is arguable (Bygballe & Swärd, 2019). Experts on this field support that team performance can be improved on the project. They carried out some interviews and they identified that the contract form and the considerable differences between organizations and disciplines have caused problems in cooperation. The contract is used too quickly where the focus should be on learning together. Additionally, through the satisfaction surveys distributed to the organization in the years 2020 and 2021, it was clear that internal project communication needs to be improved.

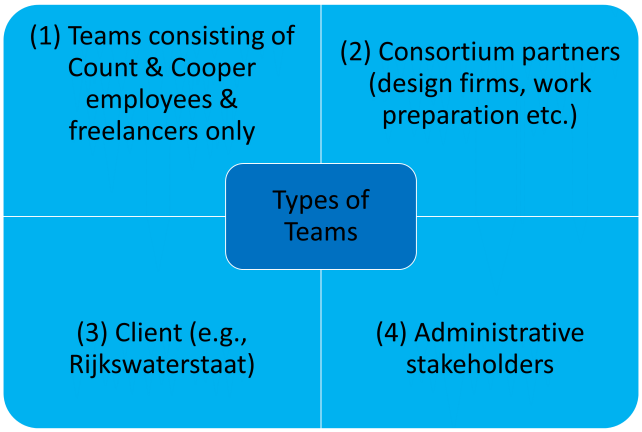


Figure 1.1: Types of teams

Information sharing and knowledge exchange may seem to be practical problems. However, the literature confirms a gap in the research domain associated with the problem that Count & Cooper is faced with. Although knowledge sharing has been in the spotlight in various industries, the studies examining knowledge sharing in the construction industry are limited (P. Zhang & Ng, 2013). Especially when it comes to multidisciplinary project teams, there are very few studies that address how to create knowledge at team levels (Fong, 2003).Zhou et al. (2022) recently stressed the need to explore the knowledge transfer mechanisms of inter-organizational teams in international construction projects. It is similar to what Ruan et al. (2012) had already highlighted when they stated that inter-organizational knowledge integration can be crucial for project performance but is still not explored to its fullest.

There have recently been requests for increased focus to be given to the ”relational” and ”social” elements of project management. However, research on project management using a network analytical approach is still lacking (S. Pryke et al., 2018). First, Cicmil and Marshall (2005) argued for more research into the complexities of building projects as social environments. Then, Wambeke et al. (2012) confirmed that studies that used social networks in the construction industry were still limited. Lastly, a recent study from Garcia et al. (2021) stated that a research gap still exists regarding the evolution of inter-organizational teams in the construction industry.

Ultimately, the researcher aims to supplement all these studies by conducting social network analysis in a case study. According to Senaratne et al. (2021), social network analysis might be an appropriate method to detect knowledge-sharing bottlenecks in inter-organizational construction projects, but it requires further research. More specifically, this study focuses on the information sharing and knowledge exchange in design phases in inter-organizational projects where designers play a significant role. In this particular field, there is even more limited research (Den Otter & Emmitt, 2008; Nipa et al., 2019).

1.3. Research objective and research questions

The main objective of this research is to investigate how information flows during the different phases of the design process in inter-organizational projects. The researcher adopted social network theory as the main research approach to study information flows in a selected case study. Thus, this study aims to improve understanding of the context of the problem in practice by applying the principles of social network theory. Three research propositions based on what literature says and what the researcher expects to find out will be tested and discussed as well. The aforementioned main objective lead to the following research question:

“How is information exchanged in inter-organizational projects during the design life cycle?”

To answer this main research question, several other sub-questions have been raised and will be

answered prior to the main one.

SQ1: What does information sharing in inter-organizational construction projects entail?

SQ2: How can information flows best be studied?

SQ3: How is the actual information flow at the targeted inter-organizational venture organized?

SQ4: Which are the most critical factors that impact how information flows and must be considered for future projects?

1.4. Thesis outline

This thesis consists of six (6) chapters. The first three (3) chapters provide context regarding the preparation phase, while the other three (3) chapters focus on the analysis of the results, the discussion and the conclusion. Below a short description of each chapter's contents is being given.

Chapter 1 – Introduction: Under this chapter, the researcher introduced the scientific context of this study. Then he described the problem that the company was faced and he mentioned the gap that lies in the literature and inspired this study. Ultimately, he presented the research objective and the research questions that he aimed to answer.

Chapter 2 – Literature Review: In this chapter, previous literature regarding the selected vital concepts is presented. The main objective of this chapter was to answer sub-question 1.

Chapter 3 – Research Methodology: The whole research design and methodology that will be followed for conducting this research is presented in chapter 3.

Chapter 4 – Results: Chapter 4 is devoted to analyzing all the research activities that have been carried out. The results from the survey are going to be analyzed, as well as the data gathered from the observations. Additionally, the expert panel workshop session is discussed. Sub-questions 3 and 4 will be answered based on the content of this chapter.

Chapter 5 – Discussion: The main findings of this study were then summarized in this chapter and discussed, together with their implications, limitations, and recommendations to the organization. Additionally, in this chapter the researcher tested the research propositions.

Chapter 6 – Conclusion: The conclusion's final chapter provides answers to the sub-questions, which eventually will help answer the main research question. Moreover, the researcher will provide future research directions that may be further investigated to close off this thesis.

2

Literature Review

A literature review is elaborated upon in this chapter for the theoretical concepts to be explored. Reviewing the existing literature is an essential part of scientific research since it provides the foundation of it (Saunders et al., 2009).

First, in section 2.1, the concept of information sharing is explored with a specific focus on knowledge transfer among employees in the construction industry.

Then, in section 2.2, the researcher dives more profound into the concept of inter-organizational information sharing by mentioning what motivates organizations to form inter-organizational relations and exchange information and knowledge, which factors act as barriers that inhibit information sharing or even prevent companies from forming inter-organizational relationships and which factors contribute to their success and what are the impacts of successful information and knowledge exchange between the organizations.

After, in section 2.3, the power of social networks in shaping information sharing practices, in general, is discussed.

Lastly, in section 2.4, three research propositions, one per design phase, based on what the literature says and what the researcher expects to find out, are formulated.

2.1. Information sharing

2.1.1. Information sharing in the construction industry

The construction industry is characterized as highly information-dependent (Malisiovas & Song, 2014). It is a fact that many construction issues are caused by missing, inadequate, or misleading data (Lin, 2015). Thus, the quality of information and the way it is exchanged are crucial components of the management of construction projects (Keung & Shen, 2013). The importance of the management of information in construction projects stems from the fact that the life cycle of such projects involves several processes associated with information, from its creation and documentation to its evaluation and archiving (Ibrahim et al., 2018).

Understanding and practising information sharing can lead organizations to new opportunities (Laurent & Leicht, 2019), make them stay competitive in the industry and boost their profitability (Hatala & George Lutta, 2009). Literature suggests that when managing construction projects, it is essential to consider not just the integration of information but also the integration of knowledge that stems from the participants' expertise and their experience (Trach & Bushuyev, 2020). In practice, the knowledge of individual project members is reflected in construction projects rather than the organization's cumulative knowledge or information garnered from past projects (Gannon & Banham, 2011). Organizations may be knowledge-intensive, but they rely heavily on the application of knowledge by their employees to be able to create value in their projects (Ni et al., 2018).

Since the construction industry is project-based, multiple sources of information and knowledge exist. Thus, much attention must be paid to how these are developed and shared within project teams (Farshchi & Brown, 2011). The construction sector may be rich both in knowledge and information, but at the same time fragmented since this knowledge is scattered across individuals with different roles in various organizations all over the world (Gannon & Banham, 2011). Among all the organizations that

collaborate in the construction industry, various specializations, work schedules, and responsibilities exist in addition to their unique interests, values, and cultures (Liu et al., 2017). As a result, organizational values, norms, and cultures impact how organizational members feel and act regarding sharing information (Yang & Maxwell, 2011).

2.1.2. Defining information and knowledge

Most discussions regarding information sharing and knowledge management differentiate data, information and knowledge (Hatala & George Lutta, 2009). Frey (2001) stated that data should be first converted into information and then transformed into knowledge (Ruan et al., 2012). While information consists of a stream of messages, knowledge is formed and structured by the same stream of information, but it is based on the holder's commitment and beliefs (Nonaka, 1994). One of the most famous models in this stream of research is the Data-Information-Knowledge-Wisdom (DIKW) hierarchy (Ackoff, 1989). Data transformation into wisdom can be visualized through a pyramid and seen in Figure 2.1. However, the definitions of data, information and knowledge are not straightforward. Zins (2007), in his study, summarised more than 130 definitions of data, information and knowledge and how they relate to each other, which highlights the lack of the concepts' definitions clarity. Around the same time, Rowley (2007) revisited the DIKW hierarchy, and she found out that typically there is an agreement in terms of the hierarchy. On the contrary, there is less agreement regarding the processes that turn lower-level components of the hierarchy into higher-level ones.

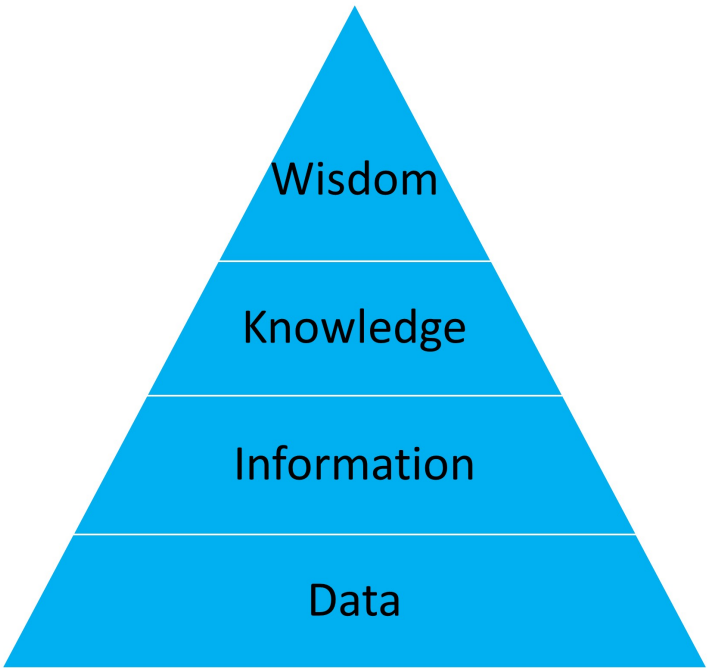


Figure 2.1: DIKW hierarchy (adapted by (Ackoff, 1989)

In the Architecture Engineering and Construction (AEC) industry, knowledge is distinguished from information and data (Senescu et al., 2013). This is due to the fact that both data and information may be used as knowledge inputs (Rowley, 2007). There are various definitions of knowledge. Buvik and Tvedt (2017) followed in their research the definition of knowledge as being described by Bartol and Srivastava (2002). The latter perceive knowledge in the organization to contain information, ideas and expertise related to tasks undertaken by employees, teams and the whole organization. P. Zhang and Ng (2013) as well as Swart et al. (2014), adapted in their studies the definition of knowledge as being

stated by Davenport, Prusak, et al. (1998). According to the latter, knowledge is ”a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of the knower”. Considering the researcher's expertise, this research will adopt the definition of knowledge as described by Bartol and Srivastava (2002) since the one given by Davenport, Prusak, et al. (1998) is more complicated.

Knowledge can be either explicit or tacit (Nonaka, 1994). Formal knowledge that can be accessed, learned, or communicated is referred to as explicit knowledge (Gannon & Banham, 2011; Nonaka, 1994). Tacit knowledge, on the other hand, has a personal aspect that makes it difficult to codify and express (Nonaka, 1994). It lies within the individuals' experience, so it is not easy to share (P. Lee et al., 2010). Farooq (2018b) referred to tacit knowledge as being subjective while explicit knowledge can be referred to as objective.

2.1.3. The importance of knowledge sharing

While most definitions of knowledge imply that knowledge exists in individuals (P. Zhang & Ng, 2013), knowledge sharing is a multilevel phenomenon that can be performed at the individual as well as intra- and inter-organizational levels (Ni et al., 2018; Swart et al., 2014). However, the knowledge transfer between individuals is critical since they mediate the knowledge transfer between groups and organizations (Zhou et al., 2022). P. Zhang and Ng (2012) support that since individuals play a major role in creating knowledge, the way they share is an individualistic behaviour. According to Buvik and Tvedt (2017), knowledge sharing is defined as the interchange of explicit and implicit task-related knowledge. Farooq (2018a) made use of C. L. Wang et al. (2009) definition of knowledge sharing. The latter support that the transmission of wisdom, skills, and technology between organizational sub-units is known as knowledge sharing. Buvik and Tvedt (2017) consider knowledge sharing to be a team-level behaviour. Hence, they expect that the type of interpersonal relationships within the team will influence information sharing. Since social relations play a major role in knowledge sharing, knowledge sharing can occur in various forms. It can take place through written letters, face-to-face contacts, or even by recording, organizing, and capturing knowledge for others (S. Wang & Noe, 2010).

Furthermore, the subjective nature of meaning should also be taken into account because what one person considers valuable information may be viewed as meaningless data by another (Rowley, 2007; Senescu et al., 2013). Thus, understanding is also necessary for assessing the information and its correct use (Santalova et al., 2018). According to Ruan et al. (2012), only when the recipient fully comprehends the information and can use it to address specific issues does the information become knowledge. Rowley (2007) though, supports that knowledge precedes understanding since what allows information to be transformed into instruction is knowledge, and without knowledge, there can be no understanding and consequently no wisdom. According to Ackoff (1989), wisdom is the pyramid component that can increase effectiveness. P. S. Chinowsky et al. (2010) stated that the success of a project is based on factors related to effectiveness rather than the traditional ones tied to efficiency. Ultimately, suppose organizations wish to achieve high-performing teams that act proactively instead of reactively to the challenges. In that case, they need to shift their focus from information sharing to knowledge sharing (P. Chinowsky et al., 2008).

Since the literature so far has indicated that, besides information, organizations need to utilize knowledge as well, two other terms that need to be contextualized for this research are Knowledge Management and Knowledge Transfer. In this research, the definition given by Ulhaq et al. (2017) has been adopted, which states that knowledge management is a comprehensive method for obtaining, organizing, and sharing employees' tacit and explicit knowledge so that others may benefit from it and become more productive and effective. On the other hand, the process through which knowledge is conveyed from the sender to the receiver and absorbed by the recipient is known as knowledge transfer (Szulanski, 1996). As a result, knowledge transfer at a team level can be considered as the sum of team members' knowledge transfer activities (Zhou et al., 2022). In the case of strategic alliances, inter-firm knowledge transfer can occur if the knowledge is transferred from one business to the other (Buckley et al., 2009).

2.2. Inter-organizational information sharing

Given that information is a source of competitive advantage, inter-organizational information sharing is characterized as a critical strategic activity (Yang & Maxwell, 2011) as it can enhance the competitiveness of each organization by increasing its information base (Cheng et al., 2013). Forming inter-organizational ventures that span organizational boundaries is becoming a popular approach in collaborative innovation (Hu et al., 2017). These ventures are temporary teams comprised of parties such as the owner, designer, contractors, and other stakeholders (Solis et al., 2013). The projects that are usually appealing to the development of such inter-organizational teams are characterized as mega-projects, and they usually encompass a vast number of occupations, each with its own set of skills that contribute to a project's success (Schröpfer et al., 2017).

Due to the numerous relationships between various organizations, construction management is faced with significant challenges (Liu et al., 2017). One of these challenges is the encouragement of information sharing (Choi et al., 2008). This is due to the fact that organizations cannot force employees to share information since such behaviour can either be facilitated or stimulated (Bock et al., 2005; Ibrahim et al., 2018). Besides the management of information that these organizations may have in their possession, what is becoming very crucial in diverse environments is the management of knowledge since knowledge is considered an essential vital asset (Boamah et al., 2021). Knowledge transfer can create a competitive advantage and thus has triggered its research in intra- and inter-organizational levels (Van Wijk et al., 2008). Even though researchers have proved that by investing in knowledge sharing, individuals and organizations can benefit greatly, the value of knowledge sharing for organizations remains to be explored (Ahmad & Karim, 2019).

Nowadays, international contractors across the globe are increasingly participating in various markets (Zhou et al., 2022). However, as Berteaux and Javernick-Will (2015) indicated, the integration of knowledge and processes in the construction industry must be adapted to local environments (Demirkesen & Ozorhon, 2017), which is a task that seems very challenging for contractors in terms of knowledge management (Zhou et al., 2022). Even though this might impose challenges on multinational corporations, the latter appears eager to learn from each market they operate to develop aggregate organizational knowledge across geographic areas (Javernick-Will, 2011). After forming inter-organizational teams, team members with diverse competence areas and work practices tend to build knowledge-transfer networks to cooperate even from the beginning stages of planning and design (Garcia et al., 2021). Aligning the knowledge of both the designers and the contractors in all the phases can result in a successful project outcome (Salam et al., 2019). In such cooperative networks, knowledge usually is transferred between people that belong to different organizations (Sun et al., 2019) by making use of various tools (Schröpfer et al., 2017).

Knowledge management is eventually rendered necessary due to the multiple sources of knowledge that stem from the numerous project practitioners from which the construction industry depends on (Boamah et al., 2021). All these project team members with a variety of knowledge must collaborate to overcome the issues that may arise throughout the course of the project (Fong, 2003). One crucial phase during the construction process is the design phase. For team members to develop a design that coalesces the knowledge of all the project team members, the latter have to exchange information continuously (J. S. J. Koolwijk et al., 2020). Supporting knowledge exchange in design teams necessitates breaking down barriers across professions (BEKTAŞ et al., 2008).

Usually, when the projects are that big and complex and require various organizations to cooperate, many design companies are involved (Chiu, 2002; Nipa et al., 2019). According to Nipa et al. (2019), when multiple entities with the same expertise and responsibilities are required to work together, there may be some friction between them, which requires effective communication to avoid delays and costs. Additionally, not all of them being familiar with the relevant technological advancements could also result in high friction and multiple changes in design (Safapour et al., 2019). On the other hand, such friction can facilitate the production of new knowledge since the members of the design teams will repeatedly gather, share and transform information (Den Otter & Emmitt, 2008). According to Pesek et al. (2019), one of the main reasons for project flaws is frequently attributed to the design team's lack of knowledge and its members' or stakeholders' lack of communication. Additionally, several other researchers believe that some of the construction industry's challenging communication problems are related to the design teams (Cheung & Yiu, 2014; Higgin & Jessop, 2013; Kamalirad et al., 2017). Thus, this research will be mainly focused on understanding how information flows during the different design phases of the design process in an inter-organizational project.

2.2.1. Drivers

In order for an organization to be competitive in a market, it needs some unique resources such as information, knowledge of its employees and technology, among others (Chan et al., 2004). What is common is the unwillingness of the organizations to share their resources with others. Due to the increase in complexity that characterizes construction projects (Bosch-Rekveldt, 2011), the growing demand for global construction (Akgul et al., 2017) as well as for sustainable construction (Memon et al., 2021), the collaboration between organizations has been improved. Especially in the case of international construction, more and more firms are motivated to collaborate under various forms such as partnerships or integrating project deliveries (Akgul et al., 2017; Park et al., 2011).

The advantages that organizations can obtain in the case of partnering are not a few, and they can act as drivers that motivate companies to form inter-organizational ventures (Khouja et al., 2021). Drivers can either be economical, knowledge-related or social (Khouja et al., 2021). Companies often form partnerships to share costs and risks, access new markets internationally and improve competition (Akgul et al., 2017; Park et al., 2011). Organizations may also be motivated to collaborate to gain access to new technologies (Park et al., 2011) or even create knowledge (Khouja et al., 2021).

By pooling the resources and competencies of every firm, competitive advantage can be created (Akgul et al., 2017). Since information and knowledge are unique sources of every organization, sharing them among all parties can help organizations respond to the client's needs more effectively and efficiently (S. Li & Lin, 2006). In that case, reciprocity among the partners can act as a driver to stimulate the willingness of the employees to share the information or the knowledge they possess (Ibrahim et al., 2018; Javernick-Will, 2012).

2.2.2. Barriers

Even though a few factors motivate companies to form inter-organizational ventures and share information between them, at the same time, some other factors act as barriers that inhibit information sharing or even prevent companies from forming inter-organizational relationships. In this section, the barriers to information sharing will be presented in three categories, namely, cultural, organizational and industry-related. According to Hatala and George Lutta (2009), some invisible barriers to information sharing also exist, such as politics and regulations, but these will not be further elaborated on. The summary of all the factors and their reference source can be seen in Table 2.1.

Cultural

First of all, there is a need to define what culture is. The social environment of an organization is known as culture, and it is ingrained in the values, beliefs, and assumptions shared by organizational members (J. S. J. Koolwijk et al., 2020). In multicultural organizational settings, demographic factors such as the diversity of the employed members could impede information sharing (Adi & Musbah, 2017; Hatala & George Lutta, 2009).

As was discussed before, information and knowledge are unique resources that can serve as a competitive advantage to organizations. Following the same logic, the notion that the possession of specific information or knowledge is power can act as a barrier to information sharing (Hatala & George Lutta, 2009; Willem & Buelens, 2007; Yang & Maxwell, 2011). Suppose individuals perceive that they are threatened of losing power by sharing the information or knowledge they possess. In that case, they will probably prefer to withhold this asset from the rest (Hatala & George Lutta, 2009) and protect their status (Yang & Maxwell, 2011).

Commitment to integrating knowledge is a thorny problem as far as knowledge management in the construction industry is concerned due to the constraints imposed by individuals, institutions, processes, and industries (Boamah et al., 2021). Ni et al. (2018), stated that one of the main obstacles to knowledge sharing is the lack of clear commitment. Later, Ibrahim et al. (2018) mention in their research that not being fully committed could lead to the discouragement of information sharing and eventually to ineffective communication between the organizations. Another reason for the unwillingness among inter-organizational members to share information is the lack of trust (Ibrahim et al., 2018; Pesek et al., 2019; Yang & Maxwell, 2011). This is most common, especially between the client and the contractor, since their interests may be diverging, as the latter tend not to reveal their financial aspects (Pesek et al., 2019). This can create the feeling of being non-trustworthy, which in the end, may inhibit information sharing (Ibrahim et al., 2018). Last but not least, according to Barua et al. (2007), one more reason for the reluctance to share information could be the divergence of individual and organizational

Table 2.1: Factors that act as barriers to information sharing in inter-organizational projects according to literature.

Barriers of information sharing in inter-organizational projects	Source
Cultural	
Lack of trust	Barua et al. (2007); S. Li and Lin (2006); Hu et al. (2017); Yang and Maxwell (2011); Willem and Buelens (2007); Kim and Lee (2006); Ibrahim et al. (2018); Pesek et al. (2019); P. Chinowsky et al. (2008)
Lack of commitment	S. Li and Lin (2006); Ibrahim et al. (2018); Ni et al. (2018)
Notion that knowledge is power	Javernick-Will (2012); Yang and Maxwell (2011); Willem and Buelens (2007)
Divergence of individual and organizational goals	Barua et al. (2007)
Organizational	
Conflicting objectives	Barua et al. (2007)
Lack of equity / Centralization	Hatala and George Lutta (2009); Yang and Maxwell (2011); Kim and Lee (2006); Gil-Garcia and Sayogo (2016)
Departmentalization	Willem and Buelens (2007) 2007;Yang and Maxwell (2011)
Lack of incentives / rewards	Bock et al. (2005); Willem and Buelens (2007); Kim and Lee (2006); Ni et al. (2018)
Industry-related	
Fragmentation	Schröpfer et al. (2017); Ni et al. (2018);
Complexity	Pirzadeh and Lingard (2017); Ding et al. (2014);
Contractual relationships	P. Chinowsky et al. (2008); Pirzadeh and Lingard (2017)
Large number of new technologies	Barua et al. (2007); Hatala and George Lutta (2009); Yang and Maxwell (2011); Schröpfer et al. (2017)

goals.

Organizational

Some of the organizational barriers to information sharing include lack of equity among the various members of the organization (Hatala & George Lutta, 2009), departmentalization (Willem & Buelens, 2007; Yang & Maxwell, 2011), conflicting objectives between the various work groups (Barua et al., 2007) and the lack of incentives or rewards to the employees for sharing their knowledge (Bock et al., 2005). Information sharing may be hampered by the organizational structure due to the division of departments and by the position of individuals since some employees may have more central positions (Hatala & George Lutta, 2009), but there are ways to overcome that kind of barriers such as the co-location of some departments (BEKTAŞ et al., 2008). Lastly, regarding information-sharing initiatives in inter-organizational ventures, one reason such actions may fail is limited financial resources (Gil-Garcia & Sayogo, 2016).

Industry-related

As has already been mentioned, the construction industry is characterized as complex and fragmented. These characteristics of the industry are also factors that inhibit information sharing. Projects can be complex both technically and socially. As far as the technical complexity is concerned, this includes the nature of the design-related tasks, which are considered to be complex (Ding et al., 2014), as well as the large number of new technologies used during the construction process (Krechowicz, 2022). Regarding the social side of complexity, this has to do with the fact that various individuals with different values and beliefs are part of the project and many organizations with varying norms and regulations participate (Franz et al., 2017). Additionally, according to Keung and Shen (2013), contractors' performance regarding communication is frequently compromised by the fragmented nature of construction projects.

The large number of new technologies is often cited as a barrier to information sharing among organizations (Barua et al., 2007; Hatala & George Lutta, 2009; Schröpfer et al., 2017; Yang & Maxwell, 2011), which can be attributed to various reasons. First, information exchange cannot be facilitated by technology alone (Barua et al., 2007). On the contrary, it can sometimes even work against it (Barua et

al., 2007) due to the incompatibility that the participating organizations' IT systems may have (Gil-Garcia & Sayogo, 2016). The medium employed to share information among organization members might potentially cause issues rather than motivate them (Hatala & George Lutta, 2009). This is because each organization has built its information systems differently since a variety of software and hardware exist in the market, making it difficult for the inter-organizational venture itself to integrate the various platforms and data standards (Yang & Maxwell, 2011) and for its members to share their knowledge since may everyone be familiar with different tools (Schröpfer et al., 2017).

Furthermore, another industry-related barrier to information sharing identified through the literature review is contractual relationships (P. Chinowsky et al., 2008; Pirzadeh & Lingard, 2017). Generally speaking, in a project context, the established contractual relationships may pose a barrier to the free flow of information and knowledge (P. Chinowsky et al., 2008), especially between the design and construction parties which are often contractually separated (Pirzadeh & Lingard, 2017).

2.2.3. Success factors

Having discussed what factors act as barriers and prevent organizations from sharing information among them, it is essential to mention how the industry can overcome these barriers. For organizations to maximize the benefits from exchanging information between them in an inter-organizational venture, it is of strategic importance to understand what motivates their employees to do so (Cheng et al., 2013). Therefore, this section discusses the success factors identified through the literature to contribute to information sharing.

Trust

Several researchers have positively associated trust with inter-organizational information sharing (Ding et al., 2007; Gil-Garcia & Sayogo, 2016; Yang & Maxwell, 2011). Organizations need to establish trust-based relationships to promote information exchange and get over concerns about information exposure and losing power over competitors (Hatala & George Lutta, 2009; S. Li & Lin, 2006). Individuals are willing to share information only when they feel protected against opportunistic behaviours (Willem & Buelens, 2007). This sense of security in sharing information and knowledge is fostered by high levels of trust between the organizations (Ning, 2014). In inter-organizational projects, where many design companies participate, trust is fundamental for dealing with all the challenges since the members are highly interdependent and do not have the knowledge required to solve them alone (Chiocchio et al., 2011; J. S. J. Koolwijk et al., 2020).

Commitment

While lack of commitment can constitute a barrier to information sharing, as was discussed earlier, commitment can also act as a success factor in information and knowledge sharing. Several studies have positively associated commitment and knowledge sharing with (Buvik & Tvedt, 2017; Hislop, 2003; Swart et al., 2014). Committed members are more willing to collaborate with their coworkers, resulting in denser communication networks (Manata et al., 2021). Individuals that belong to such high-relationship-commitment teams are very like to offer knowledge (Chang et al., 2013). Especially when speaking of tacit knowledge, the willingness of the possessors triggers its sharing (Hislop, 2003). Thus, it is managers' task to figure out ways to motivate their employees to exchange knowledge so that the overall team performance to be improved (Ding et al., 2007). Motivation will result in adequate knowledge sharing (Hislop, 2003). On the other hand, attention needs to be paid to inter-organizational teams since highly committed employees to one party may be hesitant to share knowledge with the rest of the organization (Swart et al., 2014).

Creation of a common culture / Unique identity

In order for trust, commitment and eventually information sharing to be improved, teams or in the case of inter-organizational ventures, organizations have to develop a common culture (Franz et al., 2017). Individuals behave according to the organizational culture of their parent organization, and thus creating a common culture and managing the cultural diversity appropriately could enhance information sharing (Ibrahim et al., 2018). Regarding culture, J. S. J. Koolwijk et al. (2020) found out that a no-blame culture could be an essential facilitator of knowledge exchange. If members assigned to various teams feel comfortable sharing their information or knowledge, most likely, they will do so (Edmondson & Lei, 2014). The top management has an important role to play in this situation. Several

researchers have stated that leadership in the form of top management support can act as an enabler to inter-organizational information sharing (Gil-Garcia & Sayogo, 2016; Hatala & George Lutta, 2009). If organizations wish to overcome the barrier imposed by diverging interests, top management has to respond positively to information sharing (S. Li & Lin, 2006). Last but not least, another mechanism that could strengthen the sharing of information in inter-organizational ventures is the sense of continuity by forming long-term relationships (Barua et al., 2007; J. S. J. Koolwijk et al., 2020).

Incentives

Incentives or economic rewards can also be considered as one of the success factors for inter-organizational information sharing, and a few researchers assert their importance (Gil-Garcia & Sayogo, 2016; Kim & Lee, 2006; Yang & Maxwell, 2011; P. Zhang & Ng, 2013). P. Zhang and Ng (2012) though, unexpectedly found out that they do not significantly affect the individuals' attitude toward sharing knowledge. Other factors exist that have much more influence on information and knowledge sharing.

Technology

The large number of technologies available were mentioned earlier as barriers to inter-organizational information sharing. On the other hand, technology can be considered a success factor in information sharing since, without the advancement of information technology, organizations would not have been able to develop the systems that ease information and knowledge exchange (Yang & Maxwell, 2011). One of the practices that have emerged and is believed to enhance information exchange between multiple organizations through all the phases of a construction project is Building Information Modelling (BIM) (Franz et al., 2017; Ibrahim et al., 2018; Liu et al., 2017). Furthermore, in their study, Kim and Lee (2006) found out that information technology systems that appeared to be user-friendly significantly affected the employees' attitude toward knowledge sharing.

2.2.4. Impacts

In order to foster information-sharing behaviour, organizations must identify drivers, create a collaborative culture and structure their employees' interactions through the appropriate implementation of the technology available (Ibrahim et al., 2018). By managing the knowledge of all stakeholders effectively, the project performance in terms of time, cost, and quality will be improved (Senaratne et al., 2021). In addition to project performance, a literature review has proved that team performance can also be influenced by knowledge sharing (Ahmad & Karim, 2019). Over the last decade, much attention has been put by the research community on understanding what team performance is and how to assess it (Andersson et al., 2017). In general, team performance may be described as the ability of a group to achieve predetermined objectives, such as time, costs and quality (P. Chinowsky et al., 2008; Hoegl et al., 2004). To meet these objectives, resources like labour, goods and money were regarded as of more value than the knowledge and skills that the human capital possesses (Farooq, 2018a). The significance of humans for great project results has been agreed upon by construction project management researchers (P. Chinowsky et al., 2011) and managing the human capital is becoming an increasingly important research dimension of project management (Y. Li et al., 2019). Consequently, as Demirkesen and Ozorhon (2017) stated, the foundation of effective project management within a construction project is the integration of processes and people. For a construction team to function effectively and successfully deliver projects, human synergy through teamwork needs to be created (Yap et al., 2020).

Projects become ineffective when too little or too much communication or knowledge exchange takes place (P. Chinowsky et al., 2011). Thus, effective communication is what distinguishes high performing from low-performing teams (Marlow et al., 2018), is vital for achieving all the objectives regarding cost, time and quality (Pesek et al., 2019) and it should be considered as a tool to integrate the knowledge that different parties bring in inter-organizational projects (Ruan et al., 2012). Additionally, Ni et al. (2018) stated that organizations with higher chances of performing more successfully could apply the knowledge that circulates in the organization effectively. Without the knowledge being effectively shared within the organization, the collaboration among the participating parties may fail due to coordination issues in the project (Buvik & Tvedt, 2017).

In general, there is a need for project organizations to focus on a broader sense of effectiveness rather than on efficiency (P. S. Chinowsky et al., 2010). For organizations to make such a transition, the impact of communication and social relations needs to be evaluated (Plokhov et al., 2016). According

to Chiocchio (2007), network analysis can be of extreme use in achieving high-performing teams. This is due to the fact that such teams put a great emphasis on continuously exchanging knowledge between their members (P. Chinowsky et al., 2008) to enhance the quality of the result (Schröpfer et al., 2017). Since the construction industry relies heavily on the collaboration of all the organizations involved, information exchange is vital for accomplishing high-performance (Cress et al., 2006). Therefore, in order for today's big and complex projects to be realized successfully, what is required is the formation of high-performing teams (Y. Li et al., 2019)and one practice that characterizes them is a knowledge sharing (Farooq, 2018a).

2.3. Power of social networks

The classic factors tied with the measurement of successful project management are cost, time and quality, usually referred to as the ”iron triangle” (Atkinson, 1999). However, the main actors in the whole process of a construction project are the human participants (Lin, 2015). For that reason, social aspects like communication and multidisciplinary interactions have emerged as significant success factors in building project delivery (Malisiovas & Song, 2014). These human participants may act as managers, supervisors, and designers and often belong to various organizations. Thus, a construction project can be defined as a network of organizations linked by information flows and relational communication networks (S. Pryke, 2012). In such inter-firm networks, knowledge can be exchanged between the firms, resulting in each firm learning from the other (Park & Han, 2012). Apart from that, innovation of the construction projects can be enhanced, and value can be created as well if the knowledge of every firm is taken full advantage of (L. Zhang et al., 2013).

The acquisition and use of knowledge is a social process (Mu et al., 2008). While most of the knowledge management literature focused primarily on technology-related challenges, there is a general shift to the human resource-oriented factors (Ding et al., 2007; Hislop, 2003). Most of the problems related to knowledge management often arise when people forget that they are part of the process (Schröpfer et al., 2017). So, by adopting a social network approach for the execution of a project, much emphasis is being put on the dynamic nature of the project's participants' interaction and the open flow of knowledge between them (P. Chinowsky et al., 2008). Apart from that, it can also help identify the communication structures of a system by analyzing relational data (Keung & Shen, 2013; Schröpfer et al., 2017). By doing so, communication bottlenecks can be found, and the whole communication chart can be redesigned so that the project participants to be involved more effectively (Malisiovas & Song, 2014).

According to previous studies, social relationships among project actors are vital in promoting information exchange and knowledge transfer (Van Wijk et al., 2008), both formal and informal (Mu et al., 2008). Individuals can gain crucial information and knowledge through networking (Chow, 2012). To better understand how knowledge is transferred throughout an organization, individual relationships and participant networks need to be examined (Javernick-Will, 2011). With relationships playing such an important role, the more frequently an actor interacts with another, the better they exchange information in contrast with those who rarely interact (Keung & Shen, 2013). When knowledge-transfer members have a more frequent line of communication, mechanisms are being created, and a standard code of language can be formed, accelerating the whole process of knowledge transfer (Sun et al., 2019).

While there are various reasons why inter-organizational networks form, knowledge combination is the most prevalent among the proclaimed causes (Klein et al., 2020). Farshchi and Brown (2011) concluded that Social Network Analysis approach could be proven very beneficial with respect to inter-and intra-organizational knowledge sharing. Team members rely on coworkers, friends, and ex-colleagues as rich resources for creating design expertise, with social networks regarded as the most crucial channel for information and knowledge transmission (Fong, 2003). Members from various organizations tend to exchange knowledge either with friends (Ni et al., 2018) or with members that have prior experiences with (Buvik & Rolfsen, 2015). Hence, the more the social interaction among them, the more the knowledge that will be exchanged between them is (Ni et al., 2018).

Table 2.2 summarizes the studies that made use of social network theory in the construction industry:

Table 2.2: List of studies that made use of the social network theory in the construction industry, ranked from the most-cited to the least.

Study	Description
P. Chinowsky et al. (2008)	In this study, the authors emphasize the need to develop high performance teams by recognizing the importance of the social factors in construction management.
S. D. Pryke (2004)	The author aims at establishing the usefulness of SNA for analyzing the relationships that comprise the construction project coalition.
P. S. Chinowsky et al. (2010)	In this study the social network model of construction is being extended and applied in organizations that are focused on enhancing their collaborating practices to achieve high performance teams.
Zheng et al. (2016)	The authors aimed to identify future research directions for the application of SNA in Construction Project Management by reviewing the already existing applications of SNA.
S. D. Pryke (2005)	SNA is being proposed as an analytical tool in the construction project governance
Javernick-Will (2012)	The author under the scope of this research, tried to identify the social motivations of knowledge sharing in engineering and construction organizations.
Park et al. (2011)	This study aimed to validate the applicability of SNA as a tool to analyze collaboration in the construction industry.
Son and Rojas (2011)	This paper combines SNA with game theory to identify network behaviours within interorganizational constuction project teams.
Wambeke et al. (2012)	This study provides the steps to create a social network which can be applied to various aspects related to construction and it is the first study that uses SNA to map the trades of a construction project.
C.-Y. Lee et al. (2018)	This specific review aimed to analyse and discuss various SNA metrics, identify SNA applications to complex-project-management knowledge areas and advance the application of SNA.
Ruan et al. (2012)	SNA is used in this study to examine how knowledge can be integrated in competitive and collaborative working systems in construction projects.
Schröpfer et al. (2017)	By making use of SNA, the authors aimed to investigateknowledge transfer methods in sustainable construction project teams.
Dogan et al. (2015)	This study proposes a quantitative way to measure the coordinative performance of project participants.
Lin (2015)	Job-site social networks were analysed by making use of SNA measures to discover job-site management issues and possible technology interfaces.
S. Pryke et al. (2018)	The authors of this study, made use of the social network theory to identify self-organizing networks in large infrastructure projects.
Solis et al. (2013)	Authors under this research combine SNA with another method to study the teams which aspire to develop high performance.
Javernick-Will (2011)	In this study the researcher, investigated knowledge sharing networks in construction that span geographical boundaries by adopting the social network theory.
Malisiovas and Song (2014)	This study proposes a framework through SNA for the optimization of team structures regarding communication in construction projects.
Pirzadeh and Lingard (2017)	This paper proposes SNA as a method to map and analyze communication patterns during decision making.
H. Wang et al. (2018)	The purpose of this study was the improvement of social sustainability in construction through the development of a multilayered conceptual framework which was evaluated through SNA.
Kereri and Harper (2019)	This study provides a comprehensive literature review of social networks, team formation and collaborative teams in construction.

Senaratne et al. (2021)	In this study, the researchers want to identify potential research areas within the construction industry regarding the use of SNA for knowledge management.

2.4. Research propositions

From the literature review that has been carried out, it is evident that there has been a longstanding concern about information sharing in inter-organizational projects. Studies have so far emphasized what motivates organizations to form inter-organizational relations and exchange information and knowledge, which factors act as barriers that inhibit information sharing or even prevent companies from forming inter-organizational relationships and which factors contribute to their success, what are the impacts of successful information and knowledge exchange between the organizations and what is the power of social networks in shaping information sharing practices in general.

However, knowledge of how information flows during the specific phases of the design process is still limited, and no study has been found to examine that by using social network analysis. Thus, some research propositions have been formulated based on the literature and the researcher's expectations. These are shown below and will be discussed in chapter 5 after analyzing the results.

Research proposition 1: In predesign phase (VO) interactions are mainly focused between the client and the architect (Kent & Becerik-Gerber, 2010), and organizations are not familiar yet with each other. Thus, it is expected that a lot of interactions between the departments will take place, with the departments that depend on information that is provided by the client to acquire more central positions.

Research proposition 2: During the phase of definitive design (DO), a lot of decisions should be made for the final design to be delivered (Weller, 2016). Thus, the communication network is expected to be denser and the department responsible for the management of design and integration to be the most central one.

Research proposition 3: In the execution-ready design (UO), many activities take place on-site, with suppliers and subcontractors creating their designs that need to be integrated into the overall design for which the main contractor is responsible for its consistency (Weller, 2016). Thus, construction-related departments are expected to act as link for transferring the information to the rest of the organization.

3

Research Methodology

In this chapter, the research methodology is explained. This chapter is essential because it reflects the preparation that took place before the beginning of the research activities. First, in section 3.1 how the research was designed is explained. Then sections 3.2 to 3.4. dive deeper into the specific research methodologies used to collect and analyse the data. More specifically, in section 3.2 the method of Social Network Analysis is explained, followed in section 3.3 the method of observations. Lastly, section 3.4 is focused on the method of the expert panel workshop session to first enrich and then validate the results. In general, the followed research methodology can be seen in Figure 3.1.

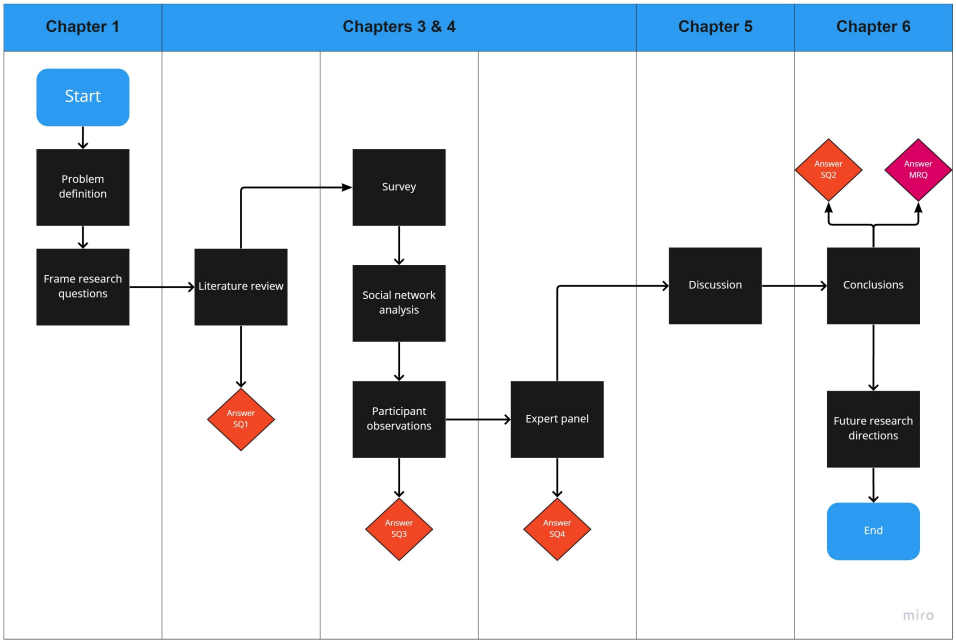


Figure 3.1: Flowchart depicting the research activities involved in this study

3.1. Research design

In order for the research to be designed, the researcher followed the guidelines provided by Saunders et al. (2009) who introduced the idea of the “research onion”. The research onion for this specific study is depicted in Figure 3.2 and this section is being used to elaborate on the logic behind it.

First, at the core of the onion lies the data collection and analysis. However, a few outer layers must be peeled to reach the core. On the first layer lies the approach to theory development. This study makes use of an inductive approach. Although some research propositions have been formulated and will be tested, these are based on what the researcher expects to find out through this study. Thus, the

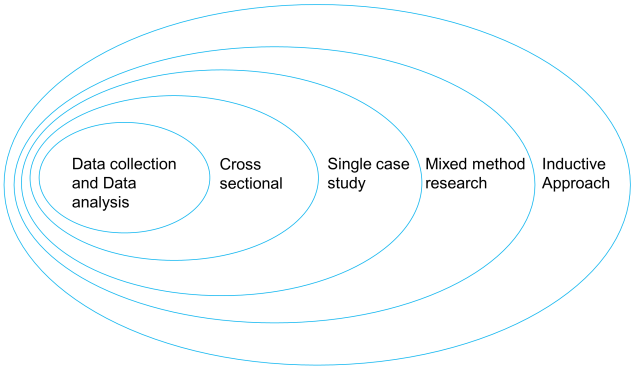


Figure 3.2: Research Onion (adapted by Saunders et al., (2016))

research has an exploratory character which, in terms of generalization, goes from specific to general and aims at generating untested conclusions. Another reason the inductive approach may be more suitable is that it is more potent than the deductive approach in social sciences. The next layer of the onion involves the methodological choice. The researcher is going to make use of both quantitative and qualitative research design. Thus, mixed-method research is considered appropriate for this study. As far as the strategy is concerned, the researcher implemented a single case study. Even though various departments and units will be examined, conclusions will be drawn, and recommendations will be provided to the organization as a whole.

Regarding the time horizon of the research, it would be very interesting to conduct longitudinal research to study the change and development over time. However, the research will be cross-sectional since the thesis needs to be completed in six to eight months. At this point is considered essential to be mentioned that the research activities will take place in two phases for the research to have a more dynamic character. The first two research activities (survey and observations) will be executed in parallel, but the third (expert panel workshop session) will take place after analyzing the two former.

Having peeled the whole onion and understood the techniques so far, its core remains. Table 3.1 summarizes all the methods used to collect and analyze the data, leading to the answer to the main research question.

Table 3.1: Methods used for data collection and analysis

Research question	Method
SQ1	Literature review
SQ2	Literature review
SQ3	Social network analysis & participant observations
SQ4	Expert panel

Sub-Question 1: What does information sharing in inter-organizational construction projects entail?

Question 1 aims at building a solid theoretical framework of what is already known concerning information sharing in inter-organizational projects. The researcher summarizes some of the most important findings by collecting data through an extensive literature review. The researcher will explore various directions relevant to this study, starting from the principle of information sharing in the construction industry in general and then zooming into the concept of inter-organizational information sharing.

Sub-Question 2: How can information flows best be studied?

An extensive literature review of the application of social network theory in the construction industry and its relevance to information sharing will be carried out to identify why such an approach could be an exciting way to study information flows. It may be the case that social network theory provides metrics that can help the researcher gain interesting insights into the way information flows in inter-organizational projects. Apart from that, the researcher will carry out some additional research activities to see whether or not they can contribute to understanding how information flows.

Sub-Question 3: How is the actual information flow at the targeted inter-organizational venture organized?

After having identified from the literature, the importance of communication in general and what social network theory contribute to offering an exciting approach to this study, the communication network of this specific inter-organizational venture will be mapped for all the three design phases the project team went through. A sociogram will be created using an SNA software available on the market named Gephi. Some key SNA measurements appropriate to this study will be applied to analyze the data collected by distributing a survey that was created in Qualtrics through a paid license from the Delft University of Technology. The results from the primary research activity will be enriched by carrying out participant observations and hosting an expert panel workshop session.

Sub-Question 4: Which are the most critical factors that impact how information flows and must be considered for future projects?

An expert panel workshop session will follow to validate the results from the social network analysis and the participant observations with selected employees from the inter-organizational venture. In this session, the experts will validate the researcher's conclusions on the most critical factors that impacted information sharing.

Finally, by combing the answers of all the sub-questions at the end it will be possible to provide both the practice and the research community with a solid answer to the main research question.

3.2. Social Network Analysis

Social network analysis is performed to provide an answer to sub-question 3. Thus, the primary purpose of this methodology is to uncover the communication network of the inter-organizational venture and identify possible bottlenecks as well as opportunities. The flowchart that depicts the whole process that the researcher went through from the beginning of the research until the conclusions can be found in Appendix A. In section 3.2.1 the benefits of social network analysis are presented. Then, in section 3.2.2 the researcher states how the data will be collected. How the data will be analyzed is made clear in section 3.2.3.

3.2.1. The principle of Social Network Analysis

Social Network Analysis (SNA) has been introduced by Moreno (1960) and focuses on identifying the interactions among a set of actors in social structures (Abbsaian-Hosseini et al., 2019; P. Chinowsky et al., 2008; P. Chinowsky et al., 2011; Dogan et al., 2015). SNA is both a quantitative and qualitative analytical approach to complicated project management that stresses the integration of social science elements (C.-Y. Lee et al., 2018). Social network theory might aid communication mapping for construction management teams and recognizing bottlenecks in information sharing (Abbsaian-Hosseini et al., 2019; Malisiovas & Song, 2014), establishing if there is sufficient information exchange inside and across groups (Parise, 2007) and revealing each actor's position in the network (Akgul et al., 2017).

The investigation of the inter-firm ties that make up the building project coalition benefits significantly from social network analysis (Akgul et al., 2017; Y. Li et al., 2011; S. D. Pryke, 2004). Hatala and George Lutta (2009), believe SNA is a valuable tool, not only for assessing the extent to which information is shared within organizational working groups but also for displaying the connectivity between these groups. The use of a sociogram can achieve the latter. A sociogram can be used to depict interpersonal connections (L. Zhang et al., 2013). The nodes in a sociogram may represent individuals, and the interaction between them can be represented by the links between the nodes (P. Chinowsky et al.,

2008). For this research, these can be information and knowledge exchange.

Once the node list data is imported, social network analysis software allows for the execution of a large number of procedures (S. D. Pryke, 2005).

3.2.2. Data collection

The majority of the studies that have applied the Social Network Analysis technique make use of a case study, and they retrieve their data via surveys (de Metz, 2022; Hatala & George Lutta, 2009; Javernick-Will, 2011; Schröpfer et al., 2017). This is the case for this research as well. In consultation with the external supervisors, the researcher reached an agreement on which case the study should be applied. This study aims to understand how the communication network of this particular inter-organizational venture evolved during the various design phases and identify the critical teams in each of the design phases. Kent and Becerik-Gerber (2010) had done something similar in their study when they wanted to identify during which phase the parties were starting to get involved in various Integrated Project Delivery projects.

To start collecting data, the researcher first went through the necessary guidelines imposed by the Human Research Ethics Committee (HREC) of the Delft University of Technology. Respondents were informed that they may withdraw from the survey anytime they wish and that their participation is entirely voluntary. Anonymity was ensured, and the data were treated confidentially. All the personal information was destroyed afterwards, and the codified data were published under the frames of this thesis report in Delft's University of Technology repository.

The survey consists of two parts in total. The first part aims to collect demographic data from the respondents, while the second relates to the social network analysis. More specifically, the second part contains statements that the participants have to say to what extent they agree or disagree and questions that the participants have to indicate with which departments or teams were communicating during the various design phases. The latter is under the format of a side-by-side matrix table. In that way, respondents can not only assess, for instance, the frequency of their communication but also whether it was beneficial or not. The researcher believes that in this case, the participants will have the chance to visually compare an action with its performance.

Regarding the response scales, all of them are scaled based on a Likert-type format (Likert, 1932). Taherdoost (2019) based on reliability, validity and response preference, recently suggested using a seven-point rating scale. As far as reliability is concerned, Symonds (1924) found out that the adoption of the seven-point scale results in the most optimal one. Furthermore, regarding the response preference, having a neutral midpoint can reduce the probabilities of response bias since some participants may not favour one side over the other (Croasmun & Ostrom, 2011) and the chances of collecting more valuable data are greater (Taherdoost, 2019). Furthermore, a seven-point scale will help capture a broader spectrum of responses since more options will be provided to the participants. This was proven in a study by Dawes (2008). Additionally, Joshi et al. (2015) stated that people's objective reality has more chances to be met due to the availability of more options.

At this point, it should be stated that the SNA survey was ego-centric since the respondents were asked to manually input and report any relationships they have with others (Javernick-Will, 2011). The complete questionnaire can be found in Appendix B. For the researcher to design the survey and collect the data, it was deemed necessary to use a paid license of Qualtrics software provided by the Delft University of Technology. The language of the survey was English since the study was applied in a project in which international parties were part of the inter-organizational team. Furthermore, an open-source SNA application named Gephi was used to visualize the communication network. Lastly, all the data were collected anonymously and all the personal information remained disclosed.

3.2.3. Data analysis

After collecting the appropriate data, the next step was to visualize them by applying the network theory and creating a sociogram and then analyze them by applying the necessary techniques. As it has already been mentioned, for the analysis of the data, use of Gephi software was made. Gephi has pre-coded algorithms that allow the researcher automatically create graphs and analyze networks. The network is formed by combining various elements which need to be explained further for clarity purposes. All the visual elements that are present in the sociograms which will be presented in the next chapter are explained below:

- **Graph layout:** First, for the visualization of the graphs the ForceAtlas layout was used. The selection of this specific layout was made in order to disperse groups and give space around larger nodes. It pushes the nodes with a low number of inputs to the periphery and the nodes with a high number of links to the centre of the graph.
- **Nodes:** The nodes represent the various teams or departments that are involved in each design phase. The colour of the node indicates the Degree while the size of the node is based on its betweenness centrality. The darkest the color the more links a node has. The larger the size of the node, the more central it is.
- **Edges:** The edges indicate how information flows between the various departments. Weights have been attributed to them based on the frequency of the information exchange. Thus the thicker the line that connects two nodes is, the more frequent their communication. The input for the frequencies has been determined by the survey's participants. They are defined as follows:
  - Daily: 5
  - Frequently: 4
  - Weekly: 3
  - Infrequently: 2
  - Rarely: 1

  Furthermore, the edges were imported in the software as directed so as to distinguish the sender from the receiver. Since the analysis is carried out in a department/team level some edges were parallel. However, no merging strategy was selected because this could cause problems in the weights that were assigned to these edges.

Following the logic that Schröpfer et al. (2017) applied in their research, there has been a categorization of the network's characteristics into three groups:

1. Network Structure
2. Tie content and tie characteristics
3. Actor attributes

Network structure:
According to Farshchi and Brown (2011), size and heterogeneity are a network's two most important characteristics. The former refers to the number of linkages an individual has in his private network. In contrast, the latter has to do with whether or not an individual tends to approach similar or diverse actors in a network. One of the critical measurements that can be applied under this category is the "Network Density".

Network density illustrates how much engagement there is between people (nodes) of a network (P. Chinowsky et al., 2008; Farshchi & Brown, 2011; Malisiovas & Song, 2014). In this study, though, nodes symbolize the teams of the inter-organizational venture, not the actors. It can take values between 0 and 1 (Schröpfer et al., 2017). It is calculated by dividing the number of the existing ties that the network nodes have by the maximum possible ties that the nodes could have had (Farshchi & Brown, 2011) if there have been relationship links which link all the nodes together (P. Chinowsky et al., 2008). The density of the network increases accordingly as the number of ties that each node has with other nodes increases (Wise, 2014). The higher the density, the bigger the communication volume inside a network (Malisiovas & Song, 2014)). Thus, it is believed that in high-density networks, there will be more knowledge transfer between the project participants (Schröpfer et al., 2017).

Tie content and tie characteristics
The number of connections between members determines the strength of a tie (Senaratne et al., 2021). Tie strength indicates the intimacy of an actor's connection and rises with the frequency of engagement and communication (Van Wijk et al., 2008). If two actors do not have ties with each other,

knowledge cannot be transferred. However, what sort of knowledge is exchanged is determined by whether the tie is strong or weak (Schröpfer et al., 2017). Previous studies have proved that explicit knowledge can be shared through weak ties while strong ties can facilitate the communication of tacit knowledge within the network (Mu et al., 2008; Schröpfer et al., 2017).

Actor attributes

Apart from the fundamental actor characteristics like cultural background, gender, age, and education level, actor centrality can also have an impact (Schröpfer et al., 2017). For this research, the following key measurements are going to be calculated:

- **Degree centrality:** The most straightforward kind of centrality is degree centrality, which counts the number of direct links a node has to other nodes (de Metz, 2022). Depending on the direction of these links, the degree can be then classified as in-degree or out-degree (Park & Han, 2012). Usually, knowledge seekers are characterized by high out-degree centrality while knowledge experts by high in-degree centrality (Schröpfer et al., 2017). Generally speaking, the higher a person's degree, the more significant their potential effect on the network since he can both generate information and potentially absorb whatever is circulating in the network (Farshchi & Brown, 2011).
- **Closeness centrality:** This measurement is used to measure the length of the path from a specific node to the rest of the network's nodes (C.-Y. Lee et al., 2018). Nodes closer to one other would get information more quickly than nodes farther apart (Borgatti & Li, 2009). The higher the closeness centrality is, the more autonomous an actor in a network is (Senaratne et al., 2021). This is because nodes that are closer to each other can reach out to other nodes easier. On the other hand, nodes that are more distant, depend on other nodes to transfer the information to them. As such, they are less autonomous and they are characterized by lower closeness centrality.
- **Betweenness centrality:** Betweenness centrality examines a node's ability to link to other network nodes (Loosemore, 1998). In other words, it is used to measure the quantity of data that goes through an actor (Malisiovas & Song, 2014). By adding this to the data analysis, it was possible to identify potential bottlenecks. This is because this measurement can determine if a member acts as a critical broker or gatekeeper in the network (Müller-Prothmann, 2007). Nodes characterized by high betweenness centrality have substantial influence over the flow of information. Thus they can act either as bridges or as a single point of failure in the network (de Metz, 2022). This is because their position grants them the power to control information flows.

A centrally located actor develops a brokerage position, allowing it to seek and trade important information or knowledge within the social network (Van Wijk et al., 2008). In the social network analysis domain, the term broker refers to network nodes that connect distinct subgroups, and they are of great importance to the network (Parise, 2007). From a network perspective, when a network is considered highly centralized, the number of nodes with multiple links with other nodes is small (Wambeke et al., 2012). Additionally, when its betweenness centrality is high as well, the flexibility of the knowledge flow is low since it is controlled by a few links (L. Zhang et al., 2013).

Last but not least, it is essential to mention that there is no right or wrong measurement. The measurements mentioned earlier were selected based on the network's patterns and characteristics that the researcher would like to reveal through the analysis. They help understand the network thoroughly, and draw meaningful conclusions about the position of the different node types such as central, peripheral and visible figures as well as gatekeepers, as they have been categorized by Berck (2020). The categorization of the nodes is illustrated in Figure 3.3.

3.3. Participant observations

The second research activity that the student conducted during this study was Participant Observation. This research method was used to supplement the primary research method and qualitatively enrich the research data gathered. More specifically, it contributed to understanding why people behaved in a certain way, whose image was produced by the Social Network Analysis. According to (Saunders et al., 2009) there are four types of participant observation as depicted in Figure 3.4. Under the frames

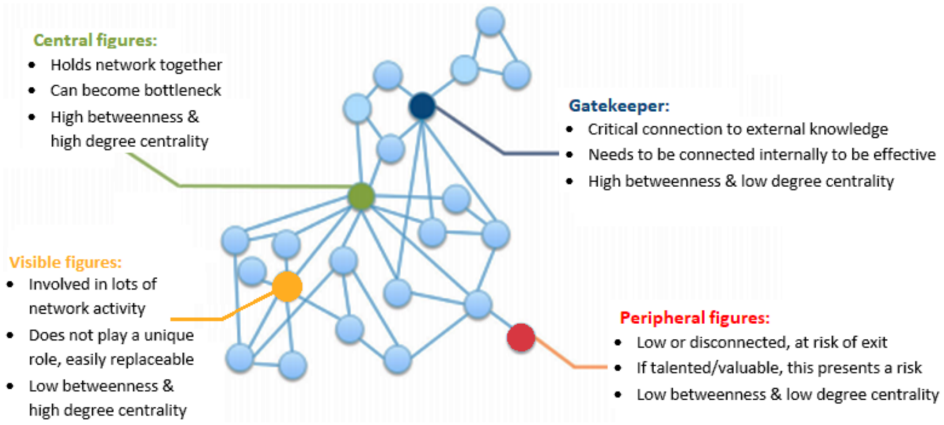


Figure 3.3: Categorization of the different node types in a network (adapted by (Berck, 2020))

of this specific research, the researcher took the role of “Observer-as-participant”. The informants, participants in case of observation, were aware of the researcher’s presence and role. Thus, the researcher shadowed certain informants in a specific setting, e.g., their work environment.

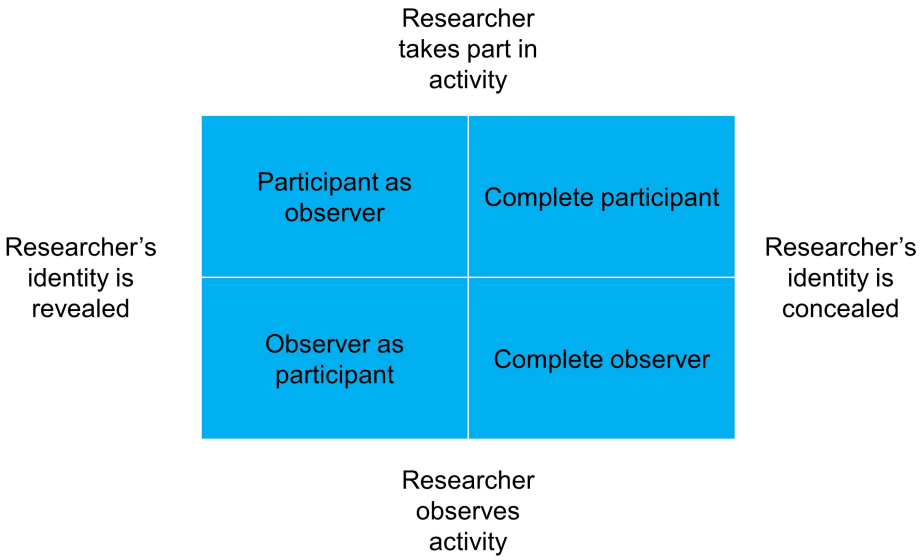


Figure 3.4: Typology of participant observation researcher roles (adapted by (Saunders et al., 2009))

Data were collected through note-making and analyzed daily, not to forget valuable data. Only primary data focused on specific interactions (e.g., information sharing and knowledge exchange) among the selected informants were collected through the observations since this research activity was supplementary to the main one. Through the social network analysis, communities may be identified by determining the modularity (Śladowski et al., 2019). These communities can be developed based on the informal relations between the employees, their profession or the employees’ location in the office (S. Pryke et al., 2018). Especially the latter was a crucial observation that the researcher used to compare the results of the social network analysis with the topology of the employees.

Furthermore, the researcher was also an observer in some weekly stand-ups that took place virtually and physically. A comparison was made between them as far as employees’ engagement is concerned. This is because such meetings can promote information sharing and knowledge exchange between employees and act as an exciting way to bridge gaps between employees from different organizations and occupations.

3.4. Expert panel workshop session

The last part of the research consisted of an expert panel workshop session. This part also added a qualitative character to the research. Its purpose was to validate the results of the two previous research activities. So, based on the outcome of the Social Network Analysis and the participant observation, the researcher compared the organizational breakdown structure of the project with the mapped communication network produced through the analysis of the survey data. Then, the researcher enriched this result with his observations to conclude. These conclusions were first enriched and secondly validated by some key members of the inter-organizational venture.

This activity was structured as follows. The researcher selected some participants strategically based on the output of the two previous research activities. The selected participants were invited to a 90-minute workshop session in which the researcher presented the main findings of his research. This constituted the first round of the workshop session, where the participants were invited to interpret the results and discuss what made sense and what should have been different. This method is similar to what (S. Pryke et al., 2018) adopted to validate their research's results. The second round of the session had to do with validating the conclusions. Thus, based on the results of the previous activities and on insights grasped from the experts in the first round, the researcher came up with some conclusions which asked the experts to validate to identify the strongest ones.

The main aim of this activity was to spark an interesting discussion among research respondents and key individuals who belong to the management team to reach a consensus on what describes best the foundation of the information sharing problems in the inter-organizational project team. Additionally, the researcher expected to enrich his results to come up with some firm conclusions which could lead to valuable recommendations to the organization and lessons learned for future projects.

4

Results

This chapter is devoted to the presentation and analysis of the results from the research activities carried out during this study's execution. In section 4.1, the researcher is presenting the results that emerged from the analysis of the data collected by the survey by performing a social network analysis. In section 4.2, the researcher is analysing some other results from the survey that could not be extracted from the social network analysis. Furthermore, the results regarding the participant's observations are discussed in section 4.3. Lastly, in section 4.4, the researcher presents the outcomes from the expert panel workshop session.

4.1. Analysis of SNA results

After having distributed the survey, the data provided by the participants have been collected and analyzed. The survey has been distributed to the organization, comprised of 413 employees, via email. Of the 413 employees, 108 filled in the survey, resulting in a response rate of 26.2%. According to Baruch and Holtom (2008), the average response rate in studies conducted at an organizational level fluctuates between 17% and 53%. Thus, the response rate achieved in this study can be considered acceptable. After closing off the survey and starting to analyze the data, it came out that valid were 82 out of the 108 responses. In this section, the results that came through the analysis of data through the performance of the social network analysis by using Gephi software are presented.

From the input that these participants provided, 44 nodes have been identified. The complete node list can be seen in Table C.1. As has already been mentioned in 3.2.3, nodes represent mainly the various teams of the inter-organizational venture and its departments in the case that the latter are not subdivided into other teams. The project is being executed in three design phases. However, it is important to mention that not all 44 nodes were present in every design phase. In subsection 4.1.1, the communication network of the predesign phase (VO) is being visualized. The communication network regarding the definitive design phase (DO) is being visualized in subsection 4.1.2, while the one concerning the execution-ready design (UO) is being presented in subsection 4.1.3. Finally, in subsection 4.1.4, the communication networks discussed per design phase are compared. Moreover, both the network's and the actor's characteristics are discussed in every section accordingly. To be able to understand some of the network's characteristics visually, it is of utmost importance to mention that the darker the colour of the node, the higher its degree centrality, the bigger the node is, the higher its betweenness centrality is, and the thicker and darker the edges are the more frequent the line of the communication between the nodes is.

4.1.1. Pre design phase (VO)

Figure 4.1 depicts the visualization of the organization's interactions between the departments in the predesign phase, while Table 4.1 gives an overview of the network's characteristics.

From the responses gathered, 28 out of the 44 teams/departments (nodes) were involved in the predesign phase. The analysis showed that these 28 nodes had 65 connections (edges), resulting in an average degree of 2.321 per node, meaning that each node had connections with almost two other nodes on average. This is a small number of interactions and indicates that there were several

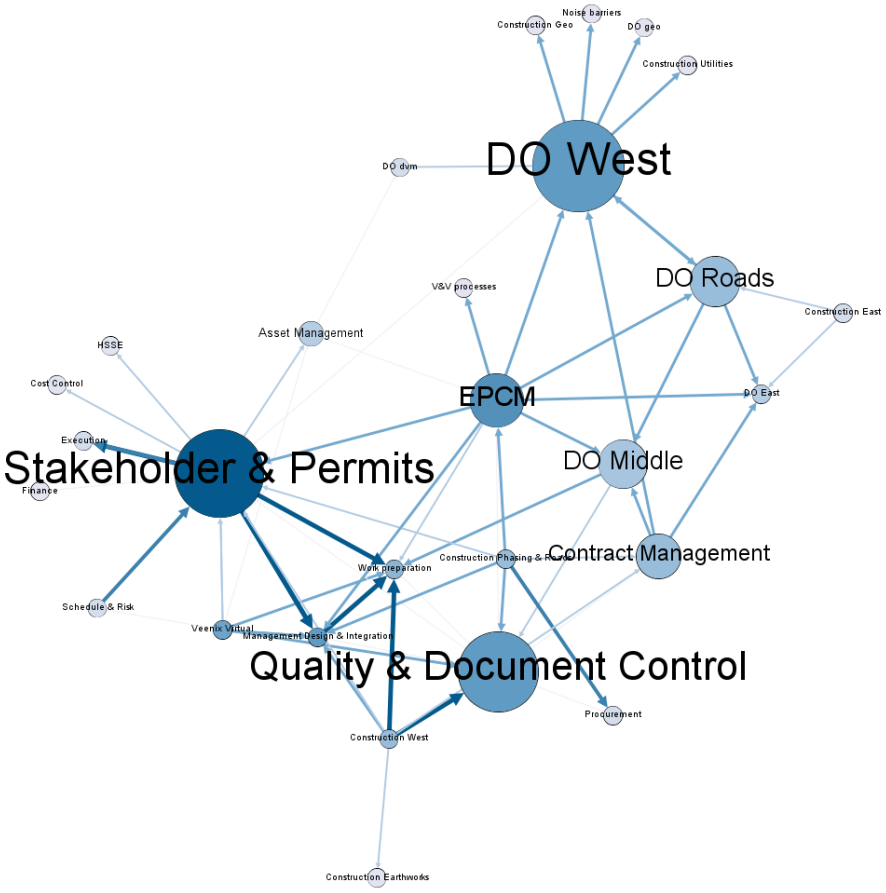


Figure 4.1: Communication network of the inter-organizational venture in predesign phase (VO)

Table 4.1: Network characteristics in pre-design phase (VO)

Network's characteristics	
Number of nodes	28
Number of edges	65
Average degree	2.321
Network density	0.169
Average frequency of information exchange	2.6 (/5)

nodes on the periphery with just one interaction lowering the average degree score and that there were departments in the network that did not have mutual connections. As far as the network's density is concerned, the analysis showed that this was equal to 16.9%, which is a bit low concerning the number of nodes present in the network. This illustrates that there was not much engagement between the departments since the existing network exploited only 16.9% of the possible connections. Furthermore, the average frequency of information exchange between the departments in this design phase was calculated at 2.6 out of 5. This indicates that employees interacted with employees from different departments to exchange information on a weekly / monthly basis. The departments that appeared to interact more frequently with each other were the stakeholder & permits, work preparation and management design & integration since they form a nice triad with frequent lines of communication as seen in Figure 4.1.

Nodes' characteristics

Table 4.2 presents the most and least influential nodes in predesign phase (VO), ranked based on their betweenness centrality from the largest to smallest. The full list of nodes with the metrics that were calculated for them can be found in Table C.2. Besides the betweenness centrality which was used as the parameter to rank the nodes the table depicts the degree centrality of these nodes which is further classified to in-degree and out-degree centrality, as wells as the closeness centrality and modularity class.

Table 4.2: Most and least influential nodes in predesign phase (VO), ranked based on their betweenness centrality from the largest to smallest.

Id	Label	Degree centrality	In-degree centrality	Out-degree centrality	Closness centrality	Betweeness centrality	Modularity class
1	DO West	10	3	7	0.466667	63	0
27	Stakeholder & Permits	17	8	9	0.888889	60	1
29	Quality & Document Control	10	4	6	0.512195	52.75	2
35	EPCM	11	2	9	0.6	30.25	0
4	DO Roads	6	3	3	0.42	27	0
2	DO Middle	5	3	2	0.355932	26	2
38	Contract Management	6	3	3	0.428571	22.25	2
33	Asset Management	4	3	1	1	5.5	0
13	Management Design & Integration	10	9	1	1	0.25	1
...	...	...	...	...	...	...	...
34	Cost Control	1	1	0	0	0	1
39	Finance	1	1	0	0	0	1
42	HSSE	1	1	0	0	0	1

As can be seen on the data, in this phase, the teams that were the most influential in the network were those related to design, such as DO West, DO Roads, DO Middle and Management Design & Integration, as well as those that were supposed to have interactions with the client such as Stakeholder & Permits, Quality & Document Control and EPCM. For clarification purposes, the number of employees that stated through the survey that they interacted with the client and the team they belong to can be seen in Figure D.1.

A further look at the Table 4.2 reveals that the team DO West was ranked first in terms of betweenness centrality, even though it had the same degree centrality as the teams Quality & Document Control and Management Design & Integration and even less compared to the teams Stakeholders & Permits and EPCM. This is because it links a bigger set of different teams to each other, which do not have another way to reach information if DO West stops sharing it. Thus, DO West acted as a gatekeeper to some teams. Additionally, team Stakeholders & Permits, the second in ranking in terms of betweenness centrality and the first in terms of degree centrality, was also acting as a gatekeeper to specific teams in the predesign phase. This can be easily distinguished by taking a look at the Figure 4.1 and notice that if Stakeholder & Permits was excluded from the network, the teams Asset Management, HSSE, Cost Control, Execution, Finance and Schedule & Risk would not have had access to information, establishing it as a critical team in this particular phase.

Interestingly, team Management Design & Integration had very low betweenness centrality, and even though its degree centrality was ranked among the highest, if someone dives deeper into the in-degree and out-degree and compares them, they will notice that it mainly was absorbing information rather than generating and distributing. According to Figure 3.3, in such a case, team Management Design & Integration could be categorized as a visible figure which is easily replaceable. However, this could not be the case since high in-degree centrality may be used as an indicator of knowledge experts. Not to mention that this was the team responsible for coordinating the whole design process, leaving shallow margins for replacement.

Comparatively to the nodes already discussed, if someone looks at the nodes with the lowest degree centrality, he/she will notice that the Cost Control department and Finance were those with the slightest degree centrality. Such nodes are peripheral since they are in the network's periphery and can easily be disconnected. Some of these nodes may possess valuable information or knowledge to the rest of the network, and the fear of being disconnected always poses a risk.

As far as the closeness centrality is concerned, the teams of Management Design & Integration and Asset Management were calculated to have the maximum closeness centrality. This indicates that they may have acted entirely autonomously in the network in this phase, meaning that they did not depend on other departments to distribute information to the rest of the network. However, it is important to

mention that these two teams distributed information to only one team since their out-degree centrality equals one.

Taking everything into account, the teams of DO West and Stakeholders & Permits were the most influential in the predesign phase. While the latter was the most central, the former had the highest betweenness centrality. Both were recognized as gatekeepers and had power over the control of information flows. However, attention should also be paid to the role that the team Management Design & Integration played during this phase, as well as the contribution of the Cost Control and Finance teams.

4.1.2. Definitive design phase (DO)

Figure 4.2 depicts the visualization of the organization's interactions between the departments in the definitive design phase, while Table 4.3 gives an overview of the network's characteristics.

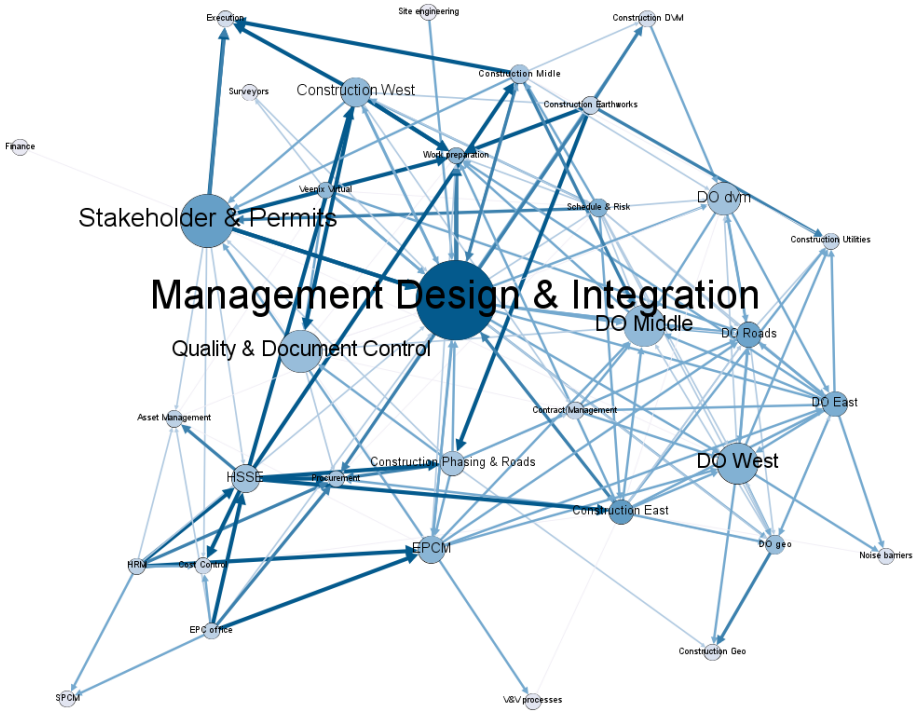


Figure 4.2: Communication network of the inter-organizational venture in definitive design phase (DO)

Table 4.3: Network characteristics in definitive design phase (DO)

Network's characteristics	
Number of nodes	35
Number of edges	173
Average degree	4.943
Network density	0.271
Average frequency of information exchange	2.8 (/5)

As can be seen in the data presented in Table 4.3, 35 out of the 44 teams/departments had an active

role in the definitive design phase. The analysis indicated that these 35 nodes had 173 edges, resulting in an average degree of 4.943 per node, meaning that each team had connections with almost five other teams on average. Not only the number of teams that participated in the definitive design phase increased, but also the average degree was more than doubled. Since the increase of the nodes was not proportional to the increase of the average degree, this can be comprehended as the departments having more mutual connections compared to the predesign phase. As far as the network's density is concerned, the analysis showed that this is equal to 27.1%, which illustrates that there was more engagement between the teams in this phase. As the network evolved, the volume of communication inside the network increased, resulting in a denser communication network. Furthermore, the average frequency of information exchange between the departments in this design phase was calculated at 2.8 out of 5. Similarly to the predesign phase, this indicates that employees interacted with employees from different departments to exchange information on a weekly / monthly basis. From Figure 4.2, it can be seen that the most frequent lines of communication involved the teams of Work Preparation and HSSE.

Nodes' characteristics

Table 4.4 presents the most and least influential nodes in definitive design phase (DO), ranked based on their betweenness centrality from the largest to smallest. The full list of nodes with the metrics that were calculated for them can be found in Table C.3. Besides the betweenness centrality which was used as the parameter to rank the nodes the table depicts the degree centrality of these nodes which is further classified to in-degree and out-degree centrality, as wells as the closeness centrality and modularity class.

Table 4.4: Most and least influential nodes in definitive design phase (DO), ranked based on their betweenness centrality from the largest to smallest.

Id	Label	Degree centrality	In-degree centrality	Out-degree centrality	Closness centrality	Betweeness centrality	Modularity class
13	Management Design & Integration	34	17	17	0.636364	216.703864	1
27	Stakeholder & Permits	19	10	9	0.5	125.640476	1
29	Quality & Document Control	12	4	8	0.509091	89.3	1
2	DO Middle	13	10	3	0.4	86.521429	0
1	DO West	15	8	7	0.4375	83.389173	0
5	DO dvm	11	8	3	0.321839	56.642857	0
19	Construction West	13	3	10	0.54902	45.797619	1
42	HSSE	11	4	7	0.56	38.877922	2
...	...	...	...	...	...	...	...
15	Work preparation	14	14	0	0	0	1
30	Veenix Virtual	13	0	13	0.526316	0	1
32	Procurement	10	10	0	0	0	1
39	Finance	1	1	0	0	0	1

As can be seen from the data, the quantity of information that went through the team Management Design & Integration was immense in this design phase. This is stated by the large betweenness centrality that this node had. Thus, team Management Design & Integration had substantial influence over the flow of information in the definitive design phase, which can be logical since this was the phase where most of the design decisions were taken. Moreover, this specific team was also ranked first in terms of degree centrality, meaning that it was the team that generated the most information and potentially absorbed whatever was circulating in the network.

Surprisingly, team Construction West was ranked among the most influential teams. To the researcher's knowledge, this can be attributed to the fact that construction of the project started from the west section, and it may have been undergone in parallel with the definitive design phase. Thus, it could be logical that Construction West and DO West were engaged in such a level of exchanging information.

By looking at the figure 4.2, no significant gatekeepers could be identified since no teams acted as single links to other teams. This could have positive effects from a risk management perspective since there were no single points of failure in the network. Most of the nodes were connected with at least two other nodes except the finance team, which was tied with the team of Stakeholders & Permits, and the site engineering team, which was tied with the team Management Design & Integration. Only these two teams can be considered peripheral elements of this network. However, in this phase, several teams could be categorized as central figures and potentially act as bottlenecks to information

sharing. Management Design & Integration, Stakeholder & Permits, Quality & Document Control could be recognized as central figures, among others, in this specific design phase. All these three have scored high both in betweenness and degree centrality and thus had control over the flow of information in the entire network.

As far as the closeness centrality is concerned, the team Management Design & Integration was calculated to have the highest closeness centrality. On the whole, all the nodes have close values regarding their closeness centrality, fluctuating between 0.4 and 0.56, which means that they almost got the information as quickly as the rest. What is worth mentioning is the role that teams Work Preparation, Veenix Virtual and Procurement played in this phase. These three teams are characterized by high degree centrality but zero betweenness centrality, and generally speaking, they could have been just visible figures in the network. On the contrary, special attention should be paid to these three teams. At least for the teams Work Preparation and Procurement due to the fact that no employees belonged in these departments that filled in the survey. Thus, in the expert panel workshop session, this will be discussed with the participants. Last but not least, the team that is responsible for the finance remained the least influential in the network in accordance with its position in predesign phase. Team Cost Control climbed up some scales, but it still had very few interactions that made no impact on the whole.

Taking everything into account, the team Management Design & Integration was by far the most influential in the definitive design phase since it was ranked first in all of the metrics calculated through the social network analysis. No significant gatekeepers were recognized, and the network had very few peripheral figures in this phase. On the other hand, several central figures were identified, making the network less centralized but running into the risk of creating multiple communication bottlenecks. Further clarification is needed regarding the role that teams Work Preparation, Veenix Virtual, Procurement and Finance played in this design phase.

4.1.3. Execution-ready design phase (UO)

Figure 4.3 depicts the visualization of the organization's interactions between the departments in the execution-ready design phase, while Table 4.5 gives an overview of the network's characteristics.

Table 4.5: Network characteristics in execution-ready design phase (UO)

Network's characteristics	
Number of nodes	36
Number of edges	166
Average degree	4.611
Network density	0.249
Average frequency of information exchange	2.9 (/5)

The data presented in Table 4.5 illustrates that 36 out of the 44 teams/departments were engaged in the execution-ready design phase. The analysis indicated that these 36 nodes had 166 edges, resulting in an average degree of 4.611 per node, meaning that each team had connections with something less than five other teams on average. The number of teams that participated in the execution-ready phase increased by one, but the average degree was slightly decreased compared to the definitive design phase. As far as the network's density is concerned, the analysis showed that this was equal to 24.9%, which illustrates that there was a bit less engagement between the teams in this phase in contrast with the previous phase. However, this cannot be translated necessarily that the situation is worse than previously in terms of communication. This may be due to the fact that this phase had very recently started, and the departments were not fully aware with whom they needed to interact. Furthermore, the average frequency of information exchange between the departments in this design phase was calculated at 2.9 out of 5, which was the highest of all the phases. However, it is still on the same scale that indicates that teams exchange information with each other on a weekly / monthly basis. From the Figure 4.3, it can be observed that the most frequent lines of communication happened between the construction-related teams, such as the different construction sections, the execution and the surveyors. HSSE departments appeared to play an active role in this phase as well.

Nodes' characteristics

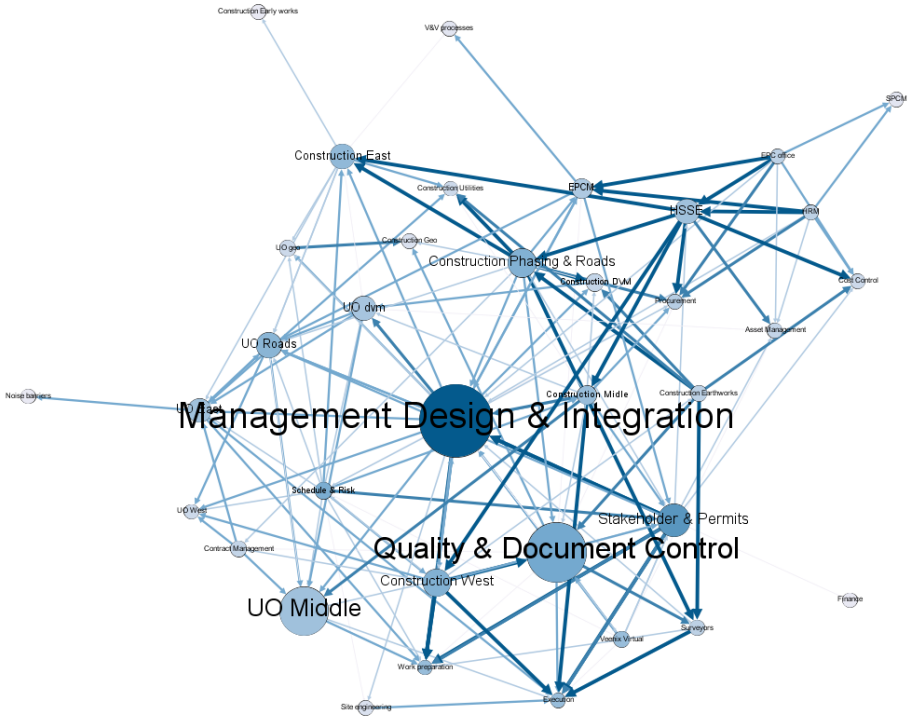


Figure 4.3: Communication network of the inter-organizational venture in execution-ready design phase (UO)

Table 4.6 presents the most and least influential nodes in execution-ready design phase (UO), ranked based on their betweenness centrality from the largest to smallest. The full list of nodes with the metrics that were calculated for them can be found in Table C.4. Besides the betweenness centrality which was used as the parameter to rank the nodes the table depicts the degree centrality of these nodes which is further classified to in-degree and out-degree centrality, as wells as the closeness centrality and modularity class.

As can be seen on the data, in this phase, the teams that were among the most influential in the network were construction-related such as UO Middle, Construction Phasing & Roads, Construction West, UO Roads and Construction East. However, Management Design & Integration as well as Quality & Document Control were ranked first and second accordingly. Special attention needs to be paid though why the team associated with Quality & Document Control climbed that high in terms of betweenness centrality. According to the researcher's knowledge the project was in a phase where a lot of documents needed to be reviewed and approved in order to proceed further with the designs. Thus, it was logical that during the execution-ready design phase this specific team would have played a major role in filtering information. As it has also been the case in the definitive design phase, team Management Design & Integration developed a critical brokerage position by having power over the flow of information within the network. This was indicated by its high centrality metrics.

Interestingly, Work Preparation and Execution teams had no influence over the flow of information in this specific phase which does not make sense. Thus, it is of outmost importance to be further examined with experts to understand why this was the case. Especially in the case of execution, the logical thing would be to have higher out-degree than in-degree centrality since in that phase information is generated on site and is being distributed to the office so as the designers to integrate all of the subcontractors' and suppliers' designs in the overall design.

Table 4.6: Most and least influential nodes in execution-ready design phase (UO), ranked based on their betweenness centrality from the largest to smallest.

Id	Label	Degree centrality	In-degree centrality	Out-degree centrality	Closness centrality	Betweeness centrality	Modularity class
13	Management Design & Integration	34	14	20	0.592593	228.105988	1
29	Quality & Document Control	17	6	11	0.542373	176.238095	2
8	UO Middle	11	6	5	0.395062	132.796898	3
27	Stakeholder & Permits	21	9	12	0.477612	70.250216	2
44	Construction Phasing & Roads	15	3	12	0.592593	53.420635	4
19	Construction West	15	4	11	0.551724	50.305375	3
10	UO Roads	14	11	3	0.307692	41.85119	0
17	Construction East	13	4	9	0.450704	40.719048	0
...	...	...	...	...	...	...	...
14	Site engineering	3	2	1	1	0.473485	3
15	Work preparation	12	12	0	0	0	3
16	Execution	12	12	0	0	0	2
39	Finance	1	1	0	0	0	2

A further look on the Figure 4.3 reveals that the construction teams had stronger communication lines in terms of frequency from the design teams. This is an interesting observation that came out through the survey and needs to be investigated further whether this was the case or not. Again, no clear gatekeepers have been recognized and the network on the whole was not highly centralized since there were quite a few central figures identified in this phase like the definitive design phase. The most prevailing central figures were the teams of Management Design & Integration, Quality & Document Control and UO Middle.

As far as the closeness centrality is concerned, the team Site Engineering was calculated to have the maximum closeness centrality. However, it is important to mention that this team distributed information to only one team since its out-degree centrality equals to one as it was also the case with two other departments in the predesign phase. After Site Engineering, Management Design & Integration and Construction Phasing & Roads were calculated to have the highest closeness centrality but in general most of the most influential nodes had close values regarding their closeness centrality, which means that they did not require a lot of intermediates to get access to information that was circulating in the network.

Considering these, the most attention should be paid in the role that the Execution team played in this phase. Work Preparation team was ambiguous in all the three design phases and its contribution to the information sharing will be re examined thoroughly in the expert panel workshop session together with the contribution of the cost-related departments. On top of these, the central figures will also be investigated further to understand whether or not they acted as bottlenecks to the flow of information.

4.1.4. Comparison between the design phases

Under this section, the network's and nodes' characteristics that have been presented for each of the design phases in the previous sections are being compared.

Table 4.7 presents the most and least influential nodes' characteristics that were also discussed per design phases in the previous sections. The first five teams were those that have been identified as the most influential in at least one of the design phases, while the last five teams were either among the least influential or their contribution was ambiguous. Those teams whose contribution was ambiguous were further investigated during the expert panel workshop session to understand why this was the case.

Among the most influential teams, team Management Design & Integration had the control over the flow of information both in the definitive design phase and the execution-ready design phase, whereas in the predesign phase, it scored low in terms of the betweenness centrality. Team Quality & Document Control maintained a high-ranking position in all of the design phases. Additionally, team Stakeholder & Permits played a significant role in the flow of information, especially in predesign and definitive design phases. Its contribution to the execution-ready design phase was also high, but other teams had more control over the information flows. The comparison between the design teams that were among the most influential is being made in the next paragraph.

Table 4.8 presents the metrics of the design teams that were part of the communication network in at least one of the three design phases. While there was a distinction between DO design and UO

Table 4.7: Comparative table of most and least influential nodes in all the design phases.

Id	Label	VO		DO		UO	
		Degree centrality	**Betweenness centrality**	**Degree centrality**	**Betweenness centrality**	**Degree centrality**	**Betweenness centrality**
13	Management Design & Integration	10	0.25	34	216.703864	34	228.105988
27	Stakeholder & Permits	17	60	19	125.640476	21	70.250216
29	Quality & Document Control	10	52.75	12	89.3	17	176.238095
8	UO Middle	0	0	0	0	11	132.796898
1	DO West	10	63	15	83.389173	0	0
38	Contract Management	6	22.25	6	4.407726	6	4.873016
26	Schedule & Risk	2	0	15	7.364566	16	9.211111
15	Work preparation	7	0	14	0	12	0
16	Execution	2	0	4	0	12	0
34	Cost Control	1	0	5	0	5	0

design teams, there was no reference to VO design teams. This is because, in the predesign phase (VO) and definitive design phase (DO), the same teams were kept in the organization consisting of the same employees, whereas in the execution-ready design phase (UO), the teams changed. Thus, to avoid confusion, it was decided to present the VO teams as DO teams.

First, what can be seen on the data is that while the West section was very information dependent in the predesign and definitive design phases, in the execution-ready design phase, we observed meager participation in exchanging information. Instead, the Middle section took the lead from the design teams in the execution-ready design phase, which had already started engaging more actively from the definitive design phase. The design teams related to Roads were equally engaged in all design phases. In contrast, section East and the design department responsible for the DVM became more active after the definitive design phase.

Table 4.8: Comparative table of design teams' metrics in all the design phases.

Id	Label	VO		DO		UO	
		Degree centrality	**Betweenness centrality**	**Degree centrality**	**Betweenness centrality**	**Degree centrality**	**Betweenness centrality**
1	DO West	10	63	15	83.389173	0	0
2	DO Middle	5	26	13	86.521429	0	0
3	DO East	4	0	16	29.999888	0	0
4	DO Roads	6	27	18	30.22587	0	0
5	DO dvm	2	0	11	56.642857	0	0
6	DO geo	1	0	12	10.90119	0	0
7	UO West	0	0	0	0	5	0
8	UO Middle	0	0	0	0	11	132.796898
9	UO East	0	0	0	0	11	35.452056
10	UO Roads	0	0	0	0	14	41.85119
11	UO dvm	0	0	0	0	10	37.588889
12	UO geo	0	0	0	0	5	7.133333

Table 4.9 presents the metrics of the construction-related teams that were part of the communication network in at least one of the three design phases. From the data presented on Table 4.9, it can be easily observed that all construction-related teams had zero betweenness centrality during the predesign phase. Team Work Preparation had the highest degree centrality, but with zero betweenness centrality this can be translated as having no impact on the communication network. In the definitive design phase, quite a few construction-related teams started being involved in information-sharing activities, with team Construction West being the most involved among the other construction-related teams. In the execution-ready design phase, the contribution of those teams was even higher since the betweenness centrality of all of them increased. However, as has already been mentioned in the previous sections, the contribution of the Work Preparation and Execution teams needs to be further investigated for all of the design phases, especially during the execution-ready design phase.

Table 4.9: Comparative table of construction-related teams' metrics in all the design phases.

Id	Label	VO		DO		UO	
		Degree centrality	Betweenness centrality	Degree centrality	Betweenness centrality	Degree centrality	Betweenness centrality
19	Construction West	6	0	13	45.797619	15	50.305375
44	Construction Phasing & Roads	6	0	10	28.145238	15	53.420635
17	Construction East	2	0	20	26.988893	13	40.719048
18	Construction Midle	0	0	10	10.07176	12	16.844986
23	Construction Earthworks	1	0	6	4.67619	7	4.74127
20	Construction DVM	0	0	4	1.5	6	10.867857
15	Work preparation	7	0	14	0	12	0
16	Execution	2	0	4	0	12	0
21	Construction Early works	0	0	0	0	1	0
22	Construction Utilities	1	0	6	0	5	0
24	Construction Geo	1	0	3	0	3	0
25	Surveyors	0	0	2	0	7	3.162302

4.2. Survey statistics

The results presented in this section aim to give a better understanding of the bottlenecks of information sharing. For that purpose, in this section, the researcher will dive deeper into how the participants ranked several statements in the survey regarding technological developments, the means of communication, contractual relationships and, most importantly, how employees communicated with each other. For those interested in the demographics of the survey please refer to Figure D.2 and Figure D.3.

As mentioned in 3.2.2, all of the response scales were based on a seven-point Likert-type rating scale. During the survey, the participants were first asked to indicate whether or not the contract format used in the project encouraged them to share information. Most of the participants, 14 in total, opted for the middle point, "Neither agree nor disagree", as this is depicted in Figure 4.4. It can also be seen that the number of positive answers (somewhat agree and agree) equalled the negative ones (somewhat disagree, disagree and strongly disagree). However, from this graph, it can be concluded that the contract format used did not substantially impact information sharing. There were an equal number of answer distributions, but the fact that three employees strongly disagreed that the contract used encouraged them to share information sparked the interest to investigate it further during the expert panel workshop session. Last but not least, for clarification purposes, the middle point category was also meant for those whose contracts did not have any impact on their case.

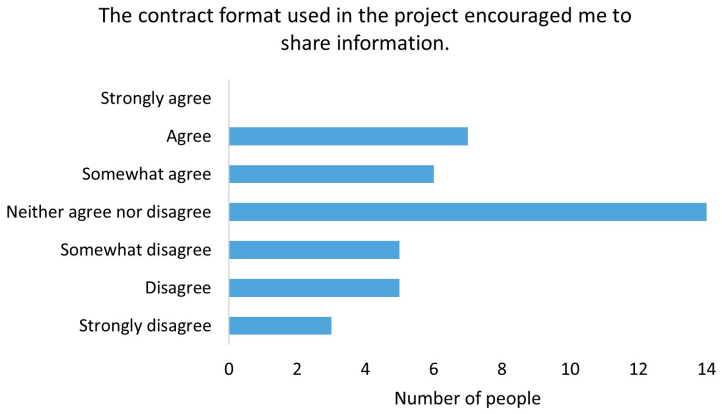


Figure 4.4: Answer distribution of participants regarding the contribution of the contract format used in the project in information sharing

Then, the participants were asked whether the new technological developments, such as the use of Building Information Modelling (BIM), enhanced information sharing. Participants responded positively to this statement, as can be seen in Figure 4.5.

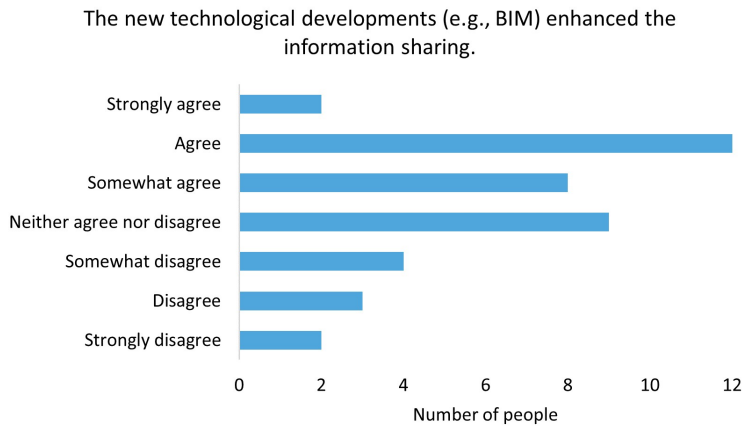


Figure 4.5: Answer distribution of participants regarding the contribution of the new technological developments in information sharing

Even though the analysis of the results to the question of whether the new technological developments enhanced information sharing or not indicated that employees had a positive stance towards BIM, when they were asked to rank the means of communication that they used more often and those that they would prefer to use, BIM documents and other technological developments such as the online collaboration platforms were ranked the lowest in both cases. This is visualized in Figure 4.6.

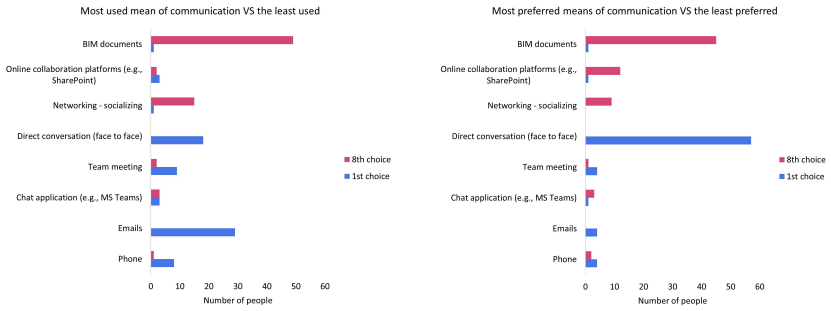


Figure 4.6: Ranking of tools/means of communication that employees used more often (left-hand side). Ranking of tools/means of communication that employees preferred to use (right-hand side).

Regarding the most used means of communication, most employees ranked emails as their first choice. Team meetings, direct conversations and phones were also used quite often by the employees. On the other hand, employees tend to make use of BIM documents as the last possible way of communication. While analysing the results of the most used means of communication, a trend was observed in the ranking for all the categories. However, this was not the case for the category of direct conversation. The people who ranked direct conversation as the most used means of communication were more than those who ranked it in lower positions. This was a side observation and thus this graph can be seen in Appendix D in Figure D.4.

Furthermore, the employees were asked to state how often they received information from other departments or teams and did not know what to do with it. The most prevailing answer to this question was ”sometimes”, but on the whole, those who had a negative stance towards the statement were more than those who had a positive, as can be seen in Figure 4.7. Since it was an inverted statement, having a negative stance on it results in positive outcomes. Thus, the results indicated that most of the time, employees had the knowledge and the expertise to use the information shared with them or the directions on how to use the information were clear, meaning that the communication between those involved was effective.

On the same logic, participants were asked to rate how often the information was not communicated correctly or in the proper format. Again, most of the employees chose the option ”sometimes”. However,

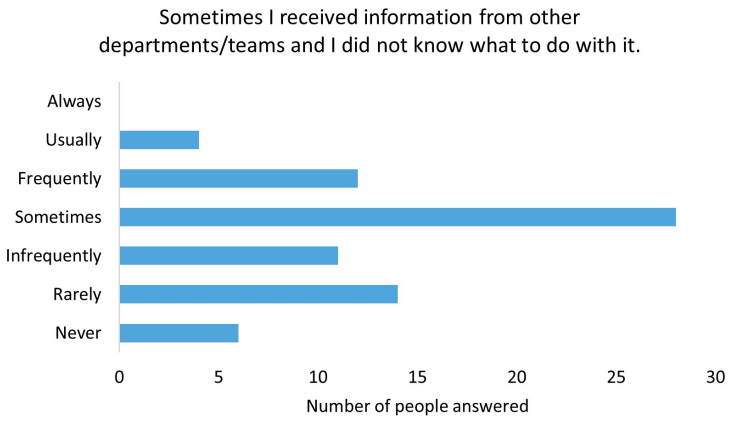


Figure 4.7: Answer distribution of participants regarding receiving information and not know what to do with them

the analysis of the results, in this case, showed that employees tend to receive information that is not adequately communicated quite often. This is illustrated in Figure 4.8. Thus, the comment made previously regarding effective communication is not valid. In fact, it appeared that most of the survey participants experienced several inconsistencies in how information was communicated.

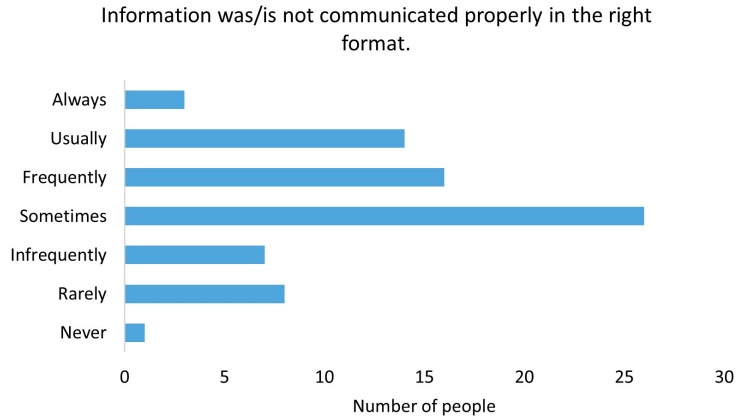


Figure 4.8: Answer distribution of participants regarding information not being communicated properly

For the same purpose as the previous two questions, employees were asked to rate whether or not people know what information they need from them and if they request it appropriately. The most preferred choice was ”frequently”, which indicates a positive attitude toward this statement. However, those who had a negative view of how people request the information were not a few. In general, though, employees with a positive stance towards the statement prevailed. How people responded to this question is depicted in Figure 4.9

The researcher attempted to correlate the participants’ contribution to each design phase with their satisfaction. However, in every design phase, the correlation of these two variables was lower than 0.2, resulting in no clear trends. Thus no conclusions could be drawn, and for that reason, these results are being presented in Appendix D and can be seen in Figure D.5 and Figure D.6.

Another stream of insights that the researcher aimed to grasp was related to team performance. Under this stream, the participants were first asked to rank the most important factors in team performance according to their beliefs. At this point, it is important to be mentioned that what team performance is, was not defined by the researcher in the survey. Thus, for interpreting the results that came through the data analysis for this question, it is assumed that the participants answered based on the most

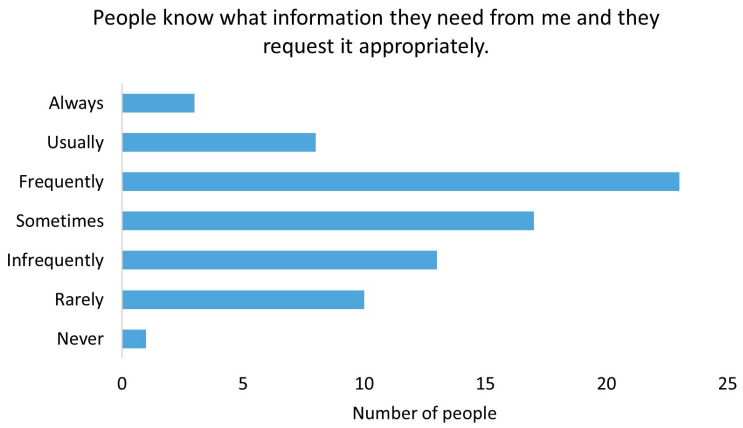


Figure 4.9: Answer distribution of participants regarding people not requesting information appropriately

important factor to improve performance in terms of information sharing. Among the participants, what was said to be the most important was the nice atmosphere/working environment, followed by improving the quality and satisfying the stakeholders' needs. On the contrary, what was ranked as the fifth most important by most of the employees was minimizing project duration, followed by minimizing cost. These results are depicted in Figure 4.10. Thus, a nice working environment encourages information sharing. Additionally, it may be the case that employees did not share information to minimize the cost but to improve quality. While analyzing the results, it was interesting that those who ranked minimizing costs as the most important factor of team performance were contractor's employees. So, in that sense, contractors may need the information to examine how they can minimize the cost.

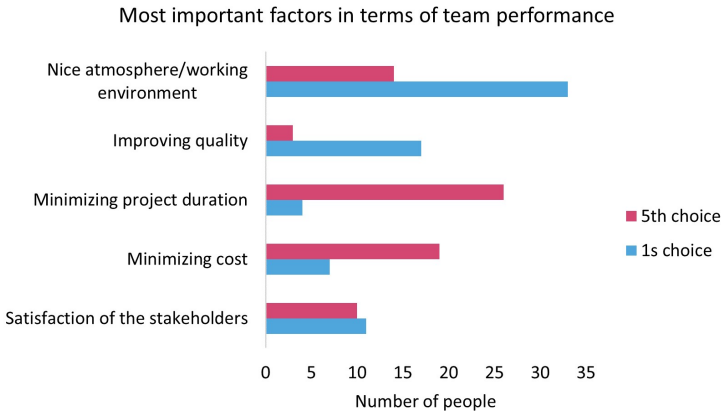


Figure 4.10: Most and least important factors in terms of team performance ranked by the survey participants

Moreover, employees were asked whether or not the performance of their team met their expectations regarding what was important to them. From the analysis of the data came out that most of the participants agreed that their teams met their expectations. Only 28 employees out of 82 that responded to this question did so in a negative way, as can be seen in Figure 4.11. Thus, it can be concluded that there was a positive team environment at the team level.

The last question concerning team performance was related to the general impression of employees regarding how their team performed in each design phase. In each design phase, employees had a positive general impression of how their team performed, which is depicted in Figure 4.12. Especially in

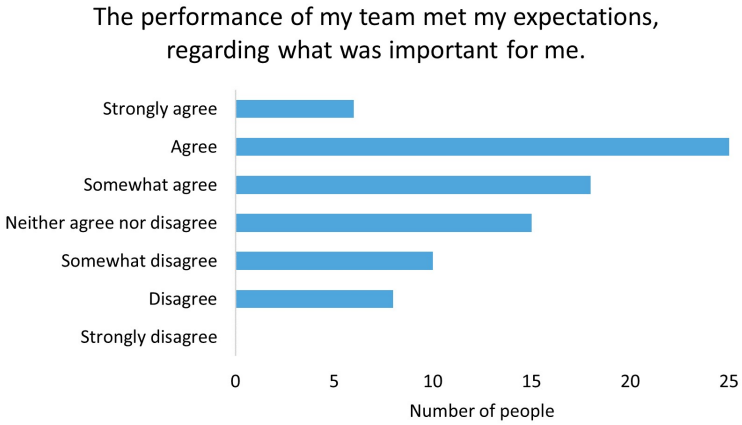


Figure 4.11: Answer distribution of participants regarding team performance expectations.

the execution-ready design phase, those who believe that they performed well as a team far outweigh those who do not believe so.

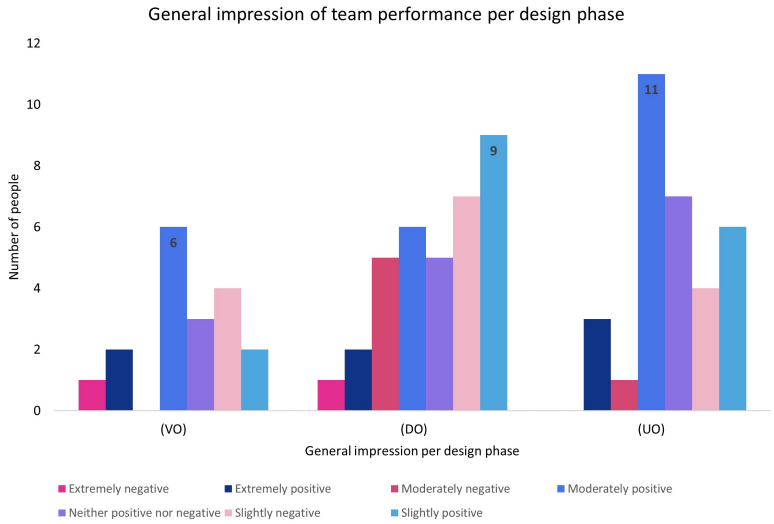


Figure 4.12: General impression of individuals regarding their team per design phase.

Furthermore, participants were asked to evaluate whether or not they found it knowledgeable working with people outside of their team and if their company played an important role in encouraging them to exchange knowledge with the rest of the organization. In both questions, most of the employees responded significantly positively, as can be seen in Figure 4.13. This indicates that people like each other and that management should find a way to make this collaboration more effective.

Last but not least, there have been some interventions from the top management aiming to enhance information sharing in the inter-organizational venture. For example, the online weekly inter-organizational stand-ups were decided to be held physically once per two weeks. The management structure changed slightly in respect of how the departments are located in the office. Of course, COVID-19 measurements have been lifted from the government and employees were invited to come to the office again. With respect to these, the researcher asked the participants to what extent they felt these interventions could positively affect information sharing. Based on the employees' answers, the imposition of COVID-19 measurements that forced employees to work from home impacted in-

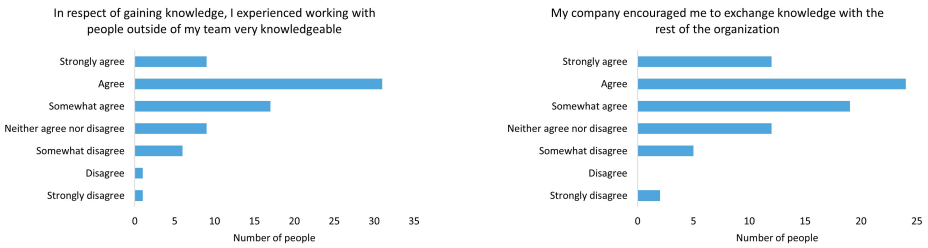


Figure 4.13: Answer distribution of participants in respect of gaining knowledge while working with people outside of their team (left-hand side bar graph). Answer distribution of participants regarding their company encouraging them to exchange information with the rest of the organization (right-hand side bar graph).

formation sharing severely. The change in the management structure was also believed to positively affect the information sharing, while the live weekly stand-ups were not that much. How the employees distributed their answers can be seen in Figure 4.14

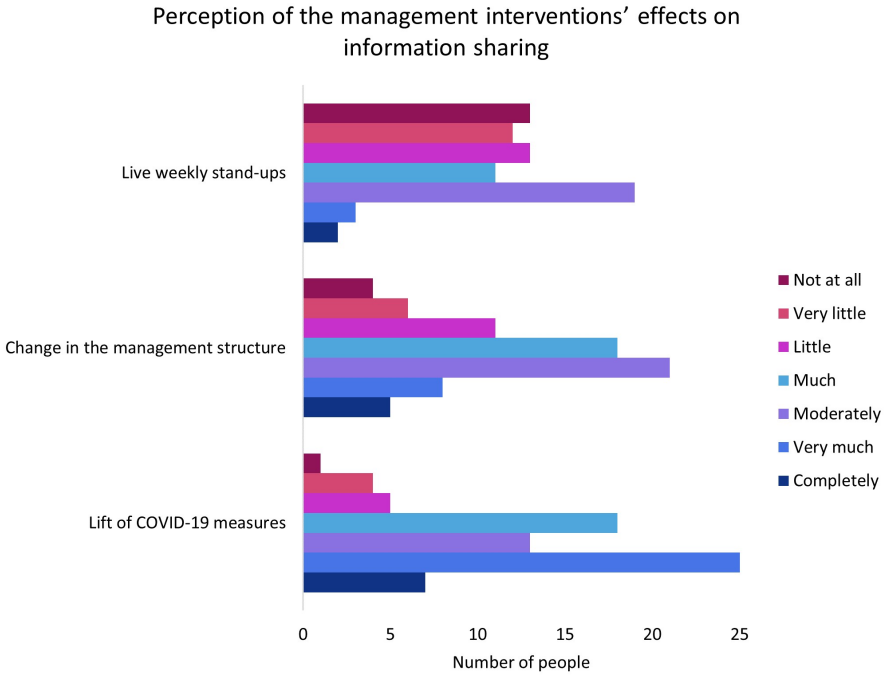


Figure 4.14: Perception of the management interventions' effects on information sharing.

4.3. Analysis of participant observations

This section will present the results that came out through the participant observations. First, in subsection 4.3.1, the researcher, based on his notes, will present some findings that may be reasons for poor information sharing. After in subsection 4.3.2, there will be a reference to some observations that took place during some weekly organizational stand-ups. Lastly, in subsection 4.3.3 some meaningful comparisons will be made between the physical location of employees, the organizational breakdown structure and the modularity analysis through the SNA software that can identify communities.

4.3.1. Behavioral attitudes

Regarding the behavioural attitudes of the employees, there have not been many incidents during the period that the researcher was carrying out his research in the organization that could be considered crucial indicators of poor information sharing. From the friction the researcher had with the rest of the organization, he encountered problems with communication only once. More specifically, while the survey was open, the responses from the contractor side were very low, which sparked some concerns. The survey was distributed through the inter-organizational email account, and the problem was that individuals that were contractor's employees did not check this account that often. On the contrary, they mainly communicated through their parent's organizational email accounts.

Another behavioural observation that could be considered a barrier to information sharing is that one could listen to people speaking at least three different languages while walking in the office corridors. This project is an inter-organizational one, and an international contractor is involved. Thus, it was prevalent that some employees were speaking the local language, others were speaking the foreign language, and when interacting, they were speaking English.

Furthermore, the researcher targeted a specific department to observe its meetings both between its members and also between other departments. This department was responsible for creating tools that would be useful to the rest of the organization; thus, its interaction with other departments was extensive. However, while it was known that twice per month, this department would present to those interested their developments, participation from employees that belonged to other departments was minimal. This alone could not be considered a problem but what is essential to be mentioned is that employees, apart from those who requested a development, did not know what tools existed for use in the organization. Consequently, employees from this department kept receiving requests to develop existing tools. Such an incident can be mentioned as poor information flow within the inter-organizational venture.

Lastly, with respect to meetings where people from various departments were required, most of the time all of them started on time, with all the participants being physically or virtually present. Some other observations have been made as well while reviewing some satisfaction surveys. However, the organization has already taken some measures to enhance information sharing based on the input it received. Thus, these observations are not relevant anymore since they do not contribute to the research in the form of recommendations that the researcher would like to provide to the organization, and they were excluded.

4.3.2. Participation in weekly stand-ups

Another stream of observations came through the researcher's participation in weekly stand-ups. In those stand-ups, the whole organization was invited. This means that all these individuals that have been assigned an email account of the inter-organizational venture, 413 in total, were receiving an invitation, and they could participate. These meetings took place every Wednesday, and they lasted fifteen minutes. Unfortunately, due to the COVID-19 pandemic, they were held online. Topics in these meetings ranged from employee introduction to key milestone achievements. However, the main reason behind these weekly stand-ups was to keep the information about the project flowing in the organization and bring the employees closer.

In total, the researcher participated in eighteen (18) weekly stand-ups. In all of these meetings, the managing director acted as the facilitator of the meetings. In the very few cases that the managing director was not present, this role was taken by the project's secretary. While participating in these meetings, the researcher kept a record of the topics discussed, the total number of employees that attended the meeting, the time they joined, and the number of questions asked. Table 4.10 shows some of these. What is not included in the table is the time that employees joined. Although a few employees were leaving the meeting before that ended or they were joining later, this was excluded from the analysis since there can always be the case that they have more important tasks to complete or other meetings to attend. For confidentiality issues, the topics that could be considered more sensitive to the organization have been generally categorized as execution status, organizational matters and technical matters.

As mentioned before, 413 people had access to these meetings, but from Table 4.10, only 52 were attending on average. Moreover, the average number of questions asked was less than two, which indicates the low level of attendants' participation in these meetings. Additionally to these statistics, since the meetings were held virtually, the researcher, by acting as an observer, noticed that a few

Table 4.10: Summary of weekly stand-ups' records.

Meetings	Topic 1	Topic 2	Total ammount of attendants	Number of questions asked
Meeting 1	General updates	-	27	0
Meeting 2	Execution status	-	50	2
Meeting 3	Organizational matter	Execution status	52	0
Meeting 4	Organizational matter	-	45	1
Meeting 5	Presentation of employee's MSc Thesis results	-	52	1
Meeting 6	Technical matter	-	47	3
Meeting 7	Story of Sinterklasse	-	45	0
Meeting 8	Traffic management	-	49	2
Meeting 9	Organizational matter	Feedback on assessment	45	1
Meeting 10	Update execution status	Latest updates on progress	63	1
Meeting 11	Technical matter	-	63	0
Meeting 12	Technical matter	-	40	2
Meeting 13	Safety culture	-	54	5
Meeting 14	Updates from the top management	-	77	2
Meeting 15	App introduction	-	69	3
Meeting 16	Introduction to Ramadan	Technical matter	62	5
Meeting 17	Execution updates	-	53	2
Meeting 18	Safety topics discussion	Important remarks	46	1

attendants were doing other things in parallel, such as eating, talking to their phones or typing, which may indicate that they used this meeting as a break rather than to be informed. However, the researcher does not acquire knowledge that allows him to evaluate such behavioural attitudes. Nevertheless, some of these observations could be used to provide some interesting recommendations to the management. Thus, even though no conclusion can be drawn from these observations, the latter can act as a starting point for some managerial implementations.

4.3.3. Co-location of employees

As several researchers have cited it (BEKTAŞ et al., 2008; S. Pryke et al., 2018), co-location of different departments or teams can form communities and enhance information sharing between them. Thus, it would be valuable to compare the communities identified through the social network analysis with the communities physically formed through the location of every department at the office. Additionally to that, there will be a comparison with the organizational breakdown structure as well to check whether or not these interactions that came out make sense.

First, it is important to mention that while the survey was distributed the changes in the management structure were already applied. Thus, the results that came out from the survey were interpreted based on the new organizational structure. The short version of the new organizational structure is depicted in Figure 4.15.

In Figure 4.15, the yellow frames symbolize the core management team in the new structure, meaning that the construction departments will lead the process onward. This is due to the fact that the organization that current period was ending the definitive design phase and entering the execution-ready design phase. Moreover, with respect to the possible communities that were to be formed by considering the organizational chart, two can be distinguished. First, Cost Control, Finance & Admin and Schedule & Risk teams should communicate with each other or at least exchange some information. Secondly, another line of communication connects the teams of Design & Integration with the different sections of Construction.

Regarding the information exchange between the first three teams, by taking a further look at Figure 4.1, it can be observed that there was no straight edge that connected them in the predesign phase. Cost Control and Finance were peripheral figures connected to the team Stakeholder & Permits. Schedule & Risk was also connected to Stakeholder & Permits, but the edge that linked these departments had the opposite direction. Thus, the information went from the Schedule & Risk team to Cost Control and Finance teams through the Stakeholder & Permits team. The same pattern was observed for the definitive design phase as well as the execution-ready design phase, with the main difference that Cost Control and Schedule & Risk acquired more central positions while Finance remained peripheral and single-connected to Stakeholder & Permits (Figure 4.2, Figure 4.3).

As far as the second line of communication is concerned, no clear pattern was observed. The teams were communicating with each other, with the team Management Design & Integration having the leading role in the flow of communication. Even in the execution-ready design phase, Management Design & Integration kept the control over the information-sharing network, but there was an increase

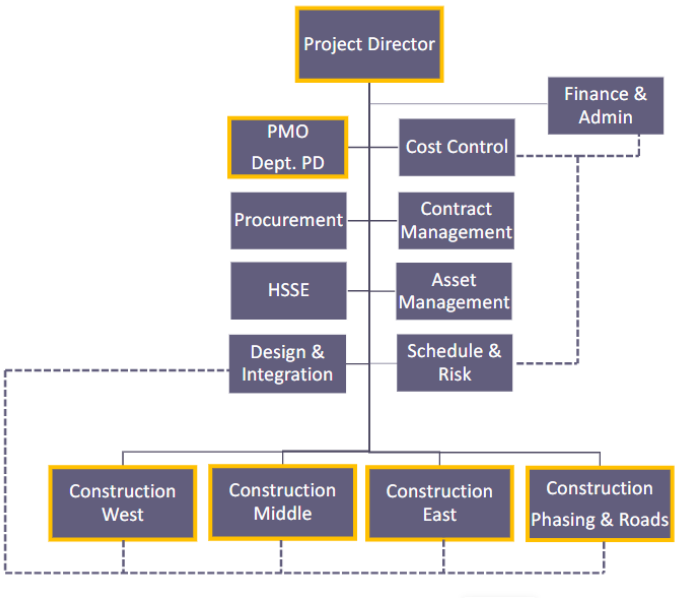


Figure 4.15: Short version of the new organizational structure.

in the construction teams acquiring more influential positions in the network, as was presented in Table 4.4. It may be the case that since the execution-ready design phase had just started, the balances in the network did not have enough time to change.

Furthermore, the change in the management structure involved some modifications regarding the location of the departments in the office. The floor plans of the office are illustrated in Figure 4.16 with the primary aim to identify possible communities due to the co-location of the teams.

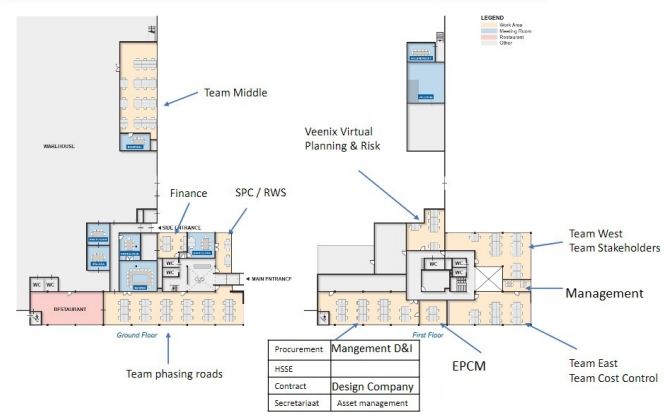
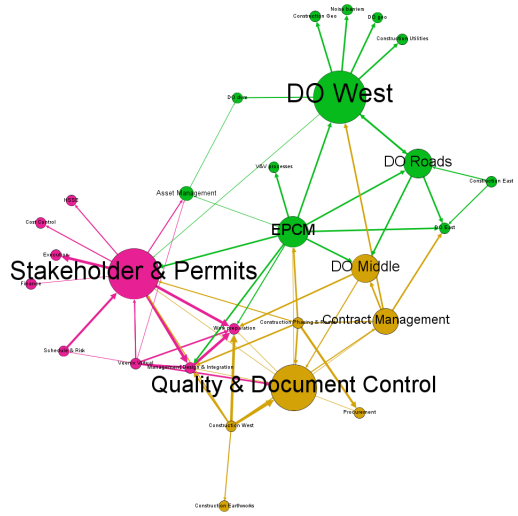


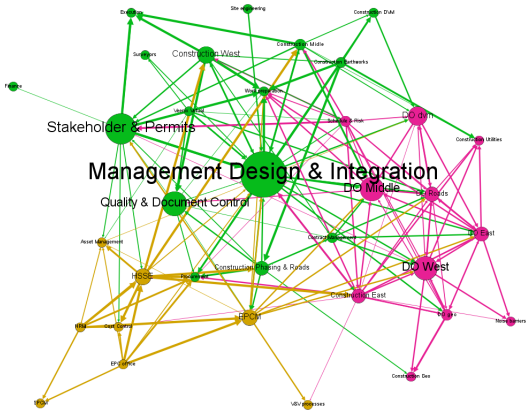
Figure 4.16: Organization's office floor plan.

As can be seen in Figure 4.16, the office consists of two floors. On the ground floor, team Middle, Finance, SPC and team Phasing & Roads were located, while on the first floor, many teams were located. By taking a closer look, we can observe that only the teams on the first floor shared their space with other teams. More specifically, Team West was co-located with Team Stakeholders & Permits. Team East was co-located with team Cost Control, Veenix Virtual with Planning & Risk and several other teams were co-located in a bigger office. Since some teams were co-located, it may have been the case that information exchange between them would have been more robust. Through the Social Network Analysis, communities were identified by running the modularity analysis in the software. This analysis was performed for every design phase, and the results that came out through this are depicted

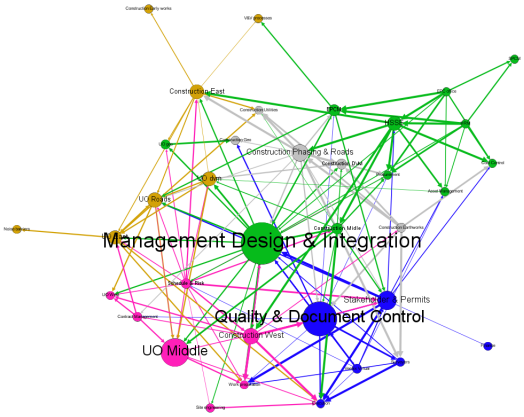
in Figure 4.17. Thus, it will be interesting to compare whether or not the modularity analysis identified the same communities that were formed physically from the co-location of the teams or that they should have formed based on how the organization is structured.



(a) Modularity classes in predesign phase (VO)



(b) Modularity classes in definitive design phase (DO)



(c) Modularity classes in execution-ready phase (UO)

Figure 4.17: Modularity classes in every design phase as have been identified through social network analysis

Interestingly, from the comparison of Figure 4.16 with Figure 4.17 it was observed that the co-located teams belonged to the same community identified by the SNA software only twice. Only in the predesign phase Veenix Virtual was part of the same community with Schedule & Risk, and in the execution-ready design phase, teams Management Design & Integration, Procurement, HSSE and Asset Management were assigned in the same community. Apart from that, no other matches were identified.

4.4. Analysis of expert panel

Under this section, an introduction to how the workshop was set up is being given in subsection 4.4.1. Subsequently, in subsection 4.4.2 the researcher is making use of the experts' input to enrich the results that came through the Social Network Analysis (SNA), survey statistics and observations. Lastly, in

section 4.4.3 the validation of the conclusions by the experts is presented.

4.4.1. Introduction

After having analyzed the results of the first three activities, the researcher chose to validate them in order to be able to come up with valuable recommendations for the organization. Thus, he invited several key members, six in total, of the inter-organizational venture to participate in a workshop session. The complete list of the experts, together with their roles, can be seen in Table E.1. The session took place in two rounds. In the first round, the researcher presented this research's findings by using PowerPoint (please refer to Appendix E for the slides of the presentation). By performing this activity, the researcher was able to enrich his results by grasping additional insights from the experts. This allowed him to come up with more vital conclusions and recommendations for the organization, which he validated in the second round of the session. The second round took place online. The experts that participated in the first round received an email with some concluding statements, and they had to state to what extent they agreed or disagreed.

4.4.2. Experts' interpretation of the results

The first round of the workshop lasted sixty to seventy-five minutes, and the main objective was to spark an interesting discussion between the experts by presenting to them some of the main observations that came out from the analysis of the data. In that way, the experts could interpret the results themselves and express their opinions which have been taken into consideration by the researcher to conclude his research. More specifically, during the presentation of the SNA results, the researcher asked the experts three questions per design phase to guide their way of thinking to match with the researcher's. The questions asked were:

- Would you expect other departments having a more central role? (which are them?)
- Would you expect the central teams not to be that central? (which are them?)
- Would you expect the communication between some departments to be stronger?

The main insights that the researched grasped through the experts' answers are being discussed below.

Predesign phase

First and foremost, much discussion took place regarding cost control's role in this phase. Experts made clear that in such an early phase, design choices should be based on how much they cost, among other criteria. Thus, cost control should have acquired a more central position. Interestingly, they confirmed that cost control was disengaged entirely in this phase, sharing very little information with the rest of the organization. In the same logic, team Schedule & Risk should also have had a better position in such an early phase. HSSE should have been also more involved since safety by design is a significant value. Lastly, what they were missing entirely from the network was the involvement of the teams Construction Early Works and Site Engineering.

Some valuable insights were also grasped in relation to the second question. More than half of the experts said that Stakeholder & Permits should not have been the leading team in this phase. Expert six specifically stated that instead of focusing on what the contract says, the organization focused more on the stakeholders and permits. Therefore, contract management should have played a more critical role in filtering information for the organization to stay within the scope of the project goals, which was to stay on budget and on time. There was also a slight disagreement on whether or not the actual status of Quality & Document Control is reflected in the communication network they were being presented to. In the end, they reached an agreement that, indeed, the degree centrality (size of the node) should be big but not the betweenness centrality (filtering of information) because the job of this team was to approve documents. They did not generate information.

Regarding the design teams, Expert 5, who acted as the manager of Design & Integration, mentioned that he would have expected DO West, DO East and DO roads to have the same node size. Based on this comment, what was discussed further was that DO East was indeed a bit disconnected from the other teams and West is characterized as a very complex area requiring much information from various disciplines, confirming their position in the network. However, the experts were concerned that

there was no link between DO DVM and DO Roads, and they were expecting stronger communication between these two.

Last but not least, when they were asked if they were expecting the communication between some departments to be stronger, most of them mentioned the department of Work Preparation. Work Preparation had zero out-degree centrality in the network that was presented to them. Even though this could have been the effect of no people from this team having filled in the survey, the experts mentioned that there were very few chances to interact with work preparators during this design phase.

Overall, the experts were surprised that the communication network which was presented to them could be considered a small representation of the reality in this phase. However, because not every person in the organization responded to the survey and the number of people that participated is not proportional to their team sizes, there is always the risk of missing some links. Apart from that, there may be people who were part of this phase and have already left the organization.

Definitive design phase

In this phase, there was a small but exciting discussion concerning the team Management Design & Integration. First, experts confirmed that undoubtedly this should have been the most central node in the network in this phase. On the other hand, they commented that there was too much dependence on that specific team, confirming the possibility of acting as a bottleneck to the whole organization. If Management Design & Integration fails, the project fails. Therefore, all of them found it very critical for Work Preparation and Execution teams to unload team Management Design & Integration in terms of the quantity of information they need to filter. Interestingly, this did not happen in the project, which can be confirmed visually from Figure 4.2 and arithmetically from Table C.3. Work Preparation and Execution did not help assist Management Design & Integration in the abovementioned task.

Furthermore, as discussed for the predesign phase, section west is a very complex and information-dense area. Thus, it was not a coincidence that Construction West started involving very actively already from the definitive design phase and DO west maintained its position on the network. Lastly, the engagement of cost control was very low in this design phase.

Execution-ready design phase

Experts did not have insights to add apart from what was already observed by the researcher for the execution-ready design phase. They agreed with what was presented and that the balances should have changed in this design phase. The lines of communication between the construction-related teams are more frequent than between the design teams and if that is the case, the organization should ensure that Management Design & Integration, which happened to be the most central node, absorbed whatever circulated in the network. Many things happened around, and this lack of interaction in terms of the frequency of communication may have resulted in a loss of information.

Regarding the team Quality & Document Control, even though some of the experts believed that this team should not have been ranked as one of the most influential teams, in the end, they reached the same consensus as in the predesign phase. Cost Control was also mentioned but in this phase in the sense that it should have had more in-degree centrality (receiving information) since they needed to be aware if the project was running well from an economic point of view.

Statistics

Finally, some of the results that came out from the analysis of the statistics were presented to the experts. All of them unanimously stated that even though this was not depicted in the participants' answers, the contract played a crucial role in information sharing. It may be the case that people either did not understand the question or were unaware of the contract strategy. The fact that there were three extremely negative answers indicated that this needed to be further investigated.

Furthermore, compared to the researcher's reaction, experts were not surprised when they were shown Figure 4.6. They confirmed that technological developments used enhanced information sharing, but at the same time, they confirmed that people did not use them. BIM360 and the rest of the online collaboration platforms, such as SharePoint, were very useful for searching for information. However, employees still preferred to send emails when they shared information or asked for it. They also mentioned that sometimes access to SharePoint was restricted, discouraging employees from turning into it as a first option.

Experts found very interesting the results stemmed from Figures 4.7, 4.8 and 4.9. These figures

indicated that the problem lay in the way information was communicated. Experts attributed this to the fact that people often received a large number of emails. Due to time pressure or since answering to some people or sharing information with them was outside their contract's scope, the information was unconsciously not communicated properly.

Last but not least, what they also discussed was under the frames of the most important factors in terms of team performance. While some of them found it very positive that employees rated the factor of nice atmosphere/working environment first, others expressed their disappointment because, under DBFM contracts, team performance is measured to what extent the project is on budget and on time. Thus, they perceived the results as people not being aware of the project goals, which is a severe issue. However, since the contractor did not share the target and Cost Control was not actively participating during any design phase, it could be considered controversial to impose the employees rather than those employed by the contractor to be cost driven.

4.4.3. Conclusions' validation

After the first round, the researcher used the experts' insights to enrich his observations and come up with some concluding statements that the experts would have to assess so as for the researcher to discover which of the conclusions is the strongest from an organizational perspective. This activity aimed to identify the most critical factors that impacted how information flowed and where the biggest bottleneck in information sharing lay in this specific organizational venture. Consequently, some valuable recommendations for the organization will be created, and lessons learned will be considered for future projects. The concluding statements are listed below and they are categorized based on the design phase. Some general concluding statements were also given to the experts to indicate to what extent they agree or disagree.

Predesign phase (VO)

1. The communication network results for the predesign phase (VO) are considered to represent information flow in reality.
2. The gatekeepers (Stakeholders & Permit and DO West) identified in the predesign phase had access to necessary information.
3. Teams Cost Control and Schedule & Risk were not actively participating during the predesign phase (VO).
4. Work preparation team had no contribution to the information provided in making the predesign (VO design).
5. Stakeholder & Permits team passed on more information in the predesign phase (VO), compared to the Contract Management team.
6. There was little involvement of Team Management Design & Integration in the predesign phase (VO).

Definitive design phase (DO)

1. The communication network results for the definitive design phase (DO) are considered to represent information flow in reality.
2. Management Design & Integration contributed the most to the information provided in making the definitive design (DO).
3. Work preparation team had no contribution to the information provided in making the definitive design (DO).
4. Execution team had no contribution to the information provided in making the definitive design (DO).
5. Interactions with the team Cost Control were very limited in the definitive design phase (DO).

Execution-ready design phase (UO)

1. The communication network results for the execution-ready design phase (UO) are considered to represent information flow in reality.
2. Work preparation team had no contribution to the information provided in making the UO design
3. Management Design Integration contributed the most to the information provided in making the execution-ready design (UO design) but lacked in interaction.
4. Team Quality & Document Control passed on a lot of information in the execution-ready design phase (UO).

General concluding statements

1. Teams consisting of individuals that were belonging in a single company were disengaged considerably.
2. Cost Control team made no impact in the way information was shared in the organization during the various phases of design.
3. Work preparation team made no impact in the way information was shared in the organization during the various phases of design.
4. Construction-related teams communicated more frequently than design teams.
5. The contract format acted as a barrier to information sharing.
6. Employees had the knowledge and the skills to make use of the information they were receiving; they knew exactly what they needed but most often information was misinterpreted.
7. Cultural differences between the organizations did not act as barriers to information sharing.

After gathering all of the experts' input, the concluding statements were ranked from the strongest to the least strong based on the five-point Likert scale from strongly agree to strongly disagree. The more the experts agreed with the statements, the stronger the conclusion for the organization. Thus, recommendations were given for the strongest conclusions. Figure 4.18 depicts the concluding statements that concern the predesign phase (VO) ranked from the strongest to the least strong.

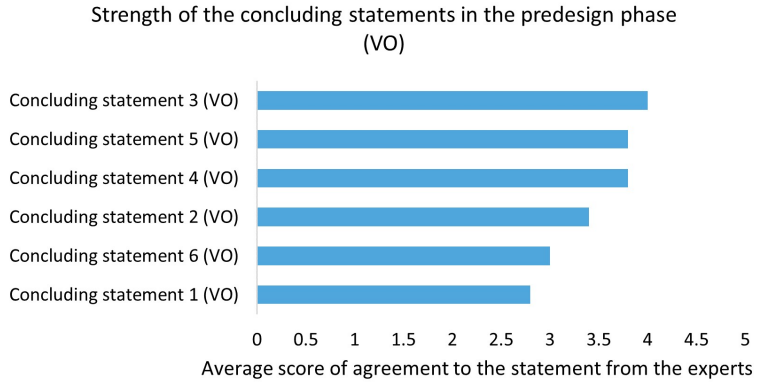


Figure 4.18: Ranking of the concluding statements in the predesign phase (VO) based on their strength

If the concluding statement 1 (VO) is excluded, the experts showed that they mostly agreed with the results. Concluding statement 1 (VO) was related to the extent to which the communication network results for the predesign phase (VO) represent reality. Thus, it appeared that this was not the case.

On the other hand, the strongest finding in this phase, with which most experts agreed, was that teams Cost Control and Schedule & Risk were not actively participating during the predesign phase.

Furthermore, by taking a look at Figure 4.19, it can be observed that experts agreed with all the concluding statements for the definitive design phase since the average scores for the statements were higher than three. Once again, what can be said to be the strongest conclusion for this phase was that interactions with the team Cost Control were very limited in the definitive design phase. Interestingly, experts agreed that the communication network results somehow matched reality in comparison with the predesign phase.

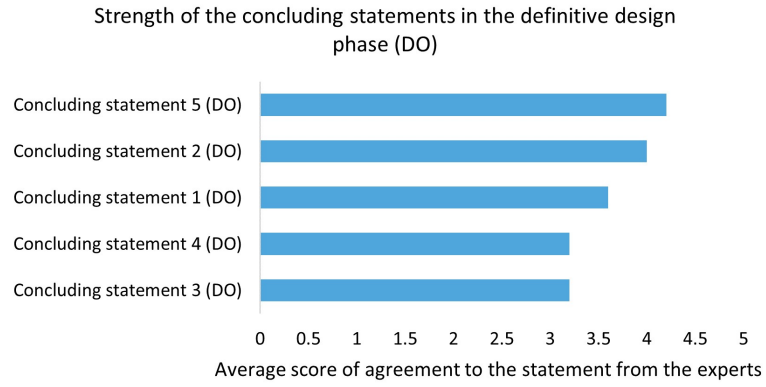


Figure 4.19: Ranking of the concluding statements in the definitive design phase (DO) based on their strength

As far as the concluding statements of the execution-ready design phase (UO) are concerned, these are presented in Figure 4.20. Experts tended to disagree with all the statements. Interestingly, they disagreed the most with concluding statement 2, which concerned the Work Preparation team. While in the previous two design phases, experts agreed that the Work Preparation team did not contribute much to the information in making the designs, in the execution-ready design phase, this was not the case. Thus, for this specific design phase, the fact that team Work preparation scored zero in betweenness centrality is attributed to no team members have participated in the survey.

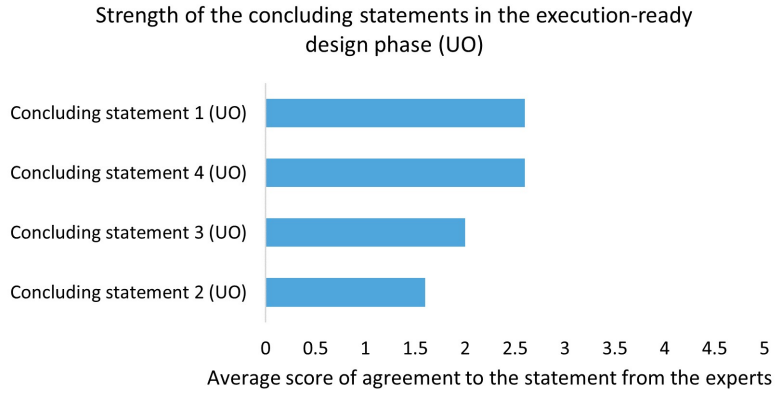


Figure 4.20: Ranking of the concluding statements in the execution-ready design phase (UO) based on their strength

Last but not least, Figure 4.21 depicts the general concluding statements ranked from the strongest to the least strong. In general there is a positive trend to the level that experts agreed with this group of concluding statements.

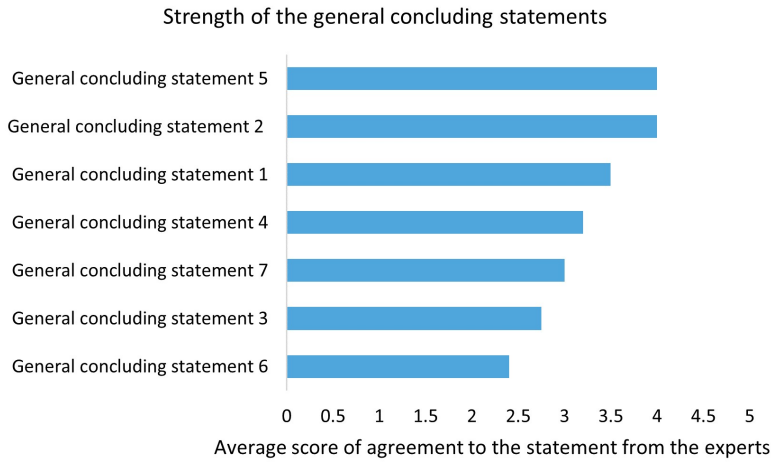


Figure 4.21: Ranking of the general concluding statements based on their strength

What needs to be discussed is that experts agreed with the absence of the Cost Control team as an influential node in all the design phases, but the fact that team Work Preparation did not rank among the most influential nodes in any of the design phases found them slightly disagreed. Experts believe that even though team Work Preparation did not contribute much in the predesign and definitive design phases, it contributed significantly in the execution-ready design phase regarding the sharing of information. Experts marked as the strongest concluding statement that the contract format acted as a barrier to information sharing. Interestingly though, they tended to disagree with the general concluding statement 6. However, it may be the case that this question contained many factors that made it difficult to agree.

On the whole, the primary key takeaways are that team Cost Control was disengaged from the design process, team Schedule & Risk should have been more involved in the predesign phase as well as team Management Design & Integration, team Work Preparation was not engaged at all in the predesign phase but this improved as the phases were going on and the contract format acted as a severe barrier to the information sharing. The predesign phase had already been completed when the survey was distributed, and many of those involved in that phase may have left the organization. Taking into account the dynamic nature of the networks, it was not possible to capture an accurate picture. The definitive design phase was the one closest to reality, but it took place while the survey was distributed, and the execution-ready design phase had just started when the survey was distributed, while the expert panel workshop session was held after two months.

5

Discussion

In this chapter, the main results of this study are summarized and discussed. Additionally, the research propositions that have been stated in section 2.4 are addressed in accordance with the main findings in Section 5.1. In Section 5.2 the researcher interprets the results, while in Section 5.3 he states why the results matter. Subsequently, in Section 5.4, there is a reference to the limitations of this study and lastly in Section 5.5 the researcher provides some recommendations based on the final interpretation of the results.

5.1. Testing the research propositions

The three research propositions stated in section 2.4 can be discussed based on the results. The first research proposition suggested that the interactions will be focused between the client and the architect. Thus, it was expected that departments that depend on the client's information would acquire more central positions. Indeed, team Stakeholder & Permits had the highest degree centrality indicating that it had the most interactions with the rest of the teams in the network but a slightly lower betweenness centrality compared to the DO West. According to the experts, it was logical that DO West had slightly more influence than the rest of the design teams since west is a very complex and information-dense area. Hossain (2009) found out through his research that those that are more capable of coordinating a project are actors characterized by high degree centrality. Additionally, S. Pryke et al. (2018), in their study, stated that actors with high degree and betweenness centrality act as coordinators to the rest of the network actors or, in this specific case study, the rest of the teams by synchronizing their activities. C.-Y. Lee et al. (2018), made it more specific and stated that if a node is characterized by a high out-degree centrality then it could act as a coordinator. In the predesign phase, the teams with higher out-degree centrality than their in-degree centrality were Stakeholder & Permits, EPCM and DO West. Especially team Stakeholder & Permits scored the highest in both in-degree and out-degree centrality. However, experts stated very explicitly that team Stakeholder & Permits should not have acted as a coordinator in this specific case in case it did, which they doubted it.

By taking a look at Figure D.2 and then at Table 4.2, it can be seen that all the nodes ranked among the most influential in the predesign phase (VO) had interactions with the client. However, not many interactions between the departments of the inter-organizational venture were observed. Only twenty-eight out of the forty-four teams actively exchanged information in this phase, and quite a few were in the network's periphery, not having mutual connections with the rest of the teams. This resulted in low network density compared to the two other design phases, but according to Schröpfer et al. (2017), the absorptive capacity of the network may be increased in sparse networks. Therefore, research proposition one is partially supported. The part that more central positions will be acquired by the teams that have access to information provided by the client was confirmed, whereas the part stating that a lot of interactions between the departments will exist did not.

Furthermore, considering the second research proposition, it was expected in the definitive design phase (DO), the communication network to be denser, and team Management Design & Integration to be the most central one. Interestingly, in the definitive design phase (DO), the network density was found to be the highest among the three phases, and team Management Design & Integration scored

the highest in all metrics (degree, betweenness and closeness centrality) calculated by the software. Additionally, experts agreed that what was presented to them represented reality to a great extent and that indeed team Management Design & Integration had the control over the flow of information. Thus, the second research proposition was confirmed. According to Schröpfer et al. (2017), actors that combine high in-degree and out-degree centrality are characterized as knowledge brokers. This makes sense since the department responsible for design scored the highest both in in-degree and out-degree centrality.

However, being found to have such a central position cannot be translated as an utterly positive situation. Of course, scoring high in degree and betweenness centrality, on the one hand, highlights the importance of such a key team (Schröpfer et al., 2017) in the definitive design phase, but on the other hand, such actors or teams can exploit their advantage to sway information flow in their favour (Loosemore, 1998). It was a positive finding that team Management Design & Integration was directing the decision-making process as Malisiovas and Song (2014) found in their study that this is what project coordinators do. However, such a high-centralized network always runs the risk of single points of failure.

The third research proposition was related to the execution-ready design phase and in this phase, it was expected that the construction-related departments would act as a link for transferring the information to the rest of the network, meaning that they would be participating more actively and start acquiring more central positions in the network. Indeed, in comparison with the previous two phases, in the execution-ready design phase, the construction-related departments were ranked higher in terms of degree and betweenness centrality. What was also found from the analysis of the results in this phase was that construction-related departments were exchanging information more often than the rest of the teams. According to Sun et al. (2019), information may be shared more easily when people communicate often. However, the frequent lines of communication were between the construction-related teams and not among all the teams, which raises the question of whether or not the rest of the teams in the network could capture all the information circulating between the construction-related teams.

Moreover, while in the predesign and definitive design phases, the modularity analysis recognized three communities, it identified five in the execution-ready design phase. According to Malisiovas and Song (2014), large modularity may indicate the formation of isolated communities resistant to outside sources of information. Thus, it can be confirmed that construction-related departments were more engaged during this phase, but it cannot be completely confirmed that they acted as a link for transferring information to the rest of the organization.

5.2. Interpretation of the results

As discussed in the previous section, most of the research propositions were either wholly or partly confirmed. However, other aspects that are part of this research's scope also need to be discussed. First of all, Manata et al. (2021) in their study stated that Integrated Project Delivery methods are being implemented more often to bring parties together since the early stages of a project so as to take better decisions and enhance performance. In this study, it was found out that as the design was moving forward more and more teams started to engage. It was expected more teams to provide input in the predesign phase and in later phases to increase the density of the network and consequently the volume of communication. However, this was not the case for this specific case study as more and more teams were added during the design process. This brings into question how early can people connect with each other in projects.

Moreover, the disengagement of the team Cost Control from all of the design phases was found to concern both the researcher and the experts. Interestingly, Schröpfer et al. (2017) in her research about sustainable construction, found out that cost consultants were not involved in exchanging information as well, probably due to the fact that they were not dependent on other participants' knowledge to perform their tasks. Indeed such a team may have very specific tasks, and they may not require information from various teams to successfully deliver them. However, based on the organizational breakdown structure presented in Figure 4.15, they should have exchanged information at least with team Finance and team Schedule & Risk, which did not happen. The communication between these three teams was found to be done in each of the three design phases mainly via the team Stakeholder & Permits. Even though the communication network in practice may be different from the one imposed by the organizational hierarchies (S. Pryke et al., 2018), the absence of team Cost Control from the

information-sharing activities was highlighted in all of the research activities. This could have probably resulted in not designing within budget.

However, according to the researcher's knowledge there were three teams (Cost Control, Finance and Procurement) that were handling costs in this specific case study. These three teams could have been considered to form a subculture in the organization since they acquire the same expertise or because they share cost-related responsibilities. Thus, they could have supported each other in case one of them failed to share information accordingly. Unfortunately, all these three teams scored very low in all of the SNA metrics and it should be further investigated whether this was the actual situation or this was because of not many people from these teams filled in the survey compared to the rest of teams.

Hatala and George Lutta (2009) stated in their research, that the method employed to share information between organizational members might potentially cause issues instead of facilitating information sharing. This research found that emails were the most used means of communication, followed by phone calls, direct conversations and team meetings. In a study carried out by Schröpfer et al. (2017), it was also found that employees were transferring knowledge via the same means of communication in all of the five case studies performed. Den Otter and Emmitt (2008) found out in their research that there is a clear preference of the employees towards face-to-face conversations during the design phases, which the survey participants in this study also confirmed. Interestingly, even though direct conversations were not the most used means of communication, the people who ranked them as the first choice were more than those who ranked them as second or third. Thus, the impact that the COVID-19 pandemic had on direct conversations during the design phases in this case study should be taken into consideration.

However, this contradicts the fact that employees did not use the new technological developments so often. In compliance with Liu et al. (2017), people not using BIM documents or other communication platforms may imply that they focused more on their interests. This may be correlated with the fact that even though employees knew what to do with the information they were getting, even though they knew what information was useful to them and requested it appropriately, the information that was reaching them was not communicated in the right format. Schröpfer et al. (2017) in her research claimed that such a misinterpretation of the information might be a common phenomenon when information is exchanged between different employees with different expertise. Thus, the existence of various subcultures in the inter-organizational venture could have impacted in a great extent the way information was exchanged between teams.

Lastly, employees stated they experienced working with people outside their team very knowledgeable. People like each other even though they may have different cultures. The clear preference for direct communication as a means of communication indicates, according to Mu et al. (2008), that employees are highly likely to have absorbed both tacit and explicit knowledge. According to Adi and Musbah (2017) and Hatala and George Lutta (2009) multicultural organizational settings may act as barrier to information sharing. However, this did not happen in this specific case study, as it was stated clearly by the survey's respondents and confirmed by the experts. Therefore, the subculture effect on terms of the different nationalities was not perceived as a barrier. On the contrary, the subculture effect in respect to the different roles and responsibilities could possibly have acted as a barrier.

5.3. Implications

This research contributes to the body of knowledge related to inter-organizational information sharing by investigating how information flows in a specific case in the various design phases. It also contributes to the studies that have adopted Social Network Analysis (SNA) in construction projects. Additionally, the research methods that the student adopted to approach the research may contribute to the existing knowledge since participant observations, and an expert panel workshop session were performed to enrich the primary data collected through a survey.

The results of this research may be helpful to the practice as well. By performing Social Network Analysis (SNA), it was made possible to uncover some of the communication patterns that did not match the organizational hierarchies (Hatala & George Lutta, 2009) and thus provide recommendations to the organization. The survey statistics identified several possible barriers to information sharing, such as how information was communicated and the fact that employees did not use the new technological developments to share information. Through the participant observations, some interesting results were

discovered as well. For instance, there was a large number of employees that used their parent's organizational email address instead of the inter-organizational email address. Employees were unaware of all the possible tools on hand, did not participate consistently in inter-organizational information-sharing activities and most importantly, their communication patterns matched neither the organizational structure nor the physical co-location of the teams. Last but not least, through the expert panel, it was discovered that a considerable barrier to information sharing was the contract format used and that several teams consisting of individuals that belonged to a single company were disengaged considerably. Thus, all of these results matter to the organization to create structures that will result in effective information sharing and successful project delivery.

5.4. Limitations

Under this section, the researcher would like to mention a few limitations that this study was subjected to. These are being listed below and they intend to raise the readers' awareness on the interpretation of the results.

First and foremost, the fact that this research was applied to a single case with a tailor-made scope focused on information flows in the various design phases of an inter-organizational infrastructure project is a critical limitation. Each organization divides the departments and assigns the roles differently. Thus, generalizing the findings based on just one case study does not allow drawing well-substantiated conclusions. Therefore, more case studies should be investigated to compare the different structures.

From a theoretical perspective, the term ”inter-organization” used throughout this research refers to the consortium shaped by the private organizations, excluding the client-public organization. If the client has been included in the collection of the data, it may have been the case that the balances in the network were different, resulting in different conclusions and different recommendations to the organization.

Networks are characterized as being dynamic. In this study, the researcher tried to understand how the communication network of the selected inter-organizational venture evolved over the three design phases by asking the respondents to fill in a survey at one particular moment in time. This cross-sectional character of the research cannot depict the exact situation since relationships are not static, and they change over time. So to study the ”evolution” of the communication network, the study should have been longitudinal. However, the time frame that this research needed to be completed did not allow that.

Another limitation this study was subjected to concerns the number of observation activities the researcher did. Because the project's office was a considerable distance from the researcher's living address, the latter could not be present very often there. Thus, the absence of the researcher from the project's office may be considered a study limitation. On the other hand, keeping a logical distance from the organization may have resulted in unbiased results. Additionally, the COVID-19 pandemic made it impossible for all employees to be at the office daily. So, when the researcher was at the office, not every department was present to observe all the possible interactions that these departments may have had with each other.

Furthermore, the way the survey was structured and distributed can also be considered a limitation since a different approach could have brought different results. The way the questionnaire was structured influenced the results in the sense that the more employees from a particular team filled in the survey, the more connected this team would be. On the same logic, the more time and effort these employees spent contributing to the survey, the more teams would list, resulting in higher connectivity of the team they belonged. Additionally, the survey was distributed using the inter-organizational mailing list, and the responses were recorded anonymously. Thus, it was unknown which specific actors filled in the survey. In that sense, the sample of individuals could have been selected more carefully. However, due to the General Data Protection Regulation (GDPR) and organizational sensitivity matters, this was not appropriate in this study.

Last but not least, another limitation in this study could be related to the analysis of the results. In this study, the analysis was carried out in a team-level and not in an individual one. It could have gone though, a level deeper by taking into consideration the proportionality of the employees from each team that filled in the survey or by investigating their nationalities and gender. Additionally, the context in which information was shared could have also been taken into consideration since this could have

added a bit more depth to the study.

5.5. Recommendations to the organization

The results of this research support that information sharing in inter-organizational ventures has logically concerned academia. Even though much is already known in the literature, inter-organizational information sharing still appears to be a problem.

For the researcher to provide valuable recommendations to the organization, several experts were invited to participate in an expert panel workshop session to enrich the findings from the various activities performed and ultimately validate them. From the expert panel, it was found that one of the most significant issues regarding information sharing was the disengagement of the teams consisting of individuals that belonged to a single company, including the Cost Control team. Thus, to deal with that, it is recommended in inter-organizational settings to have teams comprised of members from various organizations. Even if they have the same expertise, they will be forced to exchange information.

From the literature (de Metz, 2022; Müller-Prothmann, 2007), it was found out that central nodes, characterized by high degree and betweenness centrality can become bottlenecks, resulting in a huge loss of information in case some key individuals from this specific team leave the organization (Hatala & George Lutta, 2009). Team Management Design & Integration was indeed such a team running the risk of becoming a bottleneck to information sharing for the rest of the network. The organization could have minimized this risk if the teams Work Preparation and Execution contributed more to the definitive design by unloading team Management Design & Integration in terms of the quantity of information it had to filter.

Furthermore, contractual relationships can act as barriers to information sharing (P. Chinowsky et al., 2008; Pirzadeh & Lingard, 2017). From the analysis of the results, the contract was found to have acted as a barrier to information sharing in this case study. Even though this was not identified through the survey, experts stated explicitly that it had a huge impact. SNA revealed that the Contract Management team was not involved in information sharing activities in the predesign phase at the extent that team Stakeholder & Permits did. Additionally, from the analysis of the survey statistics it was found out that employees rated the factors minimizing cost and minimizing project duration as the least important in terms of team performance. During the expert panel workshop session, the involved experts interpreted this as employees not being aware of the project goals. Thus, it is recommended that the organization spend more resources at the beginning of the project to align the individual and organizational goals and inform the employees about the contract format used. This could overcome the barriers that contract strategies impose to information sharing as P. Chinowsky et al. (2008) supported in their research and foster information-sharing behaviour.

In respect to the cultural barriers that may exist in this case study, a recommendation to the top management would be to create a common culture or in other words a unique identity for those involved in the inter-organizational project. By forming long-term relationships and providing a sense of continuity to the employees, the sharing of information could be strengthened in the inter-organizational venture. More specifically, lack of commitment is often cited by several researchers (Ibrahim et al., 2018; Javernick-Will, 2012; S. Li & Lin, 2006; Ni et al., 2018; Yang & Maxwell, 2011) as a barrier to information sharing in inter-organizational projects. The fact that some employees made use of their parent-organizational email address was concerning and it might have impeded information sharing with the rest of the network. Encouraging employees to make use of the inter-organizational email address can be a valuable takeaway for future projects. Additionally, since information sometimes can be translated as power and by sharing it, employees might feel threatened of losing power, the sense of continuity could be a valuable mechanism. On top of that, a recommendation to the organization could be to create a rewarding system for those who promote information-sharing practices as it was found from the literature that lack of incentives could also be act as a barrier to information sharing (Bock et al., 2005; Kim & Lee, 2006; Ni et al., 2018; Willem & Buelens, 2007).

Last but not least, new technological developments such as Building Information Modelling and online collaboration platforms were found to enhance collaboration and, consequently, information sharing (Liu et al., 2017). Indeed, employees responded positively that adopting the new technological developments enhanced information sharing. However, they neither made use of them nor preferred to use them. This might have been attributed to the large number of technologies that were on hand, which according to literature can impede information sharing (Barua et al., 2007; Hatala & George Lutta,

2009; Schröpfer et al., 2017; Yang & Maxwell, 2011). Probably the fact that most employees in inter-organizational settings come from different organizations and are familiar with other tools and software indicates that these employees need to be educated on how to use the available tools. Maybe some guidelines should be provided beforehand to avoid frustration in the early phases of the project. Then, it is recommended that the responsible team or department find ways to motivate employees to use them.

6

Conclusion

The main objective of this research was to investigate how information flows during the different phases of the design process in inter-organizational projects. The researcher adopted social network theory to study information flows in a selected case study. Thus, this study aimed to improve understanding of the context of the problem in practice by applying the principles of social network theory. Apart from that, the researcher tested three research propositions he formed based on what he was expecting to find out when he started this research.

Therefore, in this study, the researcher initially conducted a literature review to explore the main concepts that concerned this study. Then he distributed a survey to gather data that would lead to visualizing the communication networks in each design phase. Subsequently, he carried out participant observations to add a qualitative character to the previous research activity and enrich the results from the social network analysis. Finally, the researcher hosted an expert panel workshop session to enrich the results further and validate the conclusions of the research.

6.1. Answers to the research questions

To conclude the research, the research question and the sub-questions stemming from it, stated in Section 1.3 are revisited.

Sub-question 1: ***What does information sharing in inter-organizational construction projects entail?***

By performing an extensive literature review, there was an effort to understand the theoretical context of this research. This process can conclude that, like others, the construction industry may be information-dependent, but it differs from those in the sense that it is highly fragmented and complex. This makes it difficult for all the parties that have a stake in construction projects to manage the various interactions among them and consequently share information effectively. Forming inter-organizational relationships is not a new concept. However, it is becoming increasingly popular as organizations understand its benefits and find ways to overcome the various types of barriers. Three types of barriers were found to inhibit information sharing in inter-organizational projects: cultural, organizational and industry-related. For organizations to overcome these barriers and foster information-sharing behaviour, they need to make two crucial considerations. First, they need to remind themselves that the main actors in the whole process are human beings. Second, they need to utilize the knowledge of these human beings.

Therefore, to conclude and provide an answer to the first sub-question, information sharing can take place via emails, phones and direct conversations among others. With the advancement of the technology, the new technological developments have contributed a great deal to efficient information sharing. More recently, the power of social networks was found to stimulate information-sharing behaviours since inter-organizational information sharing takes place in networks. Additionally, it is the knowledge of the employees that add value to the project. Thus, it is vital to integrate employees' knowledge when managing inter-organizational projects except integrating information. Of course, several barriers prevent organizations from sharing information among them. However, the motives to share

information and exchange knowledge between them could act as drivers for organizations that wish to achieve high-performing outcomes.

Sub-question 2: ***How can information flows best be studied?***

This research adopted social network theory to study information flows as its main research activity. By gathering data through a survey and analyzing them by performing social network analysis, it was possible to map the communication network of the inter-organizational venture by creating sociograms and extracting some key metrics that would give meaning to these. In parallel with the social network analysis, some participant observations added a qualitative character to how information flowed between the teams. However, these two research activities were insufficient due to some limitations this study was subjected. Thus, the results from the already mentioned research activities were enriched by hosting an expert panel where the experts invited could provide further insights into the networks' formation.

Overall, it is suggested to study information flows by approaching them from multiple aspects. Due to the dynamic nature of the networks and the limitations that the distribution of a survey may impose, enriching the results by having multiple data sources could be an interesting way to study information flows.

Sub-question 3: ***How is the actual information flow at the targeted inter-organizational venture organized?***

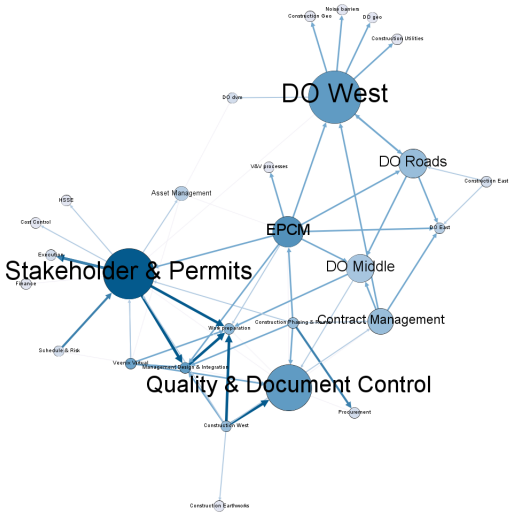
A survey was distributed to the whole organization to discover how the information flow in the selected case study was organized. By importing the data provided by the survey participants in ***Gephi***, a social network application, the communication networks of the inter-organizational venture were visualized (Figure 6.1) per design phase so as for the main teams/departments to be revealed. The results that came through the Social Network Analysis (SNA) were enriched by the researcher's participant observations and by some experts in the inter-organizational venture through an expert panel workshop session.

From Figure 6.1, it can be seen that during the definitive design phase and the execution-ready design phase, the communication between the teams of the inter-organizational venture was denser, while in the predesign phase, the density of the network was lower. This can be attributed to the fact that several peripheral figures existed in the predesign phase that did not have mutual connections with the rest of the teams. Additionally, in the predesign phase, there were two critical gatekeepers, while in the other two design phases, the critical figures that could create bottlenecks as far as information sharing is concerned were several central figures.

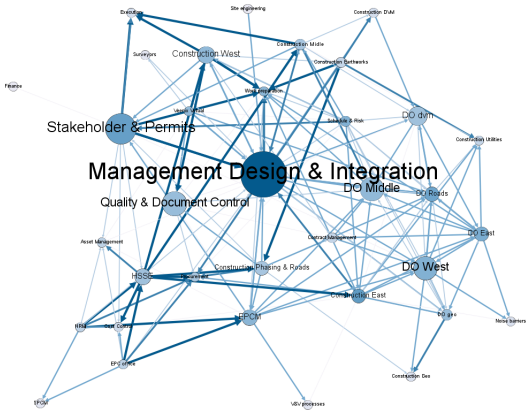
Furthermore, the team that had the control over the flow of information in the predesign phase was the team Stakeholder & Permits, according to the results from the SNA. However, according to the experts, this was not the case and should not have been. Some teams contributed more to the flow of information, but it was not depicted in the survey. This is attributed to the dynamic nature of the networks and to the fact that several people that were part of the inter-organizational venture had already left it when the survey was distributed. Team Management Design & Integration had more influence in this phase which was not depicted. Teams Cost Control, Schedule & Risk, and Contract Management should have been more involved.

As far as the definitive design phase is concerned, the volume of communication inside the network increased, resulting in a denser communication network. Team Management Design & Integration had explicit control over the flow of information. It was the team that was ranked the highest both in degree centrality and betweenness centrality. However, this could cause a severe bottleneck to the information flow. Other teams, such as Work Preparation and Execution, should have helped unload team Management Design & Integration in terms of the quantity of information it filtered. Team Cost Control remained disengaged from the rest of the network, and interactions with it were limited. From the SNA, it came out that team Work Preparation had minimal influence in sharing information in this design phase. However, experts said that this was not the case. No significant gatekeepers were recognized, and the network had very few peripheral figures in this phase. On the other hand, several central figures were identified, making the network less centralized but running into the risk of creating multiple communication bottlenecks.

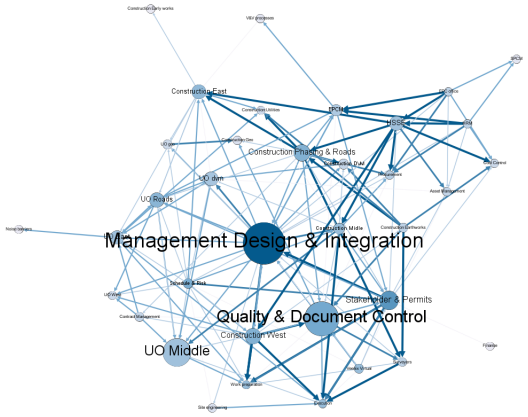
Moreover, the density of the communication network that was formed in the execution-ready design phase was a bit lower than the network's density in the definitive design phase. In contrast with the



(a) Communication network of the inter-organizational venture in predesign phase (VO)



(b) Communication network of the inter-organizational venture in definitive design phase (DO)



(c) Communication network of the inter-organizational venture in execution-ready design phase (UO)

Figure 6.1: Communication networks of the inter-organizational venture in every design phase

definitive design phase, more construction-related teams started to engage in information-sharing activities, and the lines of communication among them appeared to be more frequent than those between the design teams. Team Management design & Integration was again the most influential node in the network but the fact that much action took place around it, with more frequent information exchange, it should be investigated whether or not this team could absorb all this information. Even though team Work Preparation ranked among the least influential nodes according to the SNA, experts indicated that team Work Preparation contributed to a great extent in the execution-ready design phase.

To conclude, it appeared that the communication network in the definitive design phase was the one closest to reality. In contrast, the experts did not agree that the communication network results in the predesign and execution-ready design to represent reality. The absence of team Cost Control was highlighted in all design phases. Team Work Preparation was also a bottleneck in information sharing in most of the design phases. Indeed it had low levels of contribution in the early phases. However, in the execution-ready design phase was engaged to a great extent which, unfortunately, the SNA did not

confirm. Team Management Design & Integration had substantial control over the flow of information in almost every phase. The SNA did not confirm this for the predesign phase, and the fact that there are a lot of frequent lines of communication around it in the execution-ready design phase may indicate that it lacked interaction in this specific case. Team Stakeholder & Permits appeared as the most influential node in the predesign phase, which was contradicted by the experts as this was not the case or, in case it was, it should not have been. Lastly, construction-related teams started influencing the flow of information in the execution-ready design phase but still, team Management Design & Integration had the control over the flow of information in the network.

Sub-question 4: ***Which are the most critical factors that impact how information flows and must be considered for future projects?***

First, through the literature review, several factors that act as barriers that inhibit information sharing were identified. These have been categorized as cultural, organizational and industry-related. Regarding the cultural barriers, when employees were asked what is the most important factor in terms of team performance, the majority ranked the nice atmosphere/working environment as the most important one. Thus, the organization needs to create a nice working environment for the employees to foster information-sharing behaviour. On the other hand, experts perceived that employees ranked first the nice atmosphere/working environment factor as not being aware of the project goals, which are to minimize cost and complete the project on time. The divergence of individual and organizational goals could have been a barrier to information sharing. Therefore, the organization should spend more resources to align them.

In this specific case study, what acted as a barrier to information sharing was the contract format. Even though this was not stated clearly during the analysis of the data collected from the survey, experts confronted that employees may not have been aware of the contract format or have misinterpreted the question. Through the validation of the concluding statements by the experts, it was validated that the contract format indeed played an important role in encouraging information sharing and acted as a barrier. This may be attributed to the fact that team Contract Management was not engaged much in the predesign phase compared to team Stakeholder & Permits.

Teams consisting of individuals that belonged to a single company were considerably disengaged from information-sharing activities. This was also the case for team Cost Control which made almost no impact on how information was shared in the organization during the various phases of design. Additionally, during the predesign phase, DO East did not contribute to a favourable extent, and experts said that this was because the whole section had been given to a single organization. Thus, teams in such projects should consist of members from various organizations to limit the risk of disengaging from information-sharing activities.

Furthermore, it was found that the new technological developments enhanced information sharing. However, employees did not make use of them, and they stated clearly that they did not prefer to use them either. The unfamiliarity with the new technologies or the fact that many new technologies exist may have prevented employees from using them. Even though they turned into these systems to search for information, they used emails, phones or face-to-face conversations when they were asked to share information. Moreover, the majority responded negatively when asked if the information was appropriately communicated. Thus, employees had the knowledge and skills to use the information they were receiving; they knew what they needed, but most often, information was misinterpreted or not communicated in the right format. The fact that a large number of employees used their parent's organization's mailing list made information sharing difficult.

Last but not least, a bottleneck in how information was shared was found between the teams Cost Control, Finance and Schedule & Risk. While these three should have communicated with each other, this was not the case. The information was passed from team Schedule & Risk to Cost Control and Finance through the team Stakeholder & Permits, and team Cost Control was found to have no communication line with team Finance.

To conclude, the contract format, the technologies that employees had in hand, the divergence of individual and organizational goals, the teams not consisting of members from various organizations and some habits of the employees impacted to a great extent how information flowed in this specific inter-organizational venture. All of these, together with the teams that had control over the flow of information in each design phase, need to be considered for future projects.

Main research question: ***"How is information exchanged in inter-organizational projects during the design life cycle?"***

To begin with, all the answers provided for the sub-questions before contribute to answering the main research question. First, through the literature review, it was made clear that there has been a longstanding concern about information sharing in inter-organizational projects. Studies have so far emphasized what motivates organizations to form inter-organizational relations and exchange information and knowledge, which factors act as barriers that inhibit information sharing or even prevent companies from forming inter-organizational relationships and which factors contribute to their success, what are the impacts of successful information and knowledge exchange between the organizations and what is the power of social networks in shaping information sharing practices in general. However, knowledge of how information flows during the specific phases of the design process is still limited, and no study has been found to examine that by using social network analysis.

Therefore, social network theory was adopted, and social network analysis was performed as the primary research activity. Participant observations and an expert panel workshop session have further enriched the results. Through the survey, it was revealed that in the way the inter-organizational venture was structured, forty-four teams were found to exchange information. Only twenty-eight out of them were involved in the predesign phase, while there has been more participation in the definitive design phase and the execution-ready design phase, with thirty-five and thirty-six teams to be involved, respectively. Thus, it should be further investigated how early people can connect and share information effectively with each other.

In the predesign phase, the network's density was equal to 16.9%, whereas, in the other two phases, the communication volume increased, resulting in network densities equal to 27.1% and 24.9%, respectively. No significant difference in the average frequency of information exchange has been observed. On average, employees interacted with employees from different departments to exchange information on a weekly/ monthly basis in all of the design phases. Only in the execution-ready design phase, it was observed that the communication lines between the construction-related teams were more frequent than the rest of the inter-organizational venture's teams. However, no conclusions were made whether the higher density and frequency can be translated as being good or bad.

In terms of the node type, it is important to understand the context in which information is shared. For example, the fact that in the predesign phase two crucial gatekeepers and a lot of peripheral figures were identified, while in the other two phases, no significant gatekeepers were identified but a lot of central figures did, indicates that different information-sharing behaviours took place. In the predesign phase attention should be paid not to lose access to valuable information, while in the rest of the phases attention should be shifted to not running the risk of creating multiple communication bottlenecks.

Furthermore, as far as the most used means of communication are concerned, most employees ranked emails as their first choice. The employees often used team meetings, direct conversations, and phones. However, employees indicated a clear preference for direct conversations for sharing information in the design phases. Interestingly, BIM documents and other technological developments, such as online collaboration platforms, were ranked the lowest. Employees stated that these means of communication were not their first choice of preference, even though they believed that they enhanced information sharing in the organization.

While team Management Design & Integration was the most influential team in definitive design phase and execution-ready design phase, the team that had the control over the flow of information in the predesign phase was one of these teams that had interactions with the client. However, this should not have been the case in the predesign phase. Other teams that have interactions with the client as well and can generate valuable information should have ranked higher. Interestingly, teams consisting of representatives from a single company were considerably disengaged from information-sharing activities, not only in the predesign phase but also in the definitive and execution-ready design phases. Several barriers were found to impact how information flowed in this specific case study, with the most important one, according to the experts, to have been the contract format. However, the survey findings indicated that one of the most critical barriers to information sharing in this case study was that information was not communicated properly in the right format. Of course, this can also be a side effect of the contract format, but it can also indicate a lack of employees' time, the existence of a large number of technologies with information not being well organized and consequently lost, or it can even be attributed to the large number of employees that make use of their parent's organizational email.

On the whole, in the predesign phase, there should have been more involvement from teams that were generating valuable information to balance the control that the most influential team, according to the SNA, had over the flow of information. The different design teams should have had the same degree centrality and probably the same betweenness centrality. However, it may also be the case that one area is more complex and more information-dependent, thus ranking higher in terms of influence in the network. In the definitive design phase, team Management Design & Integration should control the flow of information. However, other teams should also support it since being the only one to have control may become a bottleneck or even a single point of failure. Such teams could be teams of the same subculture regarding their roles and responsibilities in the organization. In the execution-ready design phase, many central figures concerning the construction-related teams exist in the network since many activities take place. There are multiple sources of information; thus, team Management Design & Integration should be able to absorb all of it. Last but not least, attention must be paid to the various barriers that have been found to impact how information flows. Especially in how the information is being communicated and how to motivate employees to use the various technological developments available since they found to enhance information sharing.

6.2. Future research directions

As discussed in section 5.4, this study had some limitations due to various reasons concerning the theory, the scope and the methodology, among others. Thus, future directions are being proposed in this section that could be further investigated in future studies.

Since this study investigated the information flows between the consortium parties in the various design phases, it may have been interesting for future studies to include the client in the process. Clients could also be part of inter-organizational ventures, which may be essential in providing and sharing information with various organizations. It was just out of the scope of this research to include them in the analysis. However, such an addition to the communication network may change the balance over the flow of information, establishing an exciting direction for future research.

This research focused on information flows in an inter-organizational infrastructure project. Interestingly, it was identified from the literature that the employees' knowledge should also be integrated in such projects. Thus, it could probably be a promising idea to study how the knowledge exchange between the various stakeholders impacts the outcome of the design. Of course, designers possess the knowledge to complete their designing tasks, but with the increase in complexity, more expertise from other parties is required to deliver a construction project successfully. Understanding from which actors this source of knowledge may come could be valuable, which is why the researcher proposes such a future direction.

Observations were relatively supportive in the Social Network Analysis in this research. However, some very interesting conclusions were retrieved from performing them. A possible future research direction could be on the effect of the observations on how the information flows between the consortium parties in the various phases of design. The observations in this research were limited to participation in weekly stand-ups and the identification of communities. Future studies could add more observations regarding information sharing or knowledge exchange, such as the percentage of people at the office that went on site and establish observations as their primary research activity.

Furthermore, one of the positive impacts of information sharing was found through the literature to be improving team performance. It was also found in this study that, in terms of information sharing, high team performance is facilitated by a pleasant working environment, while in terms of organizational goals, team performance is measured on cost and project duration. A suggestion for future research could be investigating the relationship between information sharing, organizational goals and team performance.

Lastly, some interesting directions for future research can result from the following concerns. How early can eventually people connect and exchange information between each other effectively? What is the desired level of information exchange in terms of network's density and interactions' frequency that should be achieved for an inter-organizational team to perform high? To what extend does the context in which information is shared matter? All of these may be interesting main research questions to further enrich the body of knowledge related to this study.

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A

Survey design flowchart

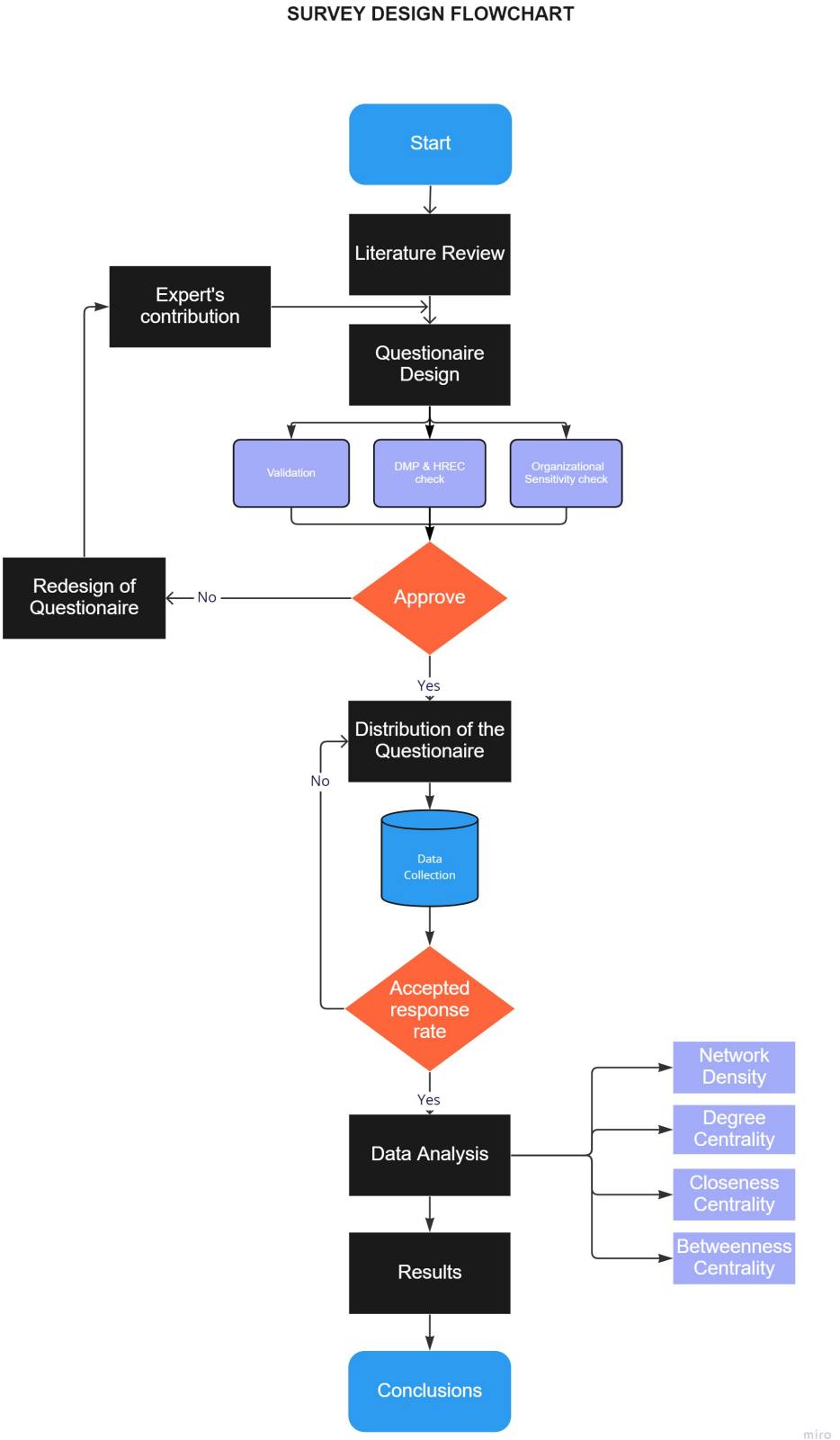

Figure A.1: Flowchart that depicts how the survey was designed

B

Questionnaire layout

MSc Thesis - Information sharing in various design phases

Start of Block: Introduction Statement

Q1 Dear Colleague,

You are being asked to participate in a research study titled **"Adopting social network theory to understand how information flows during the various design phases in inter-organizational projects - A case study"**. This study is being done by me; Konstantinos Stroumpoulis from TU Delf currently employed at Count & Cooper and it is part of my MSc Thesis.

The purpose of this research study is to identify how information flows within departments and teams in inter-organizational projects in various design phases. It will take you approximately fifteen (15) minutes to complete this survey.

The data will be used for mapping the communication network in all the design phases and understand how it evolved over time. Then it will be possible to check how to optimize the information sharing and take advantage of lessons learned for future projects.

I will be asking you to provide some demographic information at the first part, such as under which company you are employed, in which department and team you are assigned and how long you have been part of the project. At the second part of this survey, you will be asked to identify with which departments or teams you where interacting in the different design phases and assess various aspects of this interaction (e.g., frequency and quality).

Your answers in this survey will remain confidential. We will minimize any risks by conducting this survey anonymously and by codifying all of your personal data so as it will be impossible to be identified. After this research, the data will be destroyed. However, as with any online activity the risk of a breach is always possible, but in case you have any questions please contact me on the emails provided below.

Your participation in this study is entirely voluntary and highly appreciated. You can withdraw at any time. You are free to omit any questions.

Kind regards, Konstantinos Stroumpoulis
Delft University of Technology, MSc Construction Management & Engineering
kstroumpoulis@veenix.nl / stroumpoulesk@gmail.com

Page Break

Q2 I consent voluntarily to be a participant in this study and understand that I may refuse to answer questions and withdraw from the study at any time, without having to give a reason.

- ○ I consent to participate (1)
- ○ I do **NOT** consent to participate (2)

End of Block: Introduction Statement

Start of Block: Demographic data collection

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q3 **Part I - Position in the organization**

In this part, you are asked to fill in some demographic data like under which company you are employed and in which project department and team you belong to. Apart from that, you will be asked to say since when you are part of this project. These will facilitate the grouping in the stage of data analysis.

Page Break

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q4 Which company employs you?

- ○ FCC Construcción (1)
- ○ Count & Cooper (2)
- ○ Sweco (3)
- ○ Iv-Infra (4)
- ○ Arcadis (5)
- ○ Fugro (6)
- ○ Yunex (7)
- ○ WSP (8)
- ○ Antea (9)
- ○ Nobleo (10)
- ○ Optimus (11)
- ○ Other (please specify) (12) _____

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q5 In which department do you belong in the project?

- ○ EPCM (1)
- ○ SPCM (2)
- ○ EPC office (3)
- ○ Contract Management (4)
- ○ Finance (5)
- ○ HRM (6)
- ○ ICT (7)
- ○ HSSE (8)
- ○ Design & Integration (9)
- ○ Construction East (10)
- ○ Construction Middle (11)
- ○ Construction West (12)
- ○ Construction Phasing & Roads (13)
- ○ Procurement (14)
- ○ Asset Management (15)
- ○ Cost Control (16)
- ○ Project Management Office (17)
- ○ Other (Please specify) (18) _____

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q6 In which specific team do you belong?

- ○ **DO** West (1)
- ○ **DO** Middle (2)
- ○ **DO** East (3)
- ○ **DO** Roads (4)
- ○ **DO** dvm (5)
- ○ **DO** geo (6)
- ○ **UO** West (7)
- ○ **UO** Middle (8)
- ○ **UO** East (9)
- ○ **UO** Roads (10)
- ○ **UO** dvm (11)
- ○ **UO** geo (12)
- ○ Management Design & Integration (13)
- ○ Site engineering (14)
- ○ Construction (please specify the team) (15) _____
- ○ Schedule & Risk (16)
- ○ Stakeholder & Permits (17)
- ○ Quality & Document Control (18)
- ○ Veenix Virtual (19)
- ○ Veenix Academy (20)

○ Other (please specify) (21) _____

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q7 How long have you been part of this project?

○ Less than 6 months (1)

○ Between 6 months and 1 year (2)

○ Between 1 year and 1.5 years (3)

○ From the start of the project (4)

○ Already during the tender phase (5)

End of Block: Demographic data collection

Start of Block: Social Network Analysis

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q8 **Part II - Interaction with other Teams and Departments**

This is the second part of the survey. In this part you will be asked whether you were involved in the design phase or not. In case you were involved, you have to state in which of the three design phases (VO/DO/UO) you were involved (it can be more than one as well). Then, you will be asked to share with which other teams or departments you were exchanging information and assess the performance in individual, team and inter-organizational levels.

Page Break

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q9 Were/Are you involved in any design phase?

- ○ Yes (1)
- ○ No (2)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Were/Are you involved in any design phase? = Yes

Q10 In which of the design phases were/are you involved? (Please select all that apply).

- ☐ Predesign (VO) (1)
- ☐ Definitive Design (DO) (2)
- ☐ Execution-ready Design (UO) (3)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Were/Are you involved in any design phase? = No

Q11 What is the reason you were/are not involved in any design phase?

- ○ I was not part of the project. (1)
- ○ It is not my responsibility according to my expertise. (2)
- ○ My contract does not allow me to contribute to the design phase. (3)
- ○ I was not asked to do so. (4)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Were/Are you involved in any design phase? = Yes

Carry Forward Selected Choices from "In which of the design phases were/are you involved? (Please select all that apply)."

Q12 Please indicate the level of your contribution in the phases you were involved in comparison with the level of your satisfaction after its completion.

	Contribution							Satisfaction						
	Far too little (1)	Moderately too little (2)	Slightly too little (3)	Neither too much nor too little (4)	Slightly too much (5)	Moderately too much (6)	Far too much (7)	Extremely dissatisfied (1)	Moderately Dissatisfied (2)	Slightly Dissatisfied (3)	Neither Satisfied nor Dissatisfied (4)	Slightly Satisfied (5)	Moderately Satisfied (6)	Extremely Satisfied (7)
Predesign (VO) (x1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Definitive Design (DO) (x2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Execution-ready Design (UO) (x3)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Were/Are you involved in any design phase? = Yes

Carry Forward Selected Choices from "In which of the design phases were/are you involved? (Please select all that apply)."

Q13 What is your general impression of your team performance in the design phases you were involved?

	Extremely negative (1)	Moderately negative (2)	Slightly negative (3)	Neither positive nor negative (4)	Slightly positive (5)	Moderately positive (6)	Extremely positive (7)
Predesign (VO) (x1)	○	○	○	○	○	○	○
Definitive Design (DO) (x2)	○	○	○	○	○	○	○
Execution-ready Design (UO) (x3)	○	○	○	○	○	○	○

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q14 What do you consider more important in terms of team performance? (Please rank from the most important to the least important by dragging up and down each of the choices).

_____ Satisfaction and needs of the stakeholders (1)
_____ Minimizing cost (2)
_____ Minimizing project duration (3)
_____ Improving quality (4)
_____ Nice atmosphere / working environment (5)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q15 The performance of my team met my expectations, regarding what was important for me.

- ○ Strongly disagree (1)
- ○ Disagree (2)
- ○ Somewhat disagree (3)
- ○ Neither agree nor disagree (4)
- ○ Somewhat agree (5)
- ○ Agree (6)
- ○ Strongly agree (7)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Were/Are you involved in any design phase? = Yes

Q16 The contract format used in the project encouraged me to share information. (If the contract used did not have any impact in your case, please select the option "Neither agree nor disagree").

- Strongly disagree (1)
- Disagree (2)
- Somewhat disagree (3)
- Neither agree nor disagree (4)
- Somewhat agree (5)
- Agree (6)
- Strongly agree (7)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Were/Are you involved in any design phase? = Yes

Q17 The new technological developments (e.g., BIM) enhanced the information sharing.

- Strongly disagree (1)
- Disagree (2)
- Somewhat disagree (3)
- Neither agree nor disagree (4)
- Somewhat agree (5)
- Agree (6)
- Strongly agree (7)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Were/Are you involved in any design phase? = Yes

Carry Forward Selected Choices from "In which of the design phases were/are you involved? (Please select all that apply)."

Q18 Please assess how often did/do you meet as a team in combination with how effective you think these meetings were/are.

	Frequency						Effectiveness						
	Daily (at least once a day) (1)	Frequently (several times per week) (2)	Weekly (1-2 times per week) (3)	Infrequently (less than once a week) (4)	Rarely (less than once a month) (5)	Never (6)	Not at all effective (1)	Low effectiveness (2)	Slightly effective (3)	Neutral (4)	Moderately effective (5)	Very effective (6)	Extremely effective (7)
Predesign (VO) (x1)	○	○	○	○	○	○	○	○	○	○	○	○	○
Definitive Design (DO) (x2)	○	○	○	○	○	○	○	○	○	○	○	○	○
Execution-ready Design (UO) (x3)	○	○	○	○	○	○	○	○	○	○	○	○	○

Page Break

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q19 Did/do you have interactions with the client?

- ○ Yes (1)
- ○ No (2)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Did/do you have interactions with the client? = Yes

Q20 Please state how often did/do you interact with the client.

- ○ Daily (at least once a day) (1)
- ○ Frequently (several times per week) (2)
- ○ Weekly (1-2 times per week) (3)
- ○ Infrequently (less than once a week) (4)
- ○ Rarely (less than once a month) (5)

Page Break

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q21 Did/Do you have interactions with other departments/teams?

- Yes (1)
- No (2)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Did/Do you have interactions with other departments/teams? = Yes

Q22 Sometimes I received information from other departments/teams and I did not know what to do with it.

- Never (1)
- Rarely (2)
- Infrequently (3)
- Sometimes (4)
- Frequently (5)
- Usually (6)
- Always (7)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Did/Do you have interactions with other departments/teams? = Yes

Q23 Information was/is not communicated properly in the right format.

- Never (1)
- Rarely (2)
- Infrequently (3)
- Sometimes (4)
- Frequently (5)
- Usually (6)
- Always (7)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Did/Do you have interactions with other departments/teams? = Yes

Q24 People know what information they need from me and they request it appropriately.

- Never (1)
- Rarely (2)
- Infrequently (3)
- Sometimes (4)
- Frequently (5)
- Usually (6)
- Always (7)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Did/Do you have interactions with other departments/teams? = Yes

Q25 With which departments did/do you interact and in which phase? (In this stage, please list all the departments/teams you interact no matter if you provide/receive information to/from them).

	Name of the Department/Team	Design Phase		
	Please fill in the box (1)	Predesign (VO) (1)	Definitive Design (DO) (2)	Execution-ready Design (UO) (3)

Department/Team 1 (1)		☐	☐	☐
Department/Team 2 (2)		☐	☐	☐
Department/Team 3 (3)		☐	☐	☐
Department/Team 4 (4)		☐	☐	☐
Department/Team 5 (5)		☐	☐	☐
Department/Team 6 (6)		☐	☐	☐
Department/Team 7 (7)		☐	☐	☐

Department/Team 8 (8)		☐	☐	☐
Department/Team 9 (9)		☐	☐	☐
Department/Team 10 (10)		☐	☐	☐

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Did/Do you have interactions with other departments/teams? = Yes

Q26 Please indicate which of these departments was/is providing information to do your work and assess to which extent the information you received contributed to your team performance. (Please assess only the departments that provide information to you. For the rest select the "Not applicable" choice).

	Not at all (1)	Very little (3)	Little (4)	Moderately (5)	Much (6)	Very much (7)	Completely (8)	Not applicable (9)
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/1/1} (1)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/2/1} (2)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/3/1} (3)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/4/1} (4)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/5/1} (5)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/6/1} (6)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/7/1} (7)								

Display This Choice: *If If Text Response Is Not Empty* ${Q25%231/ChoiceTextEntryValue/8/1} (8)	○	○	○	○	○	○	○
Display This Choice: *If If Text Response Is Not Empty* ${Q25%231/ChoiceTextEntryValue/9/1} (9)	○	○	○	○	○	○	○
Display This Choice: *If If Text Response Is Not Empty* ${Q25%231/ChoiceTextEntryValue/10/1} (10)	○	○	○	○	○	○	○

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Did/Do you have interactions with other departments/teams? = Yes

Q27 Please indicate to which of these departments you were/are providing information to do their work and assess to which extent did it help them to increase their performance. (Please assess only the departments that you provide information to them. For the rest select the "Not applicable" choice)

	Not at all (1)	Very little (2)	Little (3)	Moderately (4)	Much (5)	Very much (6)	Completely (7)	Not applicable (8)
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/1/1} (1)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/2/1} (2)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/3/1} (3)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/4/1} (4)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/5/1} (5)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/6/1} (6)								
Display This Choice: If If Text Response Is Not Empty ${Q25%231/ChoiceTextEntryValue/7/1} (7)								

Display This Choice: *If If Text Response Is Not Empty* ${Q25%231/ChoiceTextEntryValue/8/1} (8)	○	○	○	○	○	○	○
Display This Choice: *If If Text Response Is Not Empty* ${Q25%231/ChoiceTextEntryValue/9/1} (9)	○	○	○	○	○	○	○
Display This Choice: *If If Text Response Is Not Empty* ${Q25%231/ChoiceTextEntryValue/10/1} (10)	○	○	○	○	○	○	○

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

And Did/Do you have interactions with other departments/teams? = Yes

Q28 Please assess the frequency of the communication with the departments/teams you stated. Assess also to which extent this frequency has been beneficial for the performance of your team/department.

	Frequency					Beneficial						
	Daily (at least once a day) (1)	Frequently (several times per week) (2)	Weekly (1-2 times per week) (3)	Infrequently (less than once a week) (4)	Rarely (less than once a month) (5)	Not at all beneficial (1)	Low benefits (2)	Slightly beneficial (3)	Neutral (4)	Moderately beneficial (5)	Very beneficial (6)	Extremely beneficial (7)
${Q25%231/ChoiceTextEntryValue/1/1} (1)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/2/1} (2)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/3/1} (3)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/4/1} (4)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/5/1} (5)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/6/1} (6)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/7/1} (7)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/8/1} (8)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/9/1} (9)	○	○	○	○	○	○	○	○	○	○	○	○
${Q25%231/ChoiceTextEntryValue/10/1} (10)	○	○	○	○	○	○	○	○	○	○	○	○

Page Break

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q29 Which of the following tool/means of communication do you **use** more often for your communication? (Please rank the choices by clicking and dragging them up or down).

_____ Phone (1)
_____ Emails (2)
_____ Chat application (e.g., MS Teams) (3)
_____ Team meeting (4)
_____ Direct conversation (face to face) (5)
_____ Networking - socializing (6)
_____ Online collaboration platforms (e.g., SharePoint) (7)
_____ BIM documents (8)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q30 Which of the following tool/means of communication do you **prefer** the most? (Please rank the choices by clicking and dragging them up or down).

_____ Phone (1)
_____ Emails (2)
_____ Chat application (e.g., MS Teams) (3)
_____ Team meeting (4)
_____ Direct conversation (face to face) (5)
_____ Networking - socializing (6)
_____ Online collaboration platforms (e.g., SharePoint) (7)
_____ BIM documents (8)

Page Break

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q31 In respect of gaining knowledge, I experienced working with people outside of my team very knowledgeable.

- Strongly disagree (1)
- Disagree (2)
- Somewhat disagree (3)
- Neither agree nor disagree (4)
- Somewhat agree (5)
- Agree (6)
- Strongly agree (7)

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q32 My company encouraged me to exchange knowledge with the rest of the organization.

- Strongly disagree (1)
- Disagree (2)
- Somewhat disagree (3)
- Neither agree nor disagree (4)
- Somewhat agree (5)
- Agree (6)
- Strongly agree (7)

Page Break

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q33 The past six months a lot has changed in and outside the organization. Please assess to what extent these changes had a positive impact on the information sharing in the organization.

	Not at all (27)	Very little (28)	Little (29)	Moderately (30)	Much (31)	Very much (35)	Completely (36)
Lift of COVID-19 measures (1)	○	○	○	○	○	○	○
Change in the management structure (2)	○	○	○	○	○	○	○
Live Esquina de Oradores (3)	○	○	○	○	○	○	○

Page Break

Display This Question:

If I consent voluntarily to be a participant in this study and understand that I may refuse to answe... = I consent to participate

Q34 Is there anything you want to share or you think is important to be mentioned?

_____

_____

_____

_____

_____

End of Block: Social Network Analysis

We thank you for your time spent taking this survey.
Your response has been recorded.

C

Social Network Analysis results

In this Appendix the complete tables that can provide better insight to the reader regarding the social network analysis are being presented. These tables did not contribute to the main body but they can add value to the readers' understanding.

Table C.1: Complete list of nodes identified through the survey

Id	Label	Id	Label
1	DO West	23	Construction Earthworks
2	DO Middle	24	Construction Geo
3	DO East	25	Surveyors
4	DO Roads	26	Schedule & Risk
5	DO dvm	27	Stakeholder & Permits
6	DO geo	28	V&V processes
7	UO West	29	Quality & Document Control
8	UO Middle	30	Veenix Virtual
9	UO East	31	Veenix Academy
10	UO Roads	32	Procurement
11	UO dvm	33	Asset Management
12	UO geo	34	Cost Control
13	Management Design & Integration	35	EPCM
14	Site engineering	36	SPCM
15	Work preparation	37	EPC office
16	Execution	38	Contract Management
17	Construction East	39	Finance
18	Construction Midle	40	HRM
19	Construction West	41	ICT
20	Construction DVM	42	HSSE
21	Construction Early works	43	Noise barriers
22	Construction Utilities	44	Construction Phasing & Roads

Table C.2: Complete list of nodes' characteristics in predesign phase (VO), ranked based on their betweenness centrality from the largest to smallest.

Id	Label	Degree centrality	In-degree centrality	Out-degree centrality	Closness centrality	Betweeness centrality	Modularity class
1	DO West	10	3	7	0.466667	63	0
27	Stakeholder & Permits	17	8	9	0.888889	60	1
29	Quality & Document Control	10	4	6	0.512195	52.75	2
35	EPCM	11	2	9	0.6	30.25	0
4	DO Roads	6	3	3	0.42	27	0
2	DO Middle	5	3	2	0.355932	26	2
38	Contract Management	6	3	3	0.428571	22.25	2
33	Asset Management	4	3	1	1	5.5	0
13	Management Design & Integration	10	9	1	1	0.25	1
3	DO East	4	4	0	0	0	0
5	DO dvm	2	2	0	0	0	0
6	DO geo	1	1	0	0	0	0
15	Work preparation	7	7	0	0	0	1
16	Execution	2	2	0	0	0	1
17	Construction East	2	0	2	0.309859	0	0
19	Construction West	6	0	6	0.489362	0	2
22	Construction Utilities	1	1	0	0	0	0
23	Construction Earthworks	1	1	0	0	0	2
24	Construction Geo	1	1	0	0	0	0
26	Schedule & Risk	2	1	1	0.5	0	1
28	V&V processes	1	1	0	0	0	0
30	Veenix Virtual	9	0	9	0.433962	0	1
32	Procurement	2	2	0	0	0	2
34	Cost Control	1	1	0	0	0	1
39	Finance	1	1	0	0	0	1
42	HSSE	1	1	0	0	0	1
43	Noise barriers	1	1	0	0	0	0
44	Construction Phasing & Roads	6	0	6	0.511628	0	2

Table C.3: Complete list of nodes' characteristics in definitive design phase (DO), ranked based on their betweenness centrality from the largest to smallest.

Id	Label	Degree centrality	In-degree centrality	Out-degree centrality	Closness centrality	Betweeness centrality	Modularity class
13	Management Design & Integration	34	17	17	0.636364	216.703864	1
27	Stakeholder & Permits	19	10	9	0.5	125.640476	1
29	Quality & Document Control	12	4	8	0.509091	89.3	1
2	DO Middle	13	10	3	0.4	86.521429	0
1	DO West	15	8	7	0.4375	83.389173	0
5	DO dvm	11	8	3	0.321839	56.642857	0
19	Construction West	13	3	10	0.54902	45.797619	1
42	HSSE	11	4	7	0.56	38.877922	2
35	EPCM	14	5	9	0.56	37.785814	2
4	DO Roads	18	12	6	0.368421	30.22587	0
3	DO East	16	9	7	0.373333	29.999888	0
44	Construction Phasing & Roads	10	2	8	0.56	28.145238	1
17	Construction East	20	3	17	0.608696	26.988893	0
6	DO geo	12	8	4	0.358974	10.90119	0
18	Construction Midle	10	3	7	0.509091	10.07176	1
26	Schedule & Risk	15	3	12	0.608696	7.364566	0
23	Construction Earthworks	6	1	5	0.41791	4.67619	1
38	Contract Management	6	3	3	0.358974	4.407726	1
33	Asset Management	7	6	1	0.252252	2.059524	2
20	Construction DVM	4	3	1	0.252252	1.5	1
14	Site engineering	1	0	1	0.39726	0	1
15	Work preparation	14	14	0	0	0	1
16	Execution	4	4	0	0	0	1
22	Construction Utilities	6	6	0	0	0	0
24	Construction Geo	3	3	0	0	0	0
25	Surveyors	2	1	1	0.39726	0	1
28	V&V processes	2	2	0	0	0	2
30	Veenix Virtual	13	0	13	0.526316	0	1
32	Procurement	10	10	0	0	0	1
34	Cost Control	5	5	0	0	0	2
36	SPCM	2	2	0	0	0	2
37	EPC office	7	0	7	0.491803	0	2
39	Finance	1	1	0	0	0	1
40	HRM	7	0	7	0.491803	0	2
43	Noise barriers	3	3	0	0	0	0

Table C.4: Complete list of nodes' characteristics in execution-ready design phase (UO), ranked based on their betweenness centrality from the largest to smallest.

Id	Label	Degree centrality	In-degree centrality	Out-degree centrality	Closness centrality	Betweeness centrality	Modularity class
13	Management Design & Integration	34	14	20	0.592593	228.105988	1
29	Quality & Document Control	17	6	11	0.542373	176.238095	2
8	UO Middle	11	6	5	0.395062	132.796898	3
27	Stakeholder & Permits	21	9	12	0.477612	70.250216	2
44	Construction Phasing & Roads	15	3	12	0.592593	53.420635	4
19	Construction West	15	4	11	0.551724	50.305375	3
10	UO Roads	14	11	3	0.307692	41.85119	0
17	Construction East	13	4	9	0.450704	40.719048	0
42	HSSE	11	4	7	0.52459	39.639033	1
11	UO dvm	10	7	3	0.313725	37.588889	0
9	UO East	11	6	5	0.251969	35.452056	0
35	EPCM	9	5	4	0.444444	20.13355	1
18	Construction Midle	12	3	9	0.542373	16.844986	1
20	Construction DVM	6	4	2	0.4	10.867857	4
26	Schedule & Risk	16	3	13	0.581818	9.211111	3
12	UO geo	5	4	1	1	7.133333	1
30	Veenix Virtual	12	1	11	0.516129	5.866667	2
38	Contract Management	6	3	3	0.31068	4.873016	3
23	Construction Earthworks	7	1	6	0.438356	4.74127	4
25	Surveyors	7	4	3	0.395062	3.162302	2
33	Asset Management	6	5	1	0.246154	1.325	1
14	Site engineering	3	2	1	1	0.473485	3
7	UO West	5	5	0	0	0	3
15	Work preparation	12	12	0	0	0	3
16	Execution	12	12	0	0	0	2
21	Construction Early works	1	1	0	0	0	0
22	Construction Utilities	5	5	0	0	0	4
24	Construction Geo	3	3	0	0	0	4
28	V&V processes	2	2	0	0	0	0
32	Procurement	8	8	0	0	0	1
34	Cost Control	5	5	0	0	0	1
36	SPCM	2	2	0	0	0	1
37	EPC office	7	0	7	0.465753	0	1
39	Finance	1	1	0	0	0	2
40	HRM	7	0	7	0.465753	0	1
43	Noise barriers	1	1	0	0	0	0

D

Supplementary graphs for the analysis of the results

In this Appendix some supplementary graphs that can provide better insight to the reader regarding the analysis of the results are being presented. These graphs were produced through the analysis of the survey results but did not contribute to the main body. However, they can they can add value to the readers' understanding and thus are being presented under this chapter.

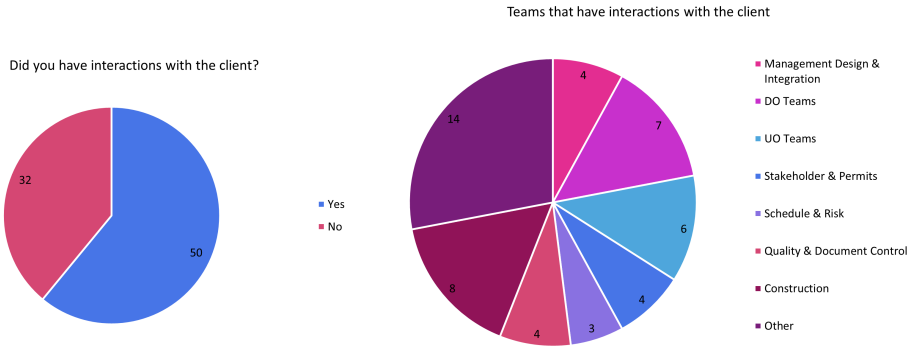

Figure D.1: In the left-hand pie chart, the number of employees that had interactions with the clients VS those who did not is being compared. In the right-hand pie chart there was a categorization between the teams that had interactions with the client.

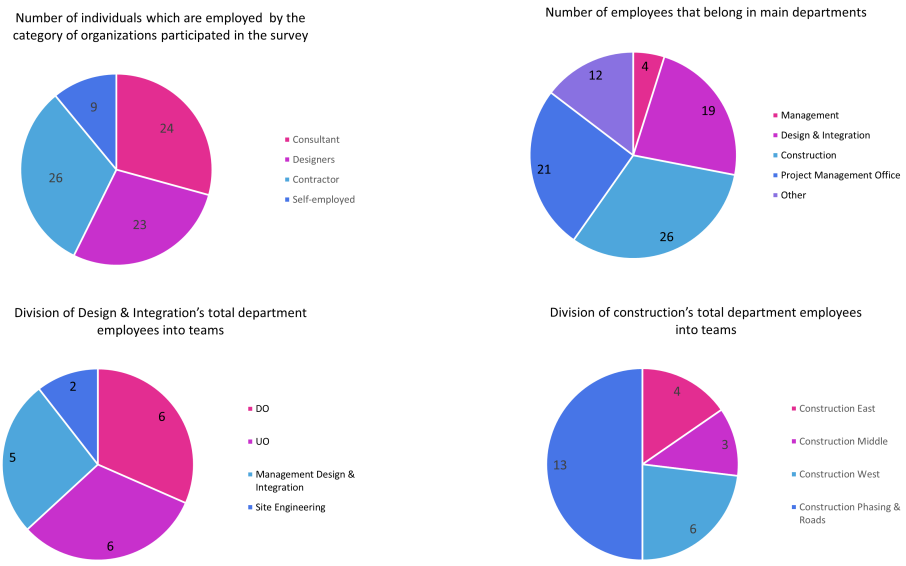

Figure D.2: Demographics concerning the type of the organizations participated in the survey (Upper-left pie chart), the categorization of the most important departments that employees who filled in the survey belong (Upper-right pie chart), division of Design & Integration's total department employees into teams (lower-left pie chart) and division of Construction's total department employees into teams (lower-right pie chart).

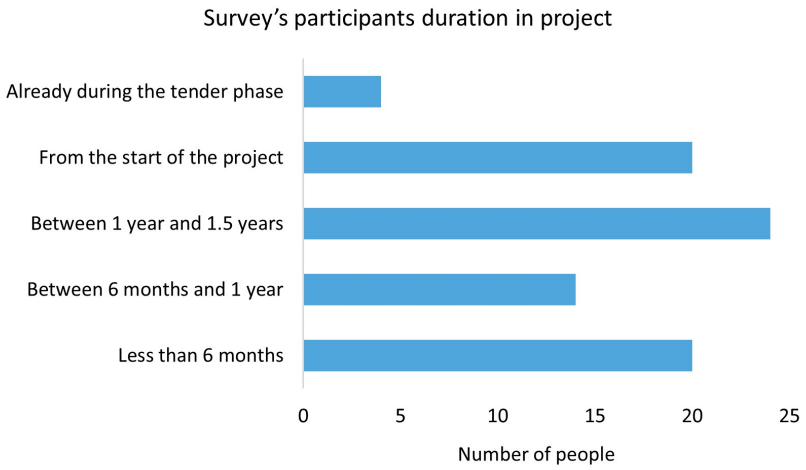

Figure D.3: Survey's participants duration in project.

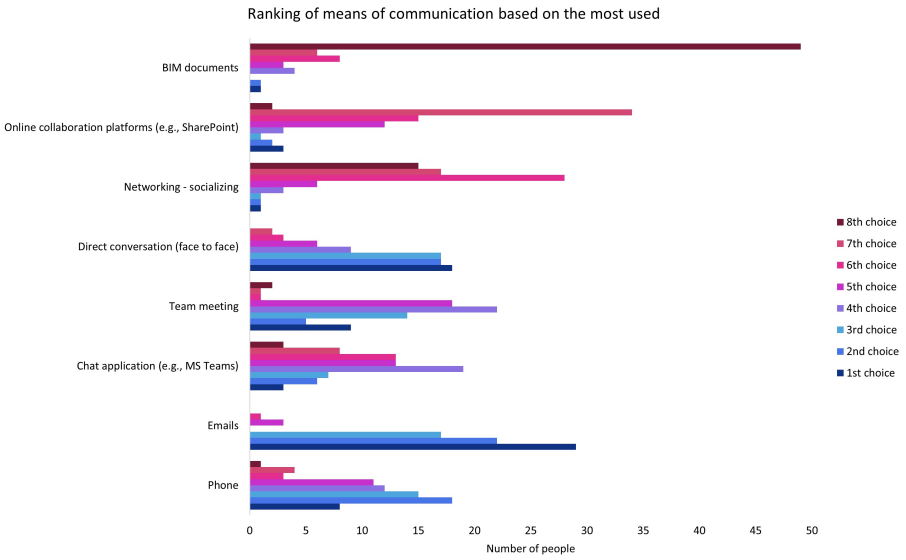

Figure D.4: Ranking of means of communication based on the most used.

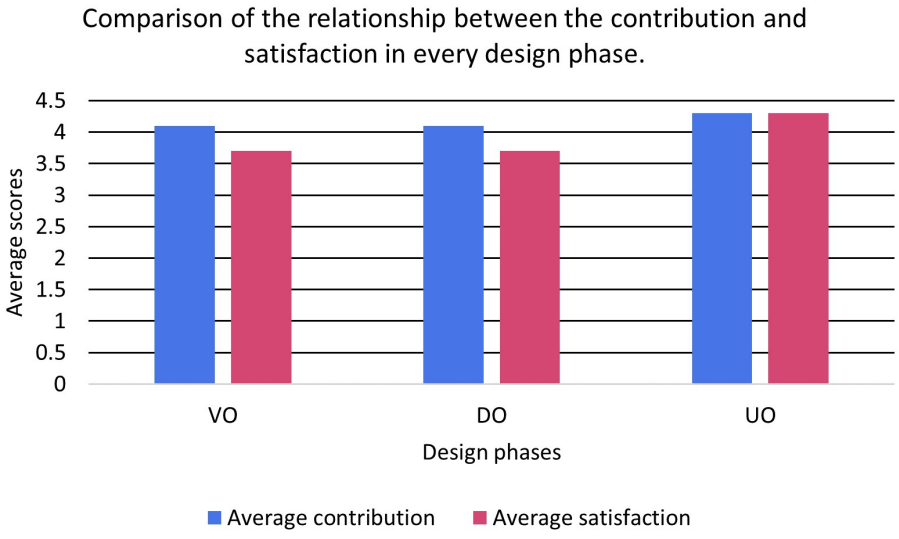

Figure D.5: Comparison of the relationship between contribution and satisfaction in every design phase.

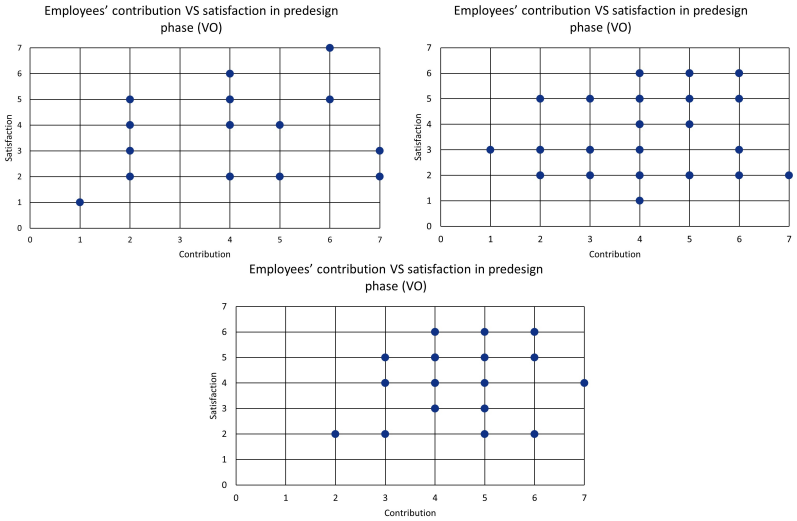

Figure D.6: Comparison of the relationship between contribution and satisfaction in predesign phase (upper-left scatter plot chart). Comparison of the relationship between contribution and satisfaction in definitive design phase (upper-right scatter plot chart). Comparison of the relationship between contribution and satisfaction in execution-ready design phase (lower-middle scatter plot chart).

E

Expert Panel Workshop session - materials used

In this Appendix, the materials used from the researcher during the expert panel workshop session are being presented. First, the researcher presented to the experts the results of his research. The presentation had a rather dynamic character, allowing the participants to engage in discussions while presenting. The researcher however was keeping his personal notes during the discussion as well. In total nine experts were invited to join the expert panel workshop session, but six out of them participated. The roles of those who participated in are presented in Table E.1.

Table E.1: Roles of the experts that participated in the expert panel workshop session

Experts	Role
Expert 1	Construction Lead subsection
Expert 2	Integration Manager subsection
Expert 3	Team lead & Work preparator
Expert 4	Design & Integration Manager
Expert 5	Academy Manager
Expert 6	Construction Manager subsection

M.Sc. Thesis results presentation

Konstantinos Stroumpoulis

TU Delft

Agenda

Introduction
Results – SNA
Results – Survey statistics
Results – Observations
Discussion

TU Delft

Introduction

The main objective of this research was to investigate how information flows during the different phases of the design process in inter-organizational projects by adopting social network theory.

While introducing the research to the organization

- Which departments are involved in each design phase and how does the information flow within these departments
- Does it match the organization chart?
- How did the communication network evolve over time?
- What are the lessons learned that can be implemented in future projects?

Thus, this study aimed to improve understanding of the context of the problem in practice by applying the principles of social network theory. Apart from that, the researcher tested test three hypotheses, based on what he was expecting to find out when he first started this research.

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Testing the validity of the Hypotheses

Hypothesis 1: In predesign phase (VO) interactions are mainly focused between the client and the Architect and organizations are not familiar yet with each other. Thus, it is expected that a lot of interactions between the departments will take place, with the departments that depend on information that is provided by the client to acquire more central positions.
Hypothesis 2: During the phase of definitive design (DO), a lot of decisions should be made for the final design to be delivered. Thus, the communication network is expected to be denser and the department responsible for the management of design and integration to be the most central one.
Hypothesis 3: In the execution-ready design (UO), many activities take place on-site, with suppliers and subcontractors creating their designs that need to be integrated into the overall design for which the main contractor is responsible for its consistency. Thus, construction-related departments are expected to act as link for transferring the information to the rest of the organization.

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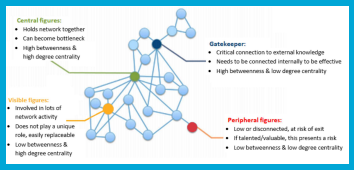
Let us first understand how the positions of the nodes may differ and what metrics will be discussed.

Social Network Analysis

- Network structure
  - Density and average degree
- Tie content
  - Number of connection between nodes
- Actor attributes
  - Degree centrality
  - Closeness centrality
  - Betweenness centrality

Survey statistics



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Explaining the visual elements that will be presented

- **Graph layout:** The nodes with a low number of inputs are pushed to the periphery and the nodes with a high number of links to the centre of the graph.
- **Nodes:** The nodes represent the various teams or departments that are involved in each design phase. The colour of the node indicates the Degree while the size of the node is based on its betweenness centrality. The darkest the colour the more links a node has. The higher the size of the node, the more central it is.
- **Edges:** The edges indicate how information flows between the various departments. Weights have been attributed to them based on the frequency of the information exchange. Thus the thicker the line that connects two nodes is, the more frequent their communication. The input for the frequencies has been determined by the survey's participants. They are defined as follows:
  – Daily: 5
  – Frequently: 4
  – Weekly: 3
  – Infrequently: 2
  – Rarely: 1

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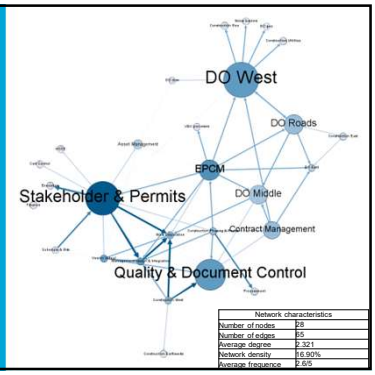
Results – SNA (VO)

Main observations
- A lot of peripheral nodes which lowers the density.
- Stakeholder & Permits and DO West acted as gatekeepers.
- A lot of frequent interactions between stakeholder & permits, Management D&I and Work preparation.
- Cost Control and Schedule & Risk ranked among the least influential teams.

Discussion
- Would you expect other departments having a more central role? (which are them?)
- Would you expect the central teams not to be that central? (which are them?)
- Would you expect the communication between some departments to be stronger?

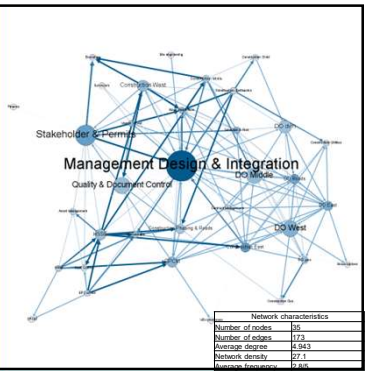


Network characteristics	
Number of nodes	28
Number of edges	65
Average degree	2.321
Network density	16.90%
Average frequence	2.6/5

Results – SNA (DO)

Main observations
- Management D&I by far the most influential node
- No significant gatekeepers and very few peripheral nodes
- Several central figures identified → risk of creating multiple communication bottlenecks.

Discussion
- Would you expect other departments having a more central role? (which are them?)
- Would you expect the central teams not to be that central? (which are them?)
- Would you expect the communication between some departments to be stronger?

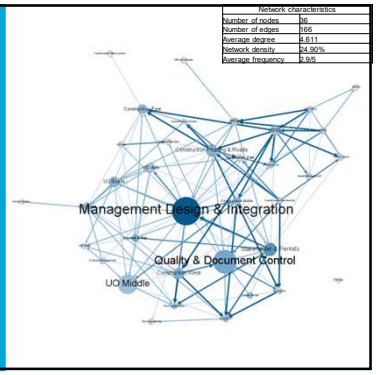


Network characteristics	
Number of nodes	35
Number of edges	173
Average degree	4.943
Network density	27.1
Average frequency	2.8/5

Results – SNA (UO)

Main observations
- Frequent lines of communication between construction-related teams.
- Attention should be paid to the role Execution team played.
- Work preparation had no influence over the flow of information.

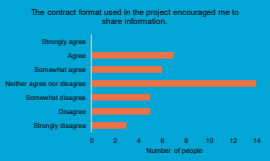
Discussion
- Would you expect other departments having a more central role? (which are them?)
- Would you expect the central teams not to be that central? (which are them?)
- Would you expect the communication between some departments to be stronger?



Network characteristics	
Number of nodes	36
Number of edges	166
Average degree	4.611
Network density	24.90%
Average frequency	2.9/5

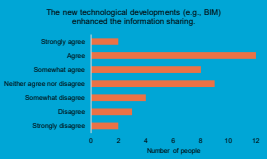
Survey statistics – contract format used

The contract format used did not play an important role in information sharing.

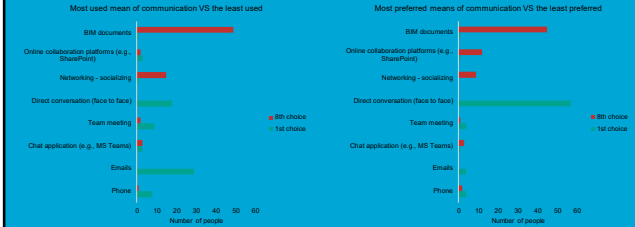


Survey statistics – technological developments

The new technological developments enhanced information sharing.

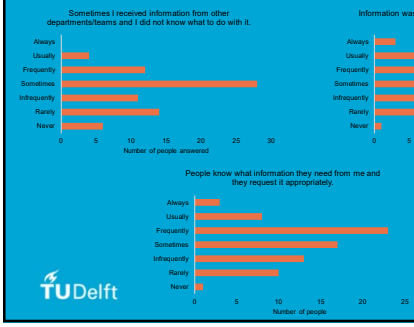


Survey statistics – Used VS Preferred means of communication



BIM documents and other technological developments such as the online collaboration platforms were ranked the lowest, when employees were asked to rank the means of the communication that they used more often and those that they would prefer to use.

Survey statistics – Communication between employees



The problem appears to lie in the way information is communicated among the employees.

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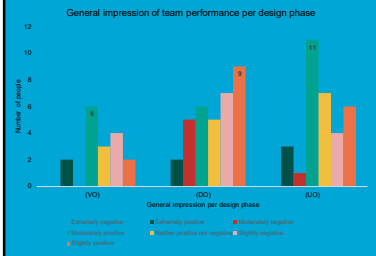
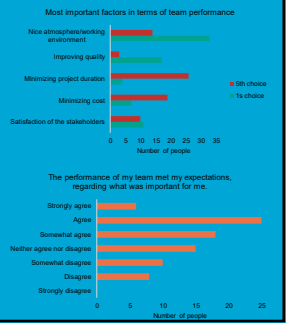
Survey statistics – team performance





In general there is a positive team environment and teams believe they perform well.

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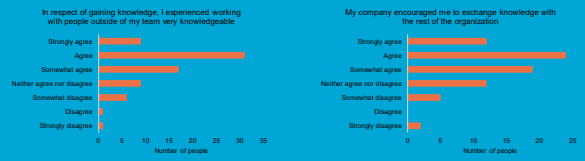
Survey statistics – Knowledge exchange



The organizations encouraged their employees to exchange knowledge and employees feel they gained a lot through knowledge exchange.

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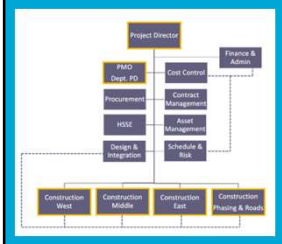
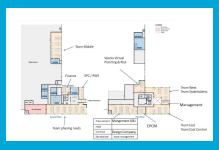
Observations– comparison between OBS – Co-location - SNA





From the OBS:
- Finance, Cost Control and Schedule & Risk
- Design & Integration and Construction sections

From the floor plan:
- Team West and Stakeholder & Permits
- Team East and Cost Control
- Veenix Virtual and Schedule & Risk
- HSSE, Procurement, Asset Management, Contract Management & Management D&I

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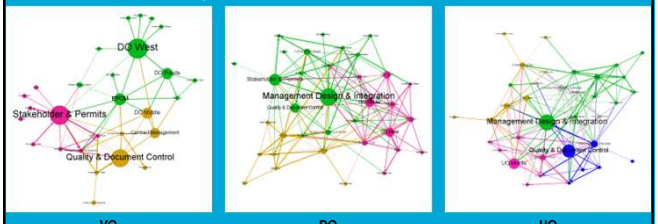
Observations– comparison between OBS – Co-location - SNA



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- predesign phase Veenix Virtual was part of the same community with Schedule & Risk
- execution-ready design phase teams Management Design & Integration, Procuremenet, HSSE and Asset Management were assigned in the same community.

Thank you for your attention

Konstantinos Stroumpoulis

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