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Integrated structural and construction engineering – A study of project team performance in Swedish bridge design

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THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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ABSTRACT

The Swedish Transport Administration (STA) ambitiously strives to increase the level of productivity and innovation within its operations while meeting and surpassing national sustainability objectives. In this effort, the STA has concluded that climate gas emissions from construction, operation, and maintenance of the infrastructure must be reduced for Sweden to maintain its position as a pioneer and to reach both national and global climate goals. Emissions from road, rail, and other civil works is mainly related to the production of construction materials, such as construction steel, concrete and reinforcement in bridges, retaining walls, and other structures. For bridges, normally designed for a long service-life, the environmental impact of all stages after realization is greatly dependent on and constrained by decisions made during design and construction of the structure. To succeed in realizing effectiveness in bridge construction project is only possible by close cooperation between all project participants, i.e. client, consultant(s), and contractor(s).

The construction industry is often described as complex, multidisciplinary, and project-focused but with no clear boundaries of who actually owns processes and, consequently, the development of them. The overall purpose of this research is, therefore, to contribute to framing a systematic and holistic design approach fostering many kinds of project-settings and pre-requisites. This research aims to further understand how to introduce construction knowledge in the early design stages through utilizing an approach with integrated projects teams. The thesis is based on several studies exploring how integration is related to the bridge construction process and the key features are for such integration. Further, this thesis explores the prevailing interprofessional dialogue in the Swedish bridge construction process and how this may both support and hinder knowledge and experience transfer in the interprofessional interface.

Given the complexity in construction today, all participants involved, individually, will lack some pieces of the puzzle, but that collectively, they can gather their knowledge and resources to achieve success for all parties involved. When integration is seen from this perspective, the following key features crystallize; skills to collaborate and communicate; interdependency between the parties; importance for the structural engineer to receive feedback from, and to have a dialogue with, the contractors; teams to be provided with the right people.

The contribution of this thesis is that it provides further knowledge to develop and improve the contemporary approach in the design and construction of bridges.

Keywords: integration in construction, integrated design, collaboration in construction, inter-disciplinary, interprofessional dialogue, integrated project teams, structural design, sustainability, performance, buildability, constructability, bridges, concrete structures, pre-construction indicators, conceptual design, project competence, project culture

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Preface

This thesis is the result of the work carried out from March 2014 until September 2019 at Chalmers University of Technology, Departement of Architecture and Civil Engineering, Division of Structural Engineering, Concrete Structures. The work has been a part of an ongoing collaboration between WSP, Swedish Transportation Administration, and Chalmers in order to enhance the prevailing work in desing and construction of bridges.

First and foremost, I would like to thank my academic supervisors, Mario Plos and Rasmus Rempling. Thank you for your guidance and tremendeous support in my, at times rough and wandering journey towards being a PhD. Magnus Gustafsson, without your unconditional commitment, this would not been possible. A special thanks also to WSP, and especially my closest colleagues and my, since recent, former manager Roland Olsson for supporting me in this opportunity. Peter Simonsson and Mats Karlsson, Trafikverket for both being very supporting and closely attached to the project during all these years. I would like to thank members of the reference group for your support during the first part of this project, including Per-Ola Svahn, Petra Bosch, Peter Harryson, Pontus Bengtson, Kent Gylltoft, and Henrik Franzén.

Also, thanks to Alexandre Mathern, Peter Nilsson, Stefan Uppenberg, Carlos Gil Berrocal, Ignasi Fernandez, and Christina Claeson-Jonsson for both interesting and challenging discussions and collaborations over the years forcing me to challenge status quo. Finally, thanks to all my present and former colleagues at both WSP and Chalmers!

Sara, Meja, and Lova. Finally there! Lets see what comes next!

Nödinge, September 2019

Daniel Ekström

LIST OF PUBLICATIONS

This thesis is based on the work presented in the following papers:

- A. Ekström, D., Rempling, R., Plos, M. (2019): Study of approaches to meet the ends in bridge design and construction – It's time to walk the talk. Submitted to *Structural Engineering International*
- B. Ekström, D., Rempling, R., & Plos, M. (2019). Integrated project team performance in early design stages – performance indicators influencing effectiveness in bridge design. Published in *Architectural Engineering and Design Management*, 15(4), pp. 249–266.
- C. Ekström, D., Rempling, R. (2019): Closing the knowing-doing gap in the feedback loop – A study of experience and knowledge transfer in bridge construction projects. Submitted to *Architectural Engineering and Design Management*
- D. Ekström, D., Rempling, R., Claeson-Jonsson, C. (2019): Predicting project performance using pre-construction performance indicators – a case study evaluation. Published in *Proceedings of 2019 IABSE Congress New York City, The evolving Metropolis*, September 4-6 2019.

ADDITIONAL PUBLICATIONS BY THE AUTHOR

Conference papers:

1. Ekström, D., Rempling, R., Plos, M. (2014): Industrial bridge building- An effective bridge construction process through an integrated design and construction process. Published in *Proceedings of the XXII Nordic Concrete Research Symposium*, (0800-6377). Vol. 2014 (2014), 2, p. 79–82.
2. Ekström, D., Rempling, R., Plos, M. (2015): Industrial bridge construction: Need for a more effective bridge construction process. Published in *Proceedings of the Eighth International Structural Engineering and Construction Conference, Sydney, Australia*, November 23-28, 2015 p. 1115-1120.
3. Ekström, D., Rempling, R., Plos, M. (2019): Integrated project team in early design stages – Key variables influencing cost effectiveness in bridge building. Published in *Proceedings 19th IABSE Congress Stockholm, Challenges in Design and Construction of an Innovative and Sustainable Built Environment*, September 21-23 2016 p.
4. Ekström, D., Al-Ayish, N., Rempling, R., Simonsson, P., Plos, M. (2017): Climate impact optimization in concrete bridges – towards sustainable construction. Published in *Proceedings 39th IABSE Symposium Vancouver, Engineering the future*, September 19-23 2017.

Popular science

1. Ekström, D., Rempling, R., Plos, M. et. al. (2014): Samarbetsprojekt för effektivare brobyggande. Published in Bygg & Teknik (0281-658X). Vol. 2014 (2014), 7, p. 58–61.
2. Al-Ayish, N., Uppenberg, S., Ekström, D. (2018): Reducerat koldioxidutsläpp från betongbroar genom dagens tillgängliga teknik. Published in Husbyggaren 2018, 2108 (1), 15–18.

1 Introduction

As a primary goal, the Swedish Transport Administration, (STA), has concluded that climate gas emissions from construction, operation and maintenance of the infrastructure must be reduced if Sweden should keep the position as a pioneer and to reach both national and global climate goals. This is done by setting long-term requirements for resource efficiency as well as reduction of greenhouse gas emissions from construction, operation and maintenance of infrastructure. To a great extent, the emissions from road and rail and other civil works (WSP, 2013) is related to the production of materials used in construction, such as construction steel, concrete and reinforcement in bridges, retaining walls and other structures. This should be a clear signal to the construction industry to work harder to lower its climate impact and be resource efficient.

In view of national sustainability objectives, the STA, ambitiously strives to increase the level of productivity and innovation within its operations. The construction industry is often described as complex, multidisciplinary, and project-focused and with no clear boundaries of who actually owns processes and, consequently the development of them. The industry is also considered as a one-of-a-kind nature; hence, the industry tends to focus on the uniqueness of projects rather than similarities.

Over the years, since multiple references have highlighted the inefficiencies in the construction process (Latham, 1994; Egan, 1998; Bygghandlingsverket, 2002; Statskontoret, 2010; SOU, 2012), it has become evident that the design and construction process needs to be understood in another way in order to facilitate all the elements essential in delivering a project, such as buildability, sustainability, productivity etc. In construction, sources to inefficiencies are mainly identified to occur in the interaction between different trades. This is also in general related to the self-interest of different parties which makes them put themselves first (Forbes and Ahmed, 2011). The integration of different trades in the construction industry has been the focus of research for several years in order to generate a more effective process (Oakland and Marosszeky, 2006; Larsson et al., 2014). Integration has also been a prioritised area by the STA for much the same reason – meeting the efficiency challenge. Utilisation of industrial thinking is one of the contemplated approaches to meet that challenge. Industrial thinking is an important prerequisite for long-term and continuous productivity and innovation development in the construction industry and should permeate the entire construction process from the early stages to management stages (Harryson, 2008; Simonsson, 2011; Larsson *et al.*, 2014).

However, both practice and research has shown that the transition towards industrial thinking in construction is laborious and requires major changes, not only for suppliers to STA, but also for STA itself as a client organisation (Harryson, 2008; Simonsson, 2008; Larsson *et al.*, 2014). One step in that change, is the transition from being project-oriented to process-oriented in construction. Yet, adopting to a process-orientation means a stronger focus on similarities than differences and also increases the demands on upstream activities. In contrast to the infrastructure sector, the housing sector in Sweden has enjoyed better success in this transition. One part of that success is due to a clear customer positioning, allowing for example housing companies to gain control over a much larger part of the supply chain including all activities from sale to delivery of the finished house (Lessing, 2006; Lidelöv *et al.*, 2015). However, operations within a customer organisation like STA ranges from small, individual bridges in rural areas to major infrastructure changes in heavily urbanised and trafficked areas. This variation

also turns STA into a complicated client requiring construction services and products ranging from a clean sheet design to off-the-shelf products (e.g. Jensen & Larsson, 2013). Consequently, this variation creates a market complicated to niche and this complexity is one of the reasons why industrial initiatives within bridge construction are rare.

Thus, to be successful within the infrastructure sector, in contrast to housing, even greater emphasis needs to put at the process rather than the product. A greater focus on processes, by necessity places greater focus on teams and the collaboration within and between teams.

According to Egan, (1998), both process-orientation and team integration are necessary changes for the construction industry to become more successful. However, simply bringing people together does not necessarily ensure they will function effectively as a team. Effective teamwork does not occur automatically. It may be challenged by various issues, such as lack of organization, misunderstandings, poor communications, and inadequate participation from team members. Therefore, it is crucial for construction project teams to find a solution to help their team members to integrate and work together effectively.

1.1 Research gap

There is plenty of research concerning integration in construction and bridging the gap between design and construction (Latham, 1994; Egan, 1998; Winch, 2003; Simonsson, 2011). Still, there is a predominant amount of research conducted in relation to construction methods and how to create an effective construction process. Less attention is directed towards the structural design process and how this enables construction activities to be more effective. Further, to use integrated project teams and extended collaboration is usually one of the outspoken ingredients for creating that change in the construction industry. Unfortunately, research results have often been rather ambiguous as to what integration in such cases entails, and how integration ultimately affects the individual during the design process. Suggesting increased teamwork and multidisciplinary/ interprofessional collaboration is likely to point out the right direction for this industry to go, but what does it mean to work integrally and together, and in a close relationship between contractors, designers, and clients? What are the opportunities and tools available to use at lower organizational levels to make things happen? In the end, it is finally what is done on the "floor" which often determines the benefit of the change.

1.2 Scope

The research primarily departs from the prevailing situation in Sweden, although the work is internationally relevant. For this research the design and construction process were identified to consist of three major stages, pre-construction, construction and post-construction. The focus of this research is from a structural design perspective in the pre-construction stage and how activities undertaken during this stage best facilitates both the construction and post-construction stages. Moreover, the project further delineated its focus on short- and medium-span road bridges.

1.3 Purpose and research questions

The overall purpose of this research is to contribute to the ambitious task of framing a systematic and holistic design approach which can foster many kinds of project-settings and pre-requisites. Through the adoption of a design approach more oriented towards construction procedures, it is more likely to establish the progress that the construction industry needs. Supporting that purpose, this research explores and aims to further understand how to introduce construction knowledge in the early design stages while utilizing an approach of integrated projects teams.

In an overall perspective and by the conducted research, there is an ambition to contribute to the development from the contemporary approach in design and construction of bridges. The research is intended to contribute to a push towards a change in both attitudes and ways of working in the bridge construction process. That includes a change towards a more enhanced use of industrialized thinking in the design and construction of bridges and an improved productivity and value added in investments.

The following research questions support fulfilling the above stated purpose:

RQ1: What is integration, and what are its key features in relation to the bridge construction process?

The first research question aims to define integration in the bridge construction process and what are the key features for integration

RQ2: What defines the interprofessional dialogue bridge construction process and how can it support the introduction of construction knowledge during early design?

The second research question aims to define the interprofessional dialogue in the bridge construction process and how this can support knowledge and experience transfer in the interprofessional interface.

1.4 Limitations

As previously highlighted, the pre-construction stages are vital for how to undertake construction and in many cases for the entire service life for a structure. The focus on integration is therefore placed on the pre-construction and early design stages. A comprehensive and exploratory approach has been adopted to this project, leaving the author with much freedom when choosing the direction. Despite that, a natural limitation is the adapted perspective from a structural engineer and how structural engineering and design issues are both effected and how this effect the integration of design and construction process.

Some limitations identified for the project are the following:

Even though, a large amount of international literature is studied, the perspective of the study is primarily focused at the current and future situation in Sweden. This is the market the research first and foremost aims to influence. Still, we claim this work to be applicable within an international perspective as well since the major part of the developed countries faces the same issues or problems, even though in different cultural contexts.

Despite the effort to strengthen knowledge concerning the integrated project team, no sub-study was conducted at a construction site, or towards a specific ongoing

construction project. There is also a reason for that. Although it is of greatest importance for researchers to have both knowledge and understanding concerning construction in general as well as construction work procedures, this research sought for a shift towards earlier stages, i.e. greater degree of upstream involvement from downstream actors.

Further, when doing research, it is easy to get caught in the “bubble” and focusing so hard at the specific task that there is a risk of missing what is happening in “the real world”. For me, being an active bridge designer, it is easy to see and follow the developments from "my" angle, but I am still quite limited to insight when it comes to the developments within contractor companies. Nevertheless, focus for this research has been to study how the working methods during design can be improved, and of course I have had a clear advantage from following my colleagues and the development at close range during all the years that this research has progressed.

2 Method

In this chapter the research is briefly described, and the methods used for carrying out the research are discussed. The discussion starts with a justification for the choice of overall research approach, followed by the choice of more specific methods.

2.1 Research design and process

Understanding how integration is understood, perceived, and how it might work better has involved a long explorative journey. There was an early understanding that progress required a much broader perspective than normally adopted within our research group. Addressing the issue with a new set of eyes, or at least with a set of eyes normally trained to see other things, required that we as researchers stepped back and raise your eyes.

It would have been perfect if this chapter described a neat research plan and how this plan was followed while ticking the boxes as the research progressed. Still, there is no point in pretending, nor trying to present some sort post-fact rationalisation. That perfect plan did not exist, our research design could not be compared with having a blueprint in your hand as described by Bryman, (2006) rather a clean sheet. The adopted approach is more similar to active design. We dug a hole and saw what we found and made a decision based on that. This approach made the journey quite arduous, with some extra holes being dug along the road. Yet, we have been determined not to follow the already trodden pathway since it has led to the current incomplete understanding of integration in the construction industry.

We have deliberately along the journey tried to keep what we study at such a generalized level as possible. By that we mean that most research done in the area study the behaviours under specific circumstances, instead we tried to lift the respondents outside the project-specific context and instead let them give us their general/overall view/opinion. This approach is still in line with a case study approach, yet the context is moved to the individual. This approach is not without problems or difficulties and challenges the researcher to interpret the responses from the context from where it originated.

The performed work for this research followed four subsequent steps presented in Figure 1 in order to establish a theoretical foundation for integration in construction as well as to establish an understanding of how to view and approach integration at the level of the individual engineer. The four steps are further explained in Section 2.2.

As a start we needed to gain a broad and general understanding of both the field of research and industry practice. The first milestone was to establish a clear focus and to understand in what direction the project should be directed and therefore aimed at a comprehensive literature review. At this stage, to use a qualitative approach is then a good start, since qualitative research is not based on a unified theoretical and methodological concept. Instead, a subjective viewpoints are a good first starting point (Flick, 2014). So, the purpose for a literature review as method, was primarily to generate a distinct understanding of the field and narrowing the area to be studied.

Adopting to an explorative approach towards existing literature and interpreting it based on many years of experience from the bridge sector allowed us to obtain a deeper knowledge of underlying root causes for the prevailing problems the construction

industry is experiencing. Further, the review created a picture of common approaches claimed to enhance and/or improve the construction industry.

From the results of the analysis in Paper A, three subsequent studies were conducted and presented in Paper B, C and D. The progression of the research is schematically displayed in Figure 1.

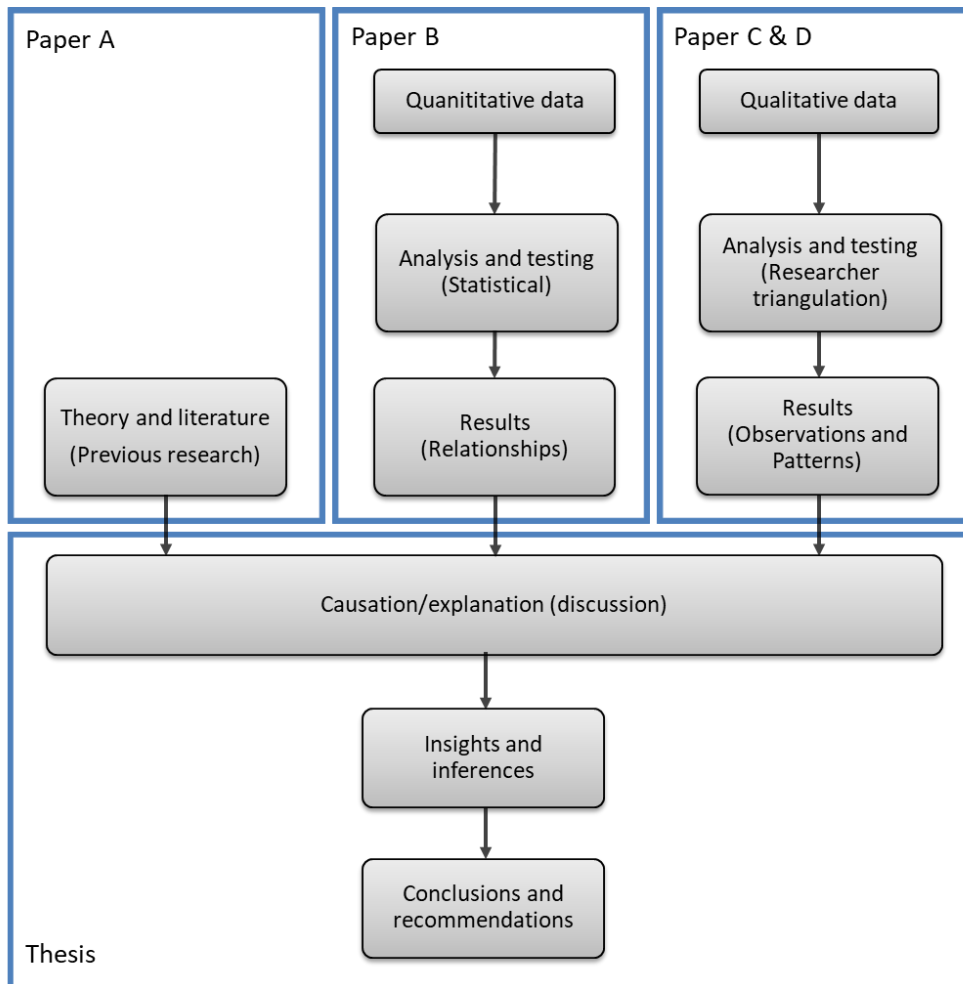


Figure 1: Model to use to inspire our research design. Modified from (Fellows & Liu, 2015)

Qualitative and quantitative research approach

For the project, a long term research study was used (Bryman, 2006; Bryman & Bell, 2011). First and foremost, the primary data gathered was of qualitative nature but for one of the four reported studies quantitative data was gathered. Thus, this thesis draws on data collected with several different methods. Jick, (1983) states that “*Qualitative and quantitative methods should be viewed as complementary rather than rival camps*”, in (Flick, 2014). So, both a qualitative and quantitative approach was used for this thesis. However, the main principal approach has been gathering qualitative data. To use mixed approaches is supported in the contemporary literature on research methods e.g. (Bryman & Bell, 2011; Flick, 2014), where it is stated that research may include both qualitative and quantitative approaches in different phases of the process. The suggestion is to use qualitative research for developing hypotheses, which afterwards

will be tested with quantitative approaches and vice versa (see e.g. Bryman & Bell, 2011).

Available approaches in research are normally related into two main approaches, qualitative and quantitative, but also the use of a mixed approach of the two formers are more frequently addressed as a third separate approach (Bryman & Bell, 2011). There are some basic differences separating the approaches, which at the simplest level can be explained by saying that a quantitative approach aims to transform information into numbers, diagrams and tables, in contrast to a qualitative approach where the researcher's own interpretations of the information are in focus but cannot be transformed into numbers and instead concerns words, behaviours etc. Yet, it is important that the choice between different approaches are based upon the purpose of the study and the most suitable approach for achieving the specific goal of the research. For example, Yin, (2014) lists five major research methods to gather data in research (*experiments, surveys, archival analyses, histories and case studies*) and the choice of method depends on three conditions: *the type of research questions posed, the extent of control the researcher has over actual behavioural events, and the degree of focus on contemporary events*.

How to conduct data analysis is the part of qualitative research that most distinctively differentiates from quantitative research approaches. Quantitative research mainly relies on statistical methods, in contrast to qualitative research which focuses on the exploration of beliefs, understanding, opinions and views of the phenomenon (group or individual e.g.) under investigation (Fellows and Liu, 2015). There exists a wide variety of data collecting methods and qualitative research often contains unstructured text-based data. The most commonly methods for gathering data in qualitative research denoted in literature are; observations, interviews, and documents (see e.g. Bryman & Bell, 2011; Flick, 2014; Fellows and Liu, 2015), and the type of research ultimately determines which is most suitable. Although, and most importantly, qualitative research relies on the interaction with the field and the individuals being studied (Flick, 2014) and instead of primarily being a technical exercise as in quantitative research, qualitative research adopts a more dynamic, intuitive and creative process of inductive reasoning, thinking, and theorising (Basit, 2003).

The process of analysing qualitative data predominantly involves coding or categorising the data. Basically, it involves making sense of huge amounts of data by reducing the volume of raw information, followed by identifying significant patterns, drawing meaning from data and subsequently constructing a logical chain of evidence (Patton, 2002; Graneheim & Lundman, 2004). Coding or categorising the data is the most important stage in the qualitative data analysis process. Coding and data analysis are not synonymous, though coding is a crucial aspect of the qualitative data analysis process. Coding merely involves subdividing the huge amount of raw information or data, and subsequently assigning them into categories (Graneheim and Lundman, 2004; Maguire & Delahunt, 2017; Nowell *et al.*, 2017). In simple terms, codes are tags or labels for allocating identified themes or topics from the data compiled in the study.

2.2 Research approaches

Despite the choice of approaches for any research project, they are all associated with both strengths and weaknesses. Thus, it is important for the researcher to gain knowledge of the associated strengths and weaknesses for the selected approach for collecting data and how it further affects the analysis of the data (Fellows & Liu, 2015). Furthermore, the researchers' pre-knowledge and the researchers' view upon the

subject affects the progression of research process. This effect is especially critical for qualitative research where the researcher's subjectivity, and of those being studied, become a part of the research process (see e.g. Bryman & Bell, 2011; Flick, 2014).

The following sections describe different research approaches and data gathering methods used for this research and are presented separately for each appended paper. In accordance with literature, the research questions governed the choice of method. Thus, each method is described in relation to the literature, as well as in terms of how research was conducted and what measures were taken to increase trustworthiness of the results. Further, a reasoning of how and in what way the specific results could be generalised.

Literature review, Paper A

The objective of the comprehensive literature review was to identify the common foundation for the suggested improvements of design and construction. Due to the variety and diversity in the identified approaches, there is a need for clarification in the field to be able to adopt changes. From the identified concepts, it is possible to provide a framework for the progression to the use of industrialized processes in construction. Different approaches used to generate productivity improvements in the construction industry are presented, evaluated and compared. The reasoning in the paper sheds light to the common features of the approaches and that they necessarily do not exclude each other.

The literature review conducted for paper A aimed to identify some of the distinctive theories/concepts described in literature to transform construction. Over the years, many clients and construction organizations have adopted new approaches at a strategical level, but what this means and how this affects the everyday activities at an operational level is still unclear in the industry. After these key theories/concepts had been identified and investigated, they were further categorized and compared regarding their similarities and dissimilarities. Both Swedish and international construction research was studied, yet with a perspective from the challenges and implications for the Swedish context.

To increase the utilization of industrial processes in construction and to adopt an integrated design approach has, in some way, been a predetermined direction for the Swedish bridge construction industry as a result of both academic and governmental reports (Bygghuset, 2002; SOU, 2012; Larsson *et al.*, 2014). Although this roadmap, or transition pathway, was already "established" by many years of research in the field, where or how to walk was still somewhat vague. The roadmap was still drawn on a relatively high strategic level. Since this research intended to focus on the interface between two key disciplines in bridge construction, structural engineering and construction engineering, reasoning for the qualitative approach in paper A was to broaden the perspective and to establish further direction for the research.

The conducted review was therefore of an exploratory character and explored a large amount of existing research literature and the observation of previous studies describing the multifaceted problem to generate a more effective bridge construction process. The literature was chosen based on the preconception that integration of disciplines and a collaborative working environment enhances project success. For the review, a multi-step procedure was employed beginning with an initial review of interesting views and aspects in relation to the development of the construction process followed by a more in-depth exploratory review, see Figure 2. Based on the initial review and the level at

which results were presented in the literature, we observed that all the efforts made to generate necessary change within the construction industry were very similar yet claimed to be different.

The continued and a more focused exploration of the literature was conducted at three levels. The first step established what the core principles are within each concept and where they originate from. The second step describes the approach towards integration and the distribution of responsibilities to create such an integration. The third and final step defines similarities and dissimilarities between the different concepts and links pre-construction and construction activities.

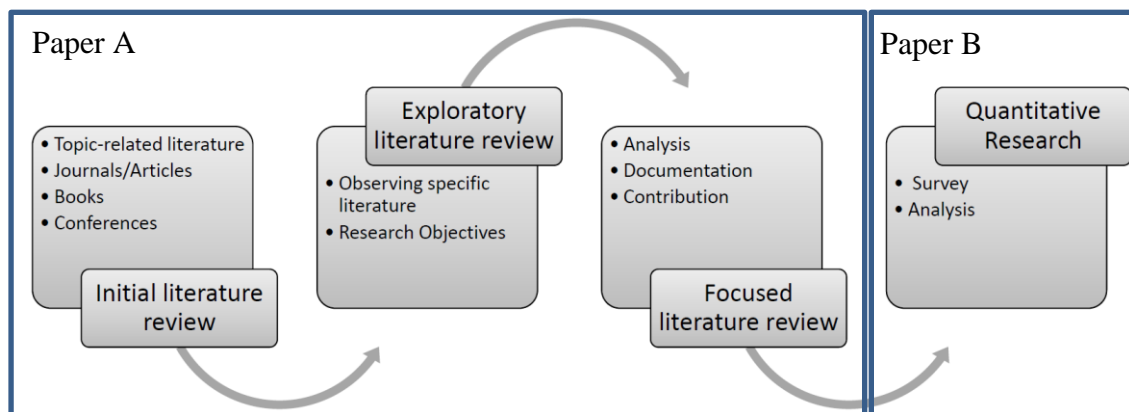


Figure 2: The subsequent stages of the conducted research (for paper A and B).

The research in paper A, aimed to establish a comprehensive, although far from complete, review of literature concerning proposed approaches and concepts to develop the construction process. The review included important research and development of project delivery, design teams, and the industrialisation of construction. Further, the literature review also established the foundation for the questionnaire study performed in paper B.

Literature reviews for the other studies are presented in each of the appended papers.

Survey, Paper B

For the survey for paper B, data was collected through a questionnaire. The study originated from the basic point to understand the different construction project participants and their perception of project performance. The objective for this second step was to identify a framework and areas of improvement in terms of generating effectiveness within Swedish bridge design teams. Using the framework supported an assessment of a part of construction sector and in order to generate an overall view of how collaboration and communication are used in the prevailing way of work and thus, giving an indication of where to address the main efforts of improvements.

The area of project team performance is complex and multi-faceted and what areas in it to approach needed to be further specified. The reason for choosing a questionnaire was based on the possibility to create such a priority between different aspects within project team performance. For the study, a framework was developed by combining previously established theoretical references (Josephson & Björkman, 2011; Rempling, Fall & Lundgren, 2015), and to pre-define nine different indicators, see Figure 3, to support that prioritizing.

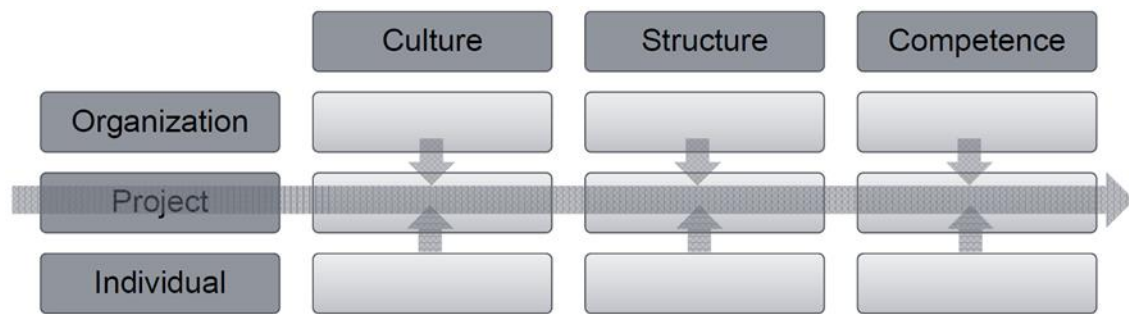


Figure 3: Survey evaluation matrix for Paper B

The questions used for the questionnaire were developed informed by a self-assessment questionnaire, e.g. (Wheelan, 2016). Such questionnaires are proposed by several team literature authors (Mickan & Rodger, 2000; Wheelan, 2009; Salas *et al.*, 2017) to provide aid to identify how to develop a group of individuals into high performance teams (HPT). In this study, the questions support the examination of how the collaboration between different disciplines works during the planning, design, and development of construction documents for new bridges in Sweden. The questions were sorted and organised into the three different levels of organisational hierarchy: organisation, project, and individual. Furthermore, the questions were also arranged according to the driving forces for customer value: culture, structure, and competence, see Figure 3.

The survey questions were originally formulated by the author; thereafter they were discussed, modified and rephrased within the reference group for the Ph.D project.

2.2.1.1 Data collection

The respondents were presented with 45 statements and were asked to answer to what extent the statement agreed with their way of working (*performance*) and to what extent this was important for the degree of project success (*importance*). Each statement was measured on a 5-point Likert scale, see e.g. (Bryman & Cramer, 2011), where 5 represents a high degree of conformity and 1 no conformity. By adopting a Likert scale to the responses it is possible to assign a numerical value to something that is a subjective opinion (Bryman & Cramer, 2011). In addition, for each statement the respondent was given the opportunity to add additional text to support their answers.

The respondents were given a short-written introduction to the aim and scope of the survey. The introduction was given to support coherence amongst the respondents regarding a target case, which they were asked to relate their responses to.

The survey was administrated to clients, contractors, and structural engineering consultants in the Swedish bridge construction industry, and distributed electronically. A total of 134 persons completed the survey. Besides the major client, STA, the respondents represented some of the largest construction and consultancy firms in Sweden. Of the 134 survey respondents there were 20 representing the client, 52 a contractor, and 62 a consultant.

2.2.1.2 Importance Performance Analysis

The Importance-Performance Analysis (IPA) model was initially presented and introduced by Martilla and James (1977) with the intention of providing a simple and graphical tool for the development of business marketing strategies (Abalo *et al.*, 2007). Combining the importance and performance measures allows for the IPA to be presented as a grid divided into four quadrants that offer a visual understanding of

overall user satisfaction (Bruyere *et al.*, 2002). The four quadrants are normally interpreted as “keep up the good work”, “concentrate here”, “low priority” and “possible overkill”. Here, the importance measure is represented on the vertical axis, and the performance measure at the horizontal axis of a two-dimensional graph.

IPA is a popular and widely spread method used in many different fields, both in academia and practice. The health care and tourism industries are the most frequent users, but the method is well documented also in the field of construction management (Albaloushi & Skitmore, 2008; Eom & Paek, 2009; Eom *et al.*, 2009; Chang *et al.*, 2017). Similar approaches also exist, for example in (Jergeas & Put, 2001) to evaluate potential benefit and the effectiveness of applying constructability principles in the Canadian construction industry. Also, (Al Mousli & El-Sayegh, 2016) assess the design-construction interface problems in the United Arab Emirates construction industry.

In IPA literature there is limited empirical evidence to support which of the derived and direct importance approaches performs best in assessing the relative importance in IPA application. The value of using IPA is to evaluate relative importance and performance scores (Martilla & James, 1977). To use an absolute evaluation significantly limits the discriminatory and predictive power of stated importance measures (Azzopardi & Nash, 2013). The analysis used here follows the procedure proposed for the traditional Importance-Performance Analysis (IPA) together with the Gap 1 analysis, described by (Feng *et al.*, 2014).

2.2.1.3 Survey analysis

Five statements are presented within every area leaving the range of score in each block between 5-25, and the total score for each organisational level in the range of 15-75, see Figure 4. In the analysis, it is possible to generate a mean value for each indicator leaving the final total score for each organisational level on a range of 5-15. By using this kind of multiple-item scale it is more likely that the generated responses give a broader view of the concept measured. This also makes it possible to draw finer distinctions between the different indicators and also minimize the error from questions being misunderstood (Bryman & Cramer, 2011).

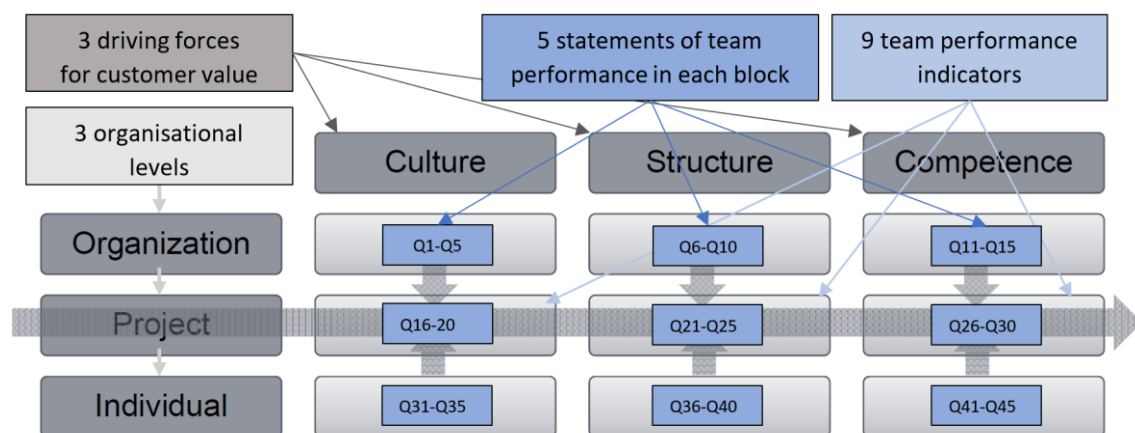


Figure 4: Survey evaluation matrix, explanation.

Research has established that from the characteristics of a team it is possible to determine a team's development level, and further a relationship between a team's level of development and its performance. The concept of team development has over the years been well documented and multiple authors have established theories in the field

of team formation and its performance (Tuckman, 1965; MacMillan, 2001; Wheelan, 2009). Teams functioning at the higher stages of development are found to be more productive (Wheelan, 2009, 2016). Scoring high on performance in the evaluation would indicate a highly mature and effective group, a so called high performance team (Wheelan, 2016). Wheelan, (2009, 2014) divides her integrated model of group development into four stages described as, (1) dependency and inclusion, (2) counter-dependency and fight, (3) trust and structure, and (4) work, a stage of intense productivity and effectiveness. In addition to determining performance, the respondents were asked to evaluate the importance of each statement regarding project success.

Interviews, Paper C

For paper C, qualitative interview methodology (Kvale & Brinkmann, 2014) was applied in order to explore how industry professionals, within the Swedish bridge construction industry, perceive knowledge and experience feedback as well as their abilities to collaborate and to share information and knowledge. The study explores how these actions are perceived both within the professional's own organisation as well as in relation to other interorganisational team members. The study was conducted with representatives from some of the largest construction and consultancy companies in the Nordic EU-countries. The interviewees were geographically spread over Sweden, but the most of them were conducted in the Gothenburg or Stockholm areas.

All interviews have been based on a semi-structured interview guide that constitutes a checklist of issues to discuss. This means that the interview was not constrained by any specific script or time limit. Although the interview guide acted as a structure for the interaction, the discussion was allowed to evolve as appropriate for the participant. In total, 17 interviews were conducted with personnel representing a client's organisations (2), contractors (6) as well as structural engineers (9). The interviews were conducted in the form of conversations that lasted between 55 and 105 minutes and all took place at the participants' places of work.

All interviews were recorded and transcribed. Notes were kept during the interview and used as a support to debrief each interview. The interviews are not completely comprehensive, or representative for the Swedish bridge construction industry in general but highlight several issues sufficiently that are generic and therefore not only of interest for the individual case. Anonymity was guaranteed to the participants to encourage as much frankness as possible during the interview.

2.2.1.4 Selection

The chosen participants were originally identified through a selection of individuals who previously completed a questionnaire survey (Ekström *et al.*, 2019). A purposeful sampling (Bryman & Bell, 2011; Flick, 2014) was made for the study to get as wide and accurate description as possible of the phenomenon to be studied. Selected persons have both different roles in their professions as well as a breadth of experience to ensure a sufficient variation of perspectives on the phenomenon discussed. A common factor amongst the chosen individuals is that they are all individuals expected to have a lot to say about the area to be described.

Determining the size of the sample in a qualitative study is not entirely self-evident, and the starting point is to continue to interview people until no more new comments appear (Kvale & Brinkmann, 2014). Numerically determining the degree of saturation is usually not necessary, nor is the selection aimed at statistical generalisability. Instead,

the number of interviews is considered to be sufficient when data saturation is achieved and verified.

2.2.1.5 Analysis

Qualitative content analysis is a method to stepwise analyse written or verbal communication while focusing on differences and similarities. There was no predetermined theory being investigated in the interviews, but rather the responses were examined for key points. The interpretation process results in one or several themes. A theme acts as a common thread which runs through each meaning-unit, code and category (Graneheim & Lundman, 2004).

The first step in the analysis is to generate an understanding and overall view over the collected material. Each interview is therefore listened to after it was finished, and then transcribed. All interviews were transcribed by the authors, and the interviews were imported to a qualitative analysis program and broken down into meaning-units in accordance with content analysis (Graneheim & Lundman, 2004; Maguire & Delahunt, 2017; Nowell *et al.*, 2017). These units are then further condensed into shorter sentences and finally concluded into a code describing the content of that meaning-unit. Codes with similar content are grouped into subthemes and further, the subthemes finally are grouped into larger parent themes which constitutes the final observations (Graneheim & Lundman, 2004).

An additional and important step in the process also includes sorting and excluding material outside the themes in the interview guide and that are not relevant for the study. The remaining text constitutes the analysis unit. In this study, main categories were formed by the codes formed by our transcription material. A number of subcategories were also created, which gave rise to subheadings in the study result. The participants were numbered in the transcribed material with numbers 1-17 to distinguish them during processing of the data.

Case study - Document analysis, Paper D

For paper D, a retrospective document analysis (Flick, 2014) was conducted. The reason was to explore the interprofessional dialogue within the structural design team and how industry professionals use their abilities to collaborate and share information and knowledge, both within their own organization and to other interorganizational team members. The case for this study was chosen with the preconception to be a generally considered successful project, including the perspective of the client, contractor, as well as the structural design engineer.

The documents are notes of meetings and have therefore been reviewed and edited in accordance with common meeting documentation procedure. The meeting notes have been documented by the engineering office for the purpose of recording decisions and responsibilities as a project management tool. Consequently, a series of design meetings was arranged parallel to the original plan. Each meeting was documented including information concerning date; place; participants and affiliation; task and associated responsibility. All known protocols concerning the re-design were gathered and stored in a case study database (Flick, 2014). The targeted audience is the project members as well as the mother organizations of the client, contractor, and engineering office.

The analysis approach for the project meeting documentation was made as a qualitative content analysis (Kvale & Brinkmann, 2014). Qualitative content analysis is a method to stepwise analyse written or verbal communication while focusing on differences and similarities. The interpretation process results in one or several themes. A theme acts

as a common thread which runs through each meaning-unit, code and category (Graneheim & Lundman, 2004).

The qualitative data consists of 17 documents. Initial codes were generated deductively based on our prior research, the conceptual framework of integrated design, and our field expertise. Codes were first fit into a pre-existing coding framework of the main theme as meaning units. The coding was then refined through interpreting the meaning units and condensing them into to provide a detailed analysis of aspects of the data. Codes with similar content were subsequently then grouped into sub-themes (Graneheim & Lundman, 2004).

The following step in the process required researcher triangulation (Anney, 2014). The triangulation included separate coding by a group of researchers. First, a group of two researchers performed a preliminary coding of the documents by coding for theoretical and reflective units as well as additional potential codes and themes. Secondly, a third researcher coded the content identified as interesting in the coding structure of the themes. After the research triangulation, a review of the generated codes and themes were done, and the coded material was checked for referential adequacy by returning to the meaning unit. The names of themes were discussed as well as the sub-theme structure. Following this coding methodology (Nowell *et al.*, 2017) we strove for trustworthiness and credibility in approach and interpretation.

2.3 Validity and reliability

During the research process, several methods were used to collect data. The overall validation₂ was obtained using multiple sources of evidence, collected by the multiple data collection techniques, e.g., document analysis, questionnaires, interviews and case studies.

Using questionnaires leaves the researcher with somewhat limited control over the environment, thus leaving the validity of the results dependent on how the respondents understand the questions as well as their honesty. The objectivity of the results from a questionnaire may consequently be questioned. A five-point Likert-scale was chosen for the questionnaire, but a larger spread from using seven-point scale might have provided more information due to the larger response range. A seven-point scale would also probably have yielded a wider span in the collected data. Further, when using questionnaires there is always a possibility that some respondents do not understand the questions properly and instead answer the questions arbitrarily. However, a reference group conducted a pilot to pre- test both for the comprehensibility of the questions as well as the applicability of the actual data collection.

Any interview situation is by nature exposed to the influence of the researcher, as it is impossible for the researcher to be completely objective. To establish validity to the findings, excerpt from the interviews were include in the article. Also, to determine the size of the sample in a qualitative study is not entirely self-evident, and there is a risk that the numbers of interviews are too few to be fully representative.

Purposeful sampling (Bryman & Bell, 2011; Flick, 2014) was chosen for the study to get as wide and accurate description as possible of the phenomenon to be studied. Selected professionals have both different roles in their professions as well as a breadth of experience to ensure a wide spread of angles towards the phenomenon. Still a sampling describes the process of selecting a sample of elements from a target population to conduct a survey (Kvale & Brinkmann, 2014). All sampling is related to random errors. If all the people within the population of interest are not interviewed,

the selection will differ slightly from the actual population. The more people interviewed, the less this difference will be, but the problem can never be avoided altogether. For any specific single selection, it is not possible to know whether the random errors caused an underestimation or overestimation. Further, an interview is by nature exposed to the influence from the researcher, as it is impossible for the researcher to be completely objective. All interviews were semi- structured interviews, and the respondents were given the opportunity to verify the correctness of the interview transcripts used in the paper.

2.4 Researcher's pre-knowledge

There are numerous points where the researcher's own bias can affect the course of the research process. There is a growing recognition that it is impossible for a researcher to be completely objective and keep the research process unaffected by the researcher's own values. Bryman & Bell, (2011) list eight possible points of researcher value intrusion in the process: *choice of research area; formulation of research question; choice of method; formulation of research design and data collection techniques; implementation of data collection; analysis of data; interpretation of data; and conclusion*. Further, the researcher's prior knowledge, experience and attitude will highly affect the research process since this will influence how the researcher, not only see things, but also what the researcher sees. To minimize researcher bias, the research was conducted by adopting a thorough and systematic approach as described in previous section.

3 Frame of reference

The theoretical framework used in this thesis will begin by explaining the notions of the structural design and construction process and how this is interpreted in the research. Continuing with involved roles and finally a brief overview of integration as perceived in construction. Integration as such is perceived as very important in the transition towards a more effective and sustainable construction process. In short, integration is required to meet the increased complexity of the task of managing productivity, cost, resource efficiency, sustainability etc. Today, even the smallest projects that include only simple and single bridges are complex in their entirety when it comes to optimization based on an increased degree of resource efficiency, including both time, cost and materials.

3.1 The structural design and construction planning process

The (building and) construction industry is usually divided into different sectors or segments. It is usually categorised by sector, such as residential, commercial, institutional, or public works and infrastructure. Further, you may also classify by the involved professions or activities, such as construction, consulting, materials and equipment supplier or manufacturer, owners and operators, etc. While the construction process has evolved over the years and increased in complexity, also the separation of the design and construction roles has increased under the traditional form of construction procurement (e.g. Puddicombe, 1997). As a result the construction industry has by tradition been, and still is, exposed to fragmentation between its stages together with a relational short-term perspective (Anumba *et al.*, 2002).

Thus, the process of construction can be viewed as an arena for collaboration between numerous of suppliers all from early design stages up until completion of construction. The nature of construction requires interaction among several different parties or professions and progress is achieved by involved participants by continuous negotiations. Still this is a process not clearly owned by any part and these negotiations are predominantly done with each individual product at focus, not project success. The process itself looks more incidental, but none the less, this is the process which determine the key outcome (Oakland and Marosszeky, 2006).

Further, bridge construction and bridge categories involve a large number of different structures, ranging from small steel-and-soil composite bridges to mega structures spanning barriers never thought to be bridged. In the everyday light, the large mega structures usually get all the attention, but most bridges are relatively small and modest. For most bridges, still necessary to bridge smaller obstacles, they are just a small part of a much longer piece of road and need to be designed accordingly. Consequently, where to place the bridge, possible location for supports, available space for traffic etc. are limitations that naturally encapsulate bridge construction projects.

Construction is also a project-based industry and due to the already mentioned fragmentation, there are also exists several sources of waste and values loss. During construction, the obvious value is generated while producing construction works, whether it is in terms of new structures and buildings or by improving the already built environment (Anumba *et al.*, 2007). Still, many of the fundamental and basic decisions which are taken early in design, such as bridge type, design materials, detailing etc. highly affects the ability to fulfil both present and future requirements. Such requirements may very well include both functional requirements as more traditional such as safety, accessibility, environmental, aesthetics, cost efficiency, life span,

flexibility. Early stage decisions are naturally taken with a higher degree of uncertainty but may still have a large impact, both short term and long term, on project or even national economy, since decisions affects both durability and the need for future repair and maintenance (fib Bulletin 01, 1999). Consequently, these early stages constitute a large effect on the overall success of the project. Responsible members from different disciplines needs to establish a collaborative environment early on and find solutions acceptable to all disciplines.

There are several ways to define and divide the stages of a construction project. To explain the typical construction project, including design, construction, maintenance and demolition processes, it can generally be divided into three different stages; pre-construction, construction and post-construction. During those stages, numerous tasks and activities are performed to fulfil the objectives and output specified by the owner. The main objective of any construction project is to finalize and deliver construction works, so from a customer perspective, this distinction of different stages with construction as a central part is of course rational and logical in that sense, Figure 5.



Figure 5: The construction project process can be divided into three main stages.

However, how the design task is undertaken during the pre-construction stages, and how this best can facilitate the activities in the construction stage is the main interest in this project.

Pre-construction stage

During the pre-construction stage, the purpose is to develop the client's needs into a final and appropriate design solution. At this stage it is important to identify and understand the customer's idea and needs since such an understanding creates the framework for establishing the design. This stage includes several different stages, or levels, of design and is usually divided into three phases, namely conceptual, preliminary and detailed design, e.g. (fib Bulletin 01, 1999; Mora *et al.*, 2006). Detailed design can further be divided into general design (or basic design) and final design (or execution design), although this division is traditionally not often used in Sweden (e.g. Harryson, 2008).

The process of structural engineering and design of new infrastructure is to its nature still an iterative and creative process based on both science and state-of-the-art knowledge. The earlier in the process you look, the more ambiguous it is. The structural design process usually includes several engineering disciplines and groups of people representing various fields of knowledge. The process is also to a large extent limited by the available experience and knowledge possessed by the project members involved such as owners, engineers, designers, and project leaders. Collaborative efforts and exchange of information are thus often a necessity to bring the project to a satisfactory conclusion within the scheduled parameters. Included in the responsibilities of a design team is to deliver a design which fulfils the client's need both in required time as well as without unjustified cost. The characteristics and the outcome of a good design includes sufficient durability, reliability, low cost, high accuracy, simplicity, low maintenance, and aesthetical appeal. Further requirements of contemporary design and

structural engineering also include life-cycle design, based on the ‘cradle to grave’ approach (Larsson, 2009; Owen *et al.*, 2010; Landolfo *et al.*, 2011; Muigai *et al.*, 2016).

Construction stage

When entering construction stage, all the necessary elements of a project that will enable its performance should be in place (Anumba *et al.*, 2007). Construction operations are highly diverse as they are performed under very different conditions, require many different types of resources, and also present a range of risks (Tatum, 2005). If the full benefits of coordination and communication have been addressed during the pre-construction stage, it is here the gain will be fully realised (Anumba *et al.*, 2007). Preferably, the only concern should be the construction works and production of the final structural solution since, at this stage, usually any changes in client’s requirements or interference with production/construction come at a high cost. Thus, discussions regarding productivity improvements are basically aimed towards this stage, see e.g. (Jergeas, 2009; Simonsson, 2011), and usually include benefits from, for example pre-fabrication, pre-assembly, off-site manufacturing etc.

Yet, studies have shown that too much time and effort are spent on the construction site trying to make the designs work in practice. For defects and rework related to design, those originating from missing co-ordination between disciplines are the largest category (Josephson and Hammarlund, 1999). Research indicates that, on average, 1/3 of the defect costs originates in pre-construction activities, i.e. can be referred to the design phase (Josephson & Saukkoriipi, 2005; Love & Sing, 2012). Engineering design as such, is consequently very important but also needs to be considered as part of a larger process. For example Olofsson, (2003), points to the risk that serious damage is largest during the construction stage based on the reason that this stage might have been neglected during the design. Consequently, if no other discipline or function completes these activities prior to construction, then construction workers will have to complete them (Tatum, 2005).

Still, safety during construction is a very high priority aspect for all construction firms and becomes a critical issue during e.g. lifts, assembling, and launching. The responsibility for customization during construction and the design of temporary structures is then often transferred to the contractor and it is therefore crucial that sufficient knowledge exist. This has evidently not always been the case. The knowledge about structural behaviour during temporary stages and the design of temporary structures and the belonging risks are something that is handled and considered as vital for any serious design-, engineering- or production process. While leaving key activities to the field therefore fails to realize potential project advantages from performing them earlier in the project and integrating them with other activities for the best project solutions. (Tatum, 2005)

Post-construction stage

This is the stage where traditional construction projects terminate and client taking ownership of the built structure. Even though the designing engineer/team are usually long since disconnected from the project, the effects of their choices during design will be present. During the service life of a bridge, several activities will take place which also are influenced by decisions during design, as well as activities during construction works. Some examples are inspection, accessibility, maintenance, repair, demolition, replacing, recycling. The effects of design during the service life will be related to structural strength, durability, operability as well as sustainability. Considering the long

service-life for bridges, a successful design will generate a structure with a well-balanced cost between structural performance, repair and maintenance, and operability.

3.2 The trinity of involved roles

In relation to housing, the constellation in a bridge construction project is usually quite simple in its composition. For this thesis the area being studied is the trinity of client, contractor, and the consultant. Of course, to complete a bridge construction project will involve more disciplines than that, but in most bridge construction projects these are the main key actors. Further, as this research are interested in the interface between the contractor and consultants, roles as construction engineer and structural engineer are used to emphasize the tasks they do.

The previously mentioned divided and sequential propulsion of a construction project also creates a separation of powers, which in turn establishes an arena where control of the project is a potential source of conflict. Normally the structural engineer is responsible for design issues, and accordingly, the contractor or construction engineer is responsible for all methods and materials used for construction works. Construction is awarded to a contractor who procures material, labour, and equipment and executes the contract requirements. This separation is an artefact that denies the intrinsic link between design and construction.(Puddicombe, 1997)

The specialisation into different disciplines is still a necessity in order to manage the complexity in most construction projects. Although, design and construction are, as mentioned, extensions of each other, and project participants perceive control of the overall project as being crucial to the achievement of a successful outcome (Puddicombe 1997). Still, there is a need for the trinity to start to function as the, since long, forgotten master builder (Forbes & Ahmed, 2011; Smits, 2013)(. There is a widespread understanding of the differences between the disciplines, but usually these differences are addressed as hindrances to collaboration. Instead, embracing them and understanding how to use them as complementary in contrast to diverging, seems as a fundamental start. To do so, each discipline also needs to learn to fully understand its own role and part in the construction process, at least with the basic understanding for closest upstream and downstream actors and activities (Emmitt, 2010). As further elaborated on later in the thesis, most work in construction is connected by interdependent relations, and it is rarely possible to isolate your own work.

In the following sections, a brief overview of the main three involved parties in the trinity and their main responsibilities as it is used in the thesis.

Consultant - Structural engineer

Structural engineering, as used in this thesis, is applying awareness with, knowledge of, and appreciation for architectural design and construction means and methods along with a deep knowledge of the behaviour and performance of structural systems to create compatible, safe, functional, economical, and reliable design alternatives; to help identify the optimum design and construction concepts and details; and to define the form of the engineered system that allows effective construction and maximizes the quality and value to the owner and to society (Luth, 2011).

Structural design engineering involves deciding and configurate the structural system, as well as defining the structural members and their cross-sections, and choosing materials. Of course, all with the objective to realize the optimal combination of material and structural shape. However, it is important to bear in mind that structural

design mostly involves solving open-ended problems and there is no definite solution. Based on the interdependency described by Figure 6, show a clear interdependency between profession and that the choices of one both control and limit opportunity for the other.

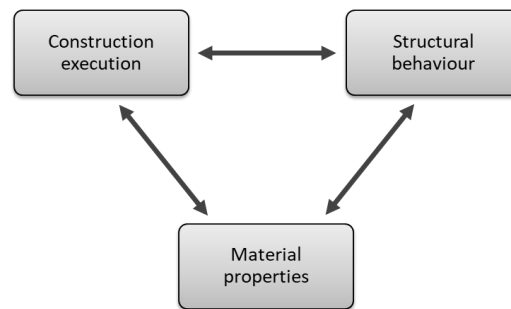


Figure 6: The design of a structure together with its characteristics and performance are strongly linked to the choice of materials that are used and their properties, as well as construction execution. Modified from (Löfgren, 2002)

Contractor - Construction engineer

The contractor is of course the role responsible for construction execution. This role includes many parts such as purchase, site logistics, project management, etc. In the interface with the structural engineer, the responsibility for the construction engineering includes a series of technical activities throughout the project to assist in meeting all types of project objectives. The activities include designing temporary works and processes for field operations, supplying temporary and permanent resources, and integrating team members and projects (Tatum, 2011).

Supported by integrated work processes, structural and construction engineering are responsible for collaboratively designing the permanent structure and the construction processes and temporary works required to build it (Tatum, 2011).

Bridge client

This chapter intends to describe the Swedish Transport administration in short and their part within bridge construction and in the bridge construction process.

In most countries, a public authority acts as the single most important client in the sector of infrastructure. In Sweden this is operated by the Swedish Transport Administration (STA). In addition to the STA, the Swedish bridge construction industry consists for the most part of approximately six to seven contractors and ten engineering consultancy firms active in bridge engineering design. Apart from very large projects, architects are very rarely used. Although these businesses have mutual differences, as a profession it is generally quite a homogenous industry. Over the years, the Swedish infrastructure market has been characterised by the traditional Design- Bid-Build (D-B-B) contract, but for bridge construction projects a modified version of Design-Build (DB) contracts has been in use for quite some time, leaving the contractor with larger, yet limited, control of detailed design. During recent years the STA has offensively introduced more D-B-B contracts, but more collaborative approaches are sparingly tested in large scale infrastructure projects.

3.3 Integration in design

Integrated design and construction as an expression may constitute a limitation in its own due to its vague statement and understanding. Still, design and construction integration have been discussed in the literature for a long time, together with the ambiguous questions of contractual relationships and how to benefit from collaborative approaches between companies during long term relationships e.g. (Bygballe *et al.*, 2010). These interdisciplinary methods (see e.g. Emmitt, 2010) in construction are best exemplified by multi-party contracting practices such as project alliancing, project partnering, integrated project delivery (IPD).

These contracting methods, usually referred to as ‘relational’, are based upon a relationship of trust between parties with fair division of responsibilities and benefits (Lahdenperä, 2012). The American Institute of Architects defined IPD as a “*method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction*” (The American Institute of Architects California Council, 2007). The relational aspect thus helps enrich inter-organizational relationships to deal with unforeseen events difficult to capture within the dictates of the contract definitions. Consequently, it encourages a flexible and speedy response to deal with the challenges usually associated with a risk event that has not been explicitly addressed in the contract.

However, this challenge is not completely understood and very little has been adopted within projects in the Swedish construction industry up to date. Contractual arrangements are only a subset of the transition towards a more efficient and sustainable construction process and can only establish the prerequisites for a project to be successful. The degree of success still lies in the hands of the project participants, i.e. the individuals involved in the daily work of engineering and construction activities. So, to reap success in a construction project, the project team should strive for an integrated project process, with a focus on the end-product, and formulate clear project goals and specify priorities regarding quality, cost, and time.

In this thesis, the meaning of an integrated design and construction process is an approach to undertake the work by a collaborative, integrated and interdisciplinary approach. Many of the concepts and methods proposed in literature are by nature multi/interdisciplinary and complex. Although several sources for the definition of integrated design exist, the basic is to implement all relevant and significant requirements into one single design process (fib Bulletin 71, 2013). Commonly defined characteristics of integrated design are a holistic mind-set and the goal of improving the performance of the resulting building structure by including long-term performance as a criterion from the earliest parts of the design process (fib Bulletin 71, 2013).

The complexity of the approach also involves a situation where the proposed changes might mean different things to the different participants within a project. Integration of design and construction often generates opportunities for the client to generate greater efficiency in construction, resulting in lower cost, reduced construction time, and/or improved quality. For the engineer, awareness of such opportunities enables an understanding for the methods and constraints of the actual construction required to execute the design. For the contractor, it is a combination of efforts required to

implement the design most efficiently and the opportunity to minimize the resource effort and cost.

The integration of design and construction as used here is not intended by merging different stages. Instead, the integration refers to the flow and use of information and how knowledge is used to transform the needs and requirements from the client and contractor into the final product. Still, the prevailing pre-construction stage consist of a fragmented approach between different design phases and different trades. It is during these phases which literature frequently suggests increased collaboration and integration to enhance the outcome of a construction project (Anumba, Baugh and Khalfan, 2002; Larsson, 2009; Owen *et al.*, 2010). To do so, this normally requires overlap of domains, for example that a contractor more actively take part during design development and in the conceptual discussions or even to compete with different bridge concepts or the structural engineer gets involved in upstream activities to support in the architectural design (Uihlein, 2015). However, the appropriate level of integration may vary from project to project and for some projects, the early or extended integration might be unnecessary and unproductive. Barriers and costs associated with integration needs to be evaluated since it may outweigh the benefits.

Many project-based industries have recognized that multi-function teams reduce the probability of costly changes and production difficulties. This is enabled by addressing design and production decisions earlier in the process (Crowley, 1998; Anumba *et al.*, 2002). Uihlein (2015) studied the integration between architects and engineers and what aspects were the underlying drivers regarding the structural integration. From the results, the time when structural engineers were introduced to the projects was considered a very important factor. The importance was found at several layers or organisational levels. If introduced in conceptual stages the structural engineers could not only be involved in the development of structural ideas in line with the aesthetics, the engineer can also attend to avoid structural inefficiencies. On the more individual level, the feeling of being valued as an asset to the end-product was significant to the engineers, clearly indicating the social part of the process. From an individual perspective, it is natural to desire to influence as far upstream as possible and to gain control and dictate your own conditions. By this, of course, the traditional domains between participants begin to overlap. This overlap offers opportunities for collaborative work and ultimately a shared understanding between all the stakeholders already in earlier stages of the project.

At this stage, an engineer can not only offer suggestions and develop structural ideas in keeping with the architectural concept, but the engineer can prevent structural inefficiencies from being added to the scheme. Additionally, this early inclusion signified to engineers that their input was valued as they were being given the opportunity to invest in the big ideas — architectural and structural—of the project. If knowledge from contractor or construction engineering (Tatum & Luth, 2012) is added and invested in — structural and construction — this investment is of course value added to the design process. This integrated and concurrent structural and construction engineering process is a way to achieve an efficient design process adapted to facilitate construction to be performed effectively.

Teams in the construction process

In modern construction management interest has increasingly shifted towards teams. In fact, the general view is that teams are expected to deliver better results than the average collection of individuals (Katzenbach & Smith, 1993; Wheelan, 2016). Several authors even assert that teamwork is not an option, it is a prerequisite for successful delivery of construction projects (Stewart & Barrick, 2000; Baiden, 2006; Salas *et al.*, 2017). Integrated design teams, as used in construction, serve to remove the traditional separation between design engineering and construction planning. Bringing together individuals and organisations with different knowledge and skills also creates a culture of efficient and effective collaboration to enhance the outcome of construction (Anumba *et al.*, 2002; Larsson, 2009; Owen *et al.*, 2010).

Examples of successful teams, for example in manufacturing, are teams sharing experience from multiple projects, and who have developed a shared culture and organisation of work and design processes. Project teams in construction on the other hand, usually work together only for the development of a single project and consequently rarely work together on more than one project (Anumba *et al.*, 2007; Senaratne & Hapuarachchi, 2009; Senaratne & Gunawardane, 2015). As a consequence of the prevailing short-term perspective in construction, there is always a significant risk that, if not well managed, design coalitions in construction will not perform well, or might even be dysfunctional (Sumner *et al.*, 1999; Forgues & Koskela, 2008).

In their research, Forgues and Koskela, (2008) found two opposing transition paths from traditional design practices towards new collaborative approaches; a development from a linear and sequential to an iterative design process; or a change in how projects are procured. Furthermore, when discussing integrated projects, it is normally the contract or the way of procurement that is given the primary focus (Kadefors, 2002, 2004; The American Institute of Architects California Council, 2007; Mosey, 2009). This limited focus is usually not enough and therefore results in a far too narrow interpretation for moving from fragmented to integrated design (Forgues & Koskela, 2009). Problems with project performance of integrated design teams are in general related to the context and not necessarily the process itself, i.e. they are not technical but socio-cognitive (Moore & Dainty, 1999; Baiden *et al.*, 2003; Forgues & Koskela, 2008).

Collaborative procurement approaches, such as Partnering (Kadefors, 2002; Bygballe *et al.*, 2010), Integrated Project Delivery (The American Institute of Architects California Council, 2007) and Early Contractor Involvement (Mosey, 2009) for example, function to stabilize and formalize the patterns between the client and its suppliers to improve the environment for an integrated design team performance. Yet, Forgues and Koskela, (2009) bring attention to the need for change also in relational patterns. The lack of socio-cognitive attention in design is supported by the results from Cross and Cross, (1995), who concluded that, especially in the engineering domain, the design process is normally treated as a technical process: a rationalized approach as a sequence of activities to solve a technical problem. Team work, however, is not only a clearly social process, the outcome of design is also limited to the cognitive skills and limitations of the individual designer/engineer. Cross and Cross, (1995), recommended treating the design process as an integration of a technical, a cognitive, and a social process.

Activities in construction are performed by individuals with different skills belonging to different companies in temporary organisations. These actors need to share

information and knowledge for optimum decisions. Management of these activities performed by individuals and groups of individuals within the organisation is coordinated to ensure a value flow, and therefore an organised flow in the work schedule. Creating both efficiency and effectiveness within the team in a construction project is consequently necessary and always needs to improve.

Process development

Since the construction industry started to adopt Lean philosophies, several methods have emerged to undertake and facilitate construction projects. Focusing on processes shifts the attention from individual products to the chain of activities that create them. Furthermore, a process focus instead promotes the question "how are the results produced" in favour of "who does what?".

Larsson *et al.*, (2014) present that two strategies that normally are undertaken to minimize the complexity of construction; standardization of products and standardization of processes. It is also stated that it has proven difficult to achieve standardization in both areas since the experiences and innovative ideas from contractors are not utilised in early stages of design. Some core elements to support standardization and increase the industrialization of infrastructure construction are identified in the article, and some barriers and its actors which have the power to eliminate them. Many of the core elements identified are related to long term actions, such as processes, rather than short term actions, such as projects. Here, integration between design and production is identified as one of the five largest core elements. Notably, and very interestingly, three out of the five largest perceived barriers can be eliminated by the client's role. Hence, lack of repetition in construction, prevailing procurement approaches, norms, and regulations.

Knowledge as such is both a complex and multifaceted phenomenon with a long history within the field of philosophy. Engaging in any discussion regarding what knowledge is or what is not lies far beyond the scope of this thesis. Instead, the discussion here is limited to focus on the dimensions of knowledge required to understand the complexity of knowledge transfer.

A fundamental prerequisite when introducing and managing industrial methods in the construction industry is to have systems to handle experience feedback. Adopting an approach for standardization and continuous improvements establishes the foundation for a learning organization (Lessing, 2006; Simonsson, 2011; Lidelöw *et al.*, 2015). In design firms, while being a knowledge enterprise, stored knowledge usually is available in reference documents from completed projects, or in the form of knowledge at the individual level. With inadequate management of information along with staff turnover there is a high risk of losing valuable knowledge if this is not handled properly. An often used citation is "we know more than we can tell" (Polanyi, 1983). By this Polanyi, (1983), indicates that when knowledge is stored on an individual level, an organization's level of knowledge may very well exceed what it explicitly can express. This problem clearly gives an indication that it is necessary to find a systematic way to carefully nurture the knowledge gained within a team or organization by creating a learning environment. Sumner *et al.*, (1999) states that "Integrating working and learning is not a desirable luxury – it is a fundamental requirement for businesses to remain competitive."

Simplicity in design and ease of construction is something valued by contractors and a challenge for the designing engineers. The possibility to influence the future properties

of a structure is at its largest during the different pre-construction stages. This is well known to the industry. The design and execution of a construction are closely attached and highly dependent to each other and consequently, the choice of construction method may very well dictate the rules of the design. Due to the sequential design process, a construction method often needs to be assumed in design without necessarily considering all its requirements (Fischer & Tatum, 1997). Even though there is an obvious need for construction knowledge in design work, there is a lack of a consistent and structured transmission of experience between the contractors and the designing engineers (Olofsson *et al.*, 2010).

4 Results

The results in this thesis are represented in four appended research papers. The brief summary presented in this chapter focuses on the main findings gained from each of the studies and thus leaving less room for how the results were obtained and the theoretical context in which they reside. The full descriptions can be found in the appended papers in the back of this thesis. The papers are appended in the same order as they emerged in the research project.

4.1 Paper A

Paper A is the result of a review of approaches developed as a response to the increasing demand for more efficient and competitive ways to design and constructing bridges. Given by the vast amount of existing literature, to make a significant change in the industry and especially when a transformative change is asked for, is perceived as difficult and cumbersome. Changes of such category requires time and continuity to sufficiently monitor and measure the effects of any implemented changes. A detailed review of literature identified that the reviewed concepts are very similar, not only in their expected outcomes, but also in its governing features. Although the concepts are developed from different perspective and stages, the review suggests that there is a variety of factors influencing the adoption of each concept that are previously not connected to implementation difficulties. In this paper, the authors address this identified gap by adding a holistic interpretation to the governing features in each approach.

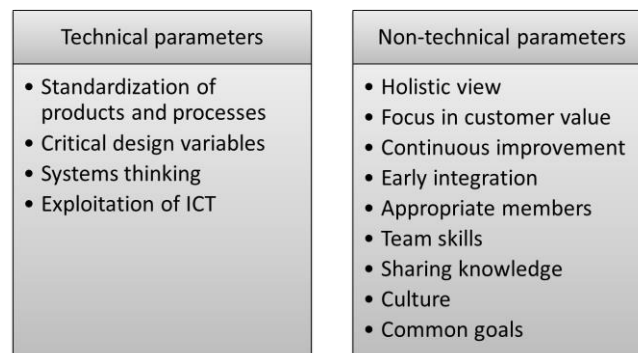


Figure 7: Main features that commonly influence the adoption to process oriented bridge construction.

The result of this detailed review identified a few main features that commonly influence the adoption to more process oriented and integrated approach in bridge construction, Figure 7. Besides the similarities between the main features which constitutes the different concepts, these main features can also be divided into (1) technical parameters: standardization of products and processes, critical design variables, systems thinking and exploitation of ICT; and (2) non-technical parameters: holistic view, focus on customer value, continuous improvement, early integration, appropriate members and team skills, sharing knowledge, culture and common goals. The number of governing non-technical parameters linking the features out-numbers the technical parameters. Still, how to accommodate these non-technical parameters in integration, and how this affects the integrated team have been overlooked. How to sufficiently undertake design and how to facilitate a team approach during pre-construction stages are relatively unexplored in Swedish literature and needs to be addressed further.

4.2 Paper B

Paper B elaborates on the results from paper A, that adopting an integrated design approach in construction and establishing integrated project teams (IPT) in the early stages intends to facilitate the configuration of an end-product with a structural design based on well-substantiated and reasoned decisions. Paper A clearly indicated that the expected effectiveness in design is commonly connected to what is referred to as highly functional teams (Baiden *et al.*, 2006; Salas *et al.*, 2017). However, how to best create and benefit from these teams is still not clear.

For example, there are several interfaces in the every-day project setting where experience feedback and knowledge transformation are possible to use, and there are opportunities to take important steps to create effectiveness over time. But the long term business relations within project teams, including experience feedback over time, are scarce today and any systematic experience feedback or knowledge transformation is seldom or never utilized, e.g. (Gadde & Dubois, 2010). So, despite all previous observations, the mechanisms of how integrated project teams are established within projects and how to influence performance are still areas that needs further clarification.

By adopting a multilevel approach, and including the individual, project, and organisational levels, the paper evaluates perceived project performance amongst Swedish bridge industry participants. The established framework, see Figure 8, aided to examine the collaboration between different disciplines during the development of construction documents for new bridges in Sweden. The result shows, that out of nine evaluated key areas, more immediate attention is crucial concerning *project culture*, *project competence*, and *organisational structure*.

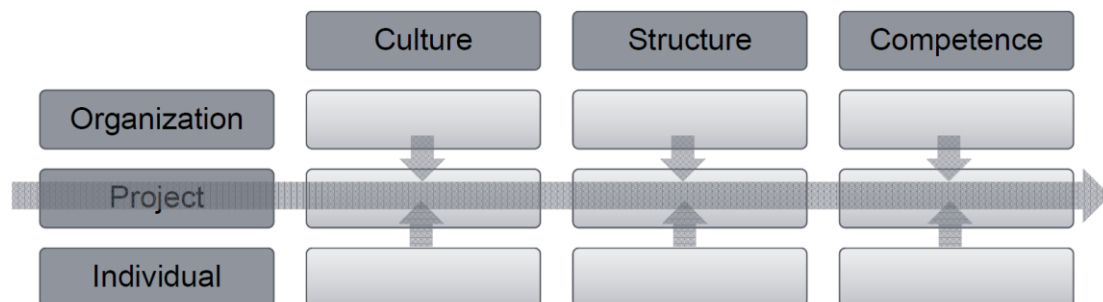


Figure 8: Survey evaluation matrix used in Paper B. The framework was established by cross-mapping organisational levels towards attributes concerning culture, structure, and competence.

Even though the greatest potential for improvement was found at the project team level, the individual contribution and the organisational support to the project team's performance cannot be overlooked or neglected. Reliable measurements are needed on all levels to sufficiently capture the true project performance and to fully benefit from the project team. The outcome and performance from the application of Integrated Project Team (IPT) in the Swedish construction industry are yet poorly evaluated. The lack of knowledge how to sufficiently collaborate in a project team setting, which is indicated by the score in *Project Culture*, are also supported by the results in previous research presented in Paper A.

4.3 Paper C

Paper C builds upon the results presented in paper B, by further investigating the indicators concerning *project culture*, *project competence*, and *organisational structure*. Although problems may arise connected to the intra-professional communication, this study focuses on the interface between the structural design engineer and the construction engineer, i.e. towards the inter-professional dialogue concerning the *what* and the *how*, (e.g. AIA, 2007).

The study for this research began with the goal to better understand the interprofessional dialogue and how experience and knowledge feedback is handled and understood amongst construction industry participants. The adopted interview methodology made possible to further understand the complexity of the interprofessional dialogue and the research interviews offered an important means for the researchers to deepen their understanding concerning structural and construction engineering integration. The findings are presented in form of observations presented in Figure 9.

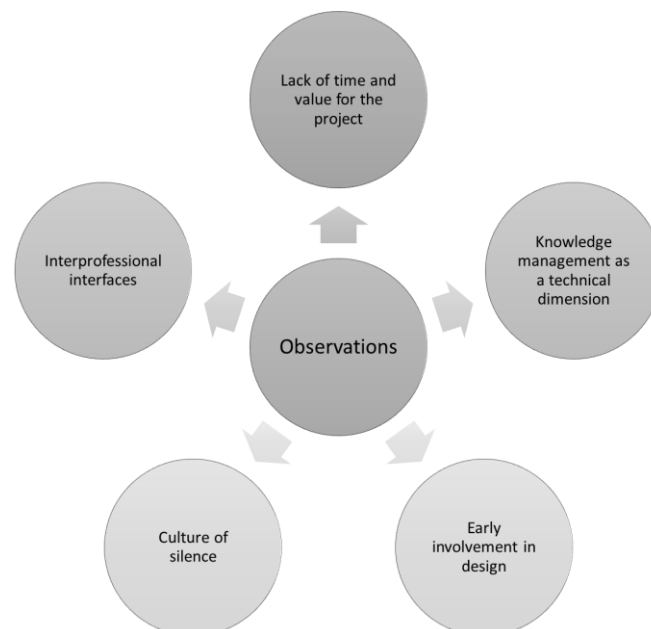


Figure 9: Interviews emerged in five observations; Lack of time and value for the project; Knowledge management as a technical dimension; Early involvement in design; Culture of silence and Interprofessional interfaces

Findings from this research supported the authors to conclude that there is a clear distinction between two situations where the interface between structural design and construction needs to be bridged. Unfortunately, at both these opportunities the structural engineer and contractor are normally separated which distinctly prevents the possibility for a constructive interprofessional dialogue.

Firstly, there is an interface during the development of construction documents, the actual input of knowledge to generate solutions (knowledge creation/knowledge transfer). During this stage, even when possible, there is no indication for any widespread effort for creating supporting activities, instead the projects team members are usually strictly bound to solve given tasks within their own professional domain. One important pillar in that development of aligned efforts is to understand the need of your project team-members. So, given that the environment of structural design (pre-construction design stage), contrary to the construction stage, is a qualitative, subjective

and in some sense related to a high degree of uncertainty, the appropriate methods and practices used in pre-construction stages are, thus, slightly different from those in construction. Consequently, there is evidently a need to establish a deeper understanding for the essentials and important task during each stage.

Secondly, the very action to learn from the results from the first (experience feedback/knowledge creation), the actual effort for evaluation and retrieval of experiences from previously performed projects. The interprofessional dialogue seem prevented by a two-way continence. Instead of engaging in dialogue, both parties are expected to understand the implications from their own actions. This becomes more apparent for small projects where there is less opportunities to repeat the same action or solution within the same project.

Supported by the above it is clear that both structural engineers and contractors establish a deeper understanding about each other and learn how to speak a common language to support the interprofessional dialogue and in the long run the performance of integrated project teams.

4.4 Paper D

Paper D explores the interprofessional dialogue between the structural engineer and contractor in a case study. The case for this study was chosen with the preconception to be a generally considered successful project, including the perspective of the client, contractor, as well as the structural design engineer. The construction project was a train-depot for regional trains, located in Stockholm, Sweden. The studied part of the project included an approximately 320 m long concrete tunnel and was executed in 2014, initially procured as a D-B-B-contract, i.e. complete construction documents were delivered by the client.

During construction planning, the contractor identified many time-consuming activities and other difficulties to improve. Together with the structural engineering company, the contractor had just completed the structural design of another project, including some long tunnels similar to this, and saw an opportunity to benefit from the experience of a previously successful collaboration and presented an alternative calculation to the client including a re-design. The date for construction start was fixed so there was time pressure to deliver the first construction documents. Within the original design there were several areas identified to improve and with the new design the intention was to optimize buildability and minimize risk during construction. The following areas were the most significant:

- construction method, including sequence, production rate etc.
- repeatability, simplicity, similarity in details
- minimizing shear reinforcement, and choice of bar type

To explore the dialogue the following questions were asked (1) What characterizes the dialogue between the different disciplines; (2) What is the dialogue about; and (3) When in the process do questions arise? The main findings are presented in Figure 10

In most D-B-B construction projects, the possibility for any constructive dialogue between contractor and structural engineer is usually limited. For this specific case, finalized construction documents were provided to the contractor by the client due to a tight schedule. Although the construction documents were based on current codes and regulations, and assumed site conditions, the contractor saw great potential for improvements and wanted to re-design and remake the construction documents. While rethinking construction, the contractor established a clear picture of how they wanted to organize construction and could bring this input as new entry values to the new structural engineering company. In some way, there was a fairly completed "design intent" as an entry point for the contractor and the structural engineer dialogue.

The meeting documents distinguished that the interprofessional dialogue from the structural engineer to the contractor is much more difficult to identify than the opposite (Loop 1 and 3), see Figure 10. This dialogue may be embedded within the project delivery itself and the structural engineer's dialogue is conducted through the product or service that is provided, in this case the construction documents.

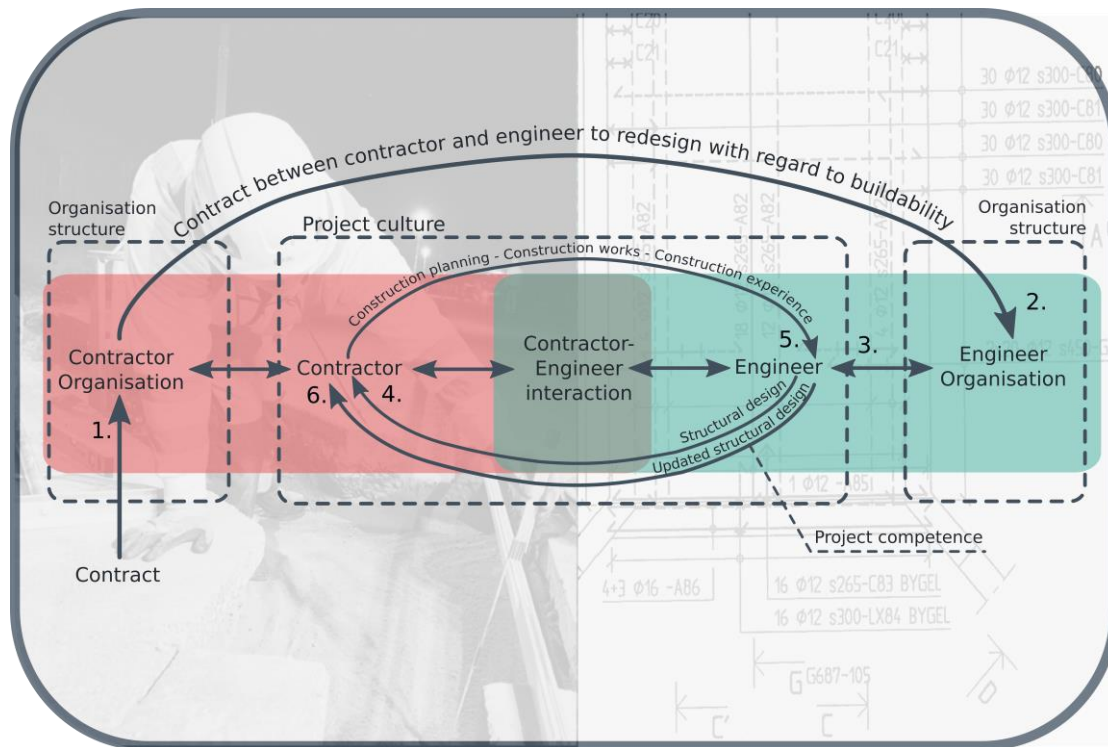


Figure 10: Illustrates the researchers' interpretation of the documents on how the interprofessional dialogues evolved during the project. clarifies some main topics that are affected during the dialogues and at what stage these topics appear. Further, it also describes the dialogues to appear in three loops originating from: (1) Initial structural design, (2) Construction -Planning/-Works/ and – Experience, (3) Updated structural design.

Further, meeting documents revealed a high presence from all actors. All parties had the individuals needed present to be decisive at the meeting and were thus organizationally ready, which simplifies the inter-disciplinary dialogue. It is normally difficult to receive early feedback on construction documents due to staff shifting between design and construction personnel. Such shifting is a problem since late error detection or changes leads to further time-rushed revisions or re-work that further increases the risk of errors. When the structural engineer needs input concerning reinforcement layout and intended construction sequencing, these issues have normally not yet come to light for the contractor. Further, when the contractor starts to think about construction procedures, the structural engineer has moved on to other projects.

The project was initially given very limited work-site area , so discussions about the possibility of utilizing the finished constructions became a clear issue. Questions such as: When and in what order can finished constructions be backfilled to make construction procedure more efficient? How is the access to and within the construction site and availability of cranes during staging? Can cranes be placed on top of finished construction works instead of alongside? The fact that these questions about construction procedures remain, highlights these issues as largely unpredictable. Yet, the project team demonstrated a strive to constantly improve and streamline construction procedures when solving them.

An environment for collaborative efforts needs to be established and supported by the client. Here, allowing for a re-evaluation of the structural design and construction

planning created that environment despite the short available time and the established interprofessional dialogue enabled a sound project team development.

Further, to support the interprofessional dialogue requires some form of vehicle, it is important of have something to discuss around, otherwise the dialogue tend to fail . Allowing the contractor to establish a "design intent" created that vehicle to carry the dialogue.

4.5 Discussion and conclusion

This section aims to interpret and describe the significance of the findings and highlight observations and new insights rendered by this research by addressing the two research questions in order.

The first research question aims to define integration as related to bridge construction process and what are the key features for integration. The second research question aims to define the interprofessional dialogue in the bridge construction process and how this support/hinders knowledge and experience transfer in the interprofessional interface.

RQ1: What is integration, and what are its key features in relation to the bridge construction process?

To succeed in realizing effectiveness with construction efforts can only be made possible by close cooperation between all project participants, i.e. client , consultant(s), contractor(s), and suppliers (Jergeas & Van der Put, 2001). To improve the relation between the structural design and construction it is necessary to identify the common interfaces between the disciplines, as elaborated on in Paper A. With the complexity in construction today, it is important to consider the construction process as different stages with various outcomes as the primary objective, where structural design is one such stage. For this to happen, recognizing that each of involved participants, individually, might lack some pieces to puzzle, but that collectively, they can gather their knowledge and resources to achieve success for all of the participants (Jergeas & Van der Put, 2001). If integration is seen in this perspective the following key features crystallizes:

- skills to collaborate and communicate;
- interdependency between the parties;
- importance for the structural engineer to receive feedback from, and to have a dialogue with, the contractors;
- teams to be provided with the right people.

As presented in Paper A, the common intent with the integration and adopting a team approach is to overcome a linear and fragmented design approach. Construction projects are normally planned and executed in teams or groups, in one way or the other, and the outcome of a construction project is therefore in almost all cases dependent on individual skills to collaborate and communicate. The most common factors to the shortcomings that appear during construction can also be related to design errors. According to Claeson-Jonsson, (2013) the top three factors are (1) lack of communication between the client and the design team; (2) lack of understanding the production needs; and that (3) construction documents are not ready when production begins. Based on established communication in and between teams, such risks and uncertainties can commonly be reduced. As shown in Paper B, communication is a key feature for both project culture and team performance, maybe especially in construction due to its dependence on different professions. Communication, and more specifically,

knowledge transfer within and between disciplines was identified in Paper B, as a clear deficiency today.

Still, it would be overly simplistic to only proclaim that better communication will solve all the problems in construction. Communication in itself will not automatically lead to a better team performance. There is also a need to understand what to communicate about, to establish effective communication. To overcome such inefficiencies, the structural engineer or the structural design teams need to generate an understanding for site activities and core elements in construction. Further, the contractor also needs to create a deeper understanding about upstream activities, and to understand the structural design process, which is also highlighted as an important point by several contractors interviewed in Paper C. It is required for the different professions to overlap domains, and to be more active during adjacent stages than normal in order to better address, for example buildability considerations. These buildability considerations are not only subjected to uncertainty and risk during tendering stage for the contractor, e.g. (Olofsson *et al.*, 2010), they also generate interdependency between the parties involved. For contractors to operate construction activities both efficiently and competitively, they are directly dependent on the chosen design concept, the detailing, as well as the choice of materials, rendering another key feature (Löfgren, 2002). As previously mentioned, to understand this interdependency is important for both structural engineers as well as contractor since it effects both upstream and downstream activities. However, buildability considerations are normally based only on the structural engineer's knowledge or experience from previous construction projects and without the input from any appointed contractor. This lack of input is usually related to traditional procurement strategies where the contractor is procured first after fully realized construction documents. But as highlighted by interviewees in Paper C, involved organizations usually do not have the "right" people involved at the "right" time and the opportunity for improvements may pass. Still, when succeeding with the right staffing, as shown by the case study in Paper D, there is still possible to alter the outcome even within D-B-B contracts if only there is enough goodwill from the involved parties. There is also a clear trend that construction projects continue to increase in both size and complexity, which makes it more and more difficult for designers to be fully aware of all the implications from their designs. This complexity underlines a third key feature: the importance for the structural engineer to receive feedback from, and to have a dialogue with, the contractors who are experienced in construction engineering and meet the problems daily.

As several publications stresses (e.g. Hon, 1988; Lessing, 2006; Anumba *et al.*, 2007), most concepts contain both technical and non-technical parameters, often also referred to as hard and soft parameters or systems. Blockley & Godfrey, (2017) further claims that such soft systems even enclose hard systems, meaning that the hard system is dependent on the soft in order for the overall success. As presented in Paper A, when unpacking the different approaches, they are found to be made out of the same core elements, which are mainly related to soft parameters, such as *a holistic view, focus on customer value, continuous improvement, early integration, appropriate members and team skills, sharing knowledge, culture, and common goals*. Consequently, based on individuals' intention, the outcome of our projects is in the hands of project team members.

That perspective further adds weight to "*Project success relies upon the right people having the right information at the right time*" (Anumba *et al.*, 2007, p. 106). This statement origins from a view in favour for the integrated and collaborative

environment which concurrent engineering proposes. While a bit simplistic, this statement does not lack reason. Still “*the challenge is to ensure that the right information gets to the appropriate person at the right time*” (Baiden & Price, 2011, p. 130). So as emphasized in Paper C (key feature four), it is critical for teams to be provided with the right people in order to be successful, also stressed by (Radtke and Jeffrey, 1993; Paris, Salas and Cannon-Bowers, 2000; Forbes & Ahmed, 2011). Baiden, (2006) underlines that the right people are a composition of personnel from owner, design-engineering and contractor organizations. These key members are recommended to be hand-picked and involved early in the projects as well as consistent through the different project stages. However, the right people may vary over time since the tasks to be solved are of varying nature and what available individuals’ organizations have contains a great deal of flexibility (Emmitt, 2010).

Still findings from Paper B suggests that multidisciplinary constellations in construction are rarely viewed or evaluated in terms of integrated teams. In most projects, though, the work is done in teams or groups, in one way or the other. To establish teams requires investment in time, and all tasks or problems do not require fully developed teams to solve them. It is therefore important to utilize team-work approaches to the degree that it is necessary. Based on established communication in and between teams, both risks and uncertainties are commonly reduced. Still, the client holds the main beneficial role of enhanced project performance and should establish the required and favourable environment for integrated teams to operate in.

RQ2: What defines the interprofessional dialogue in the bridge construction process and how can it support/hinders the introduction of construction knowledge during early design?

As stated in the previous section and demonstrated in Papers A and B, structural design and construction execution are clearly interdependent, and construction projects are becoming more and more complex. The complexity is growing in terms of size, where to build, as well as the requirements for sustainable development. That challenge may be addressed by further focusing on the integration and interdependency of construction professions.

As mentioned in the beginning of this section, there is no point only arguing for better communication without establishing what to communicate about. Even though a project contains more than the constructive dialogue, we still need to address what the dialogue should contain. Both in Paper C and D we follow the interprofessional dialogue between structural engineer and contractor concerning buildability issues. A common expression from contractors is that solid knowledge concerning construction activities is something that the structural engineer usually lacks and needs to acquire more. This is on a general level probably true, but the interviews in Paper C revealed a lacking understanding how this knowledge should be created or gained. Who is supposed to learn who? Fully understanding the complexity in construction and its related construction activities, however, is not exclusively linked to the structural engineer. Results from both Paper B and C show that there exist difficulties even with intra-dialogue, i.e. difficulties to learn or transfer understanding even within your own organization. This is true for all involved professions, since there are no specific indications that participants handle experiences in any structured way.

The interviews in Paper C revealed a clear hinder to knowledge transfer: an embedded “culture of silence” which strongly contributes to breaking the learning cycle in the construction process. This break or interference disables the opportunity to learn from

the experiences gained by the individual (Senge, 2006). During the construction stage, it is usually too late for any major alterations and for any detected errors or possible adjustments, corrective measures are instead taken to solve the issue here and now and without consideration or reflection if this could have been done any other way. From the engineer's perspective, stated in the interviews in Paper C, such "feedback loops" only appears when things have gone wrong enough.

In order to support the introduction of construction knowledge during early design it is important to engage in any opportunity to create long term learning. Especially for small projects, typically single short to medium span bridges, in contrast to large projects where you can benefit from the natural repeatability which creates the manoeuvring space to question used solutions and thinking patterns within the project, which could be seen as a result from the case study presented in Paper D. A clear benefit from reusing and sharing previous project experiences is that it creates an opportunity to align a specific task to be performed in a similar and repetitive way. The interprofessional dialogue that can be followed in Paper D, show a targeted work to minimize the variation in how, both structural engineers and contractors, perform a specific design and construction processes, and how this also is key to ensuring that the total product quality meets all customer requirements. Yet, by reuse there is always a significant risk to become prisoners of our own experience, i.e. we perform the next project in the same way as the previous one without really questioning or reflecting over the actual outcome of the same.

Adopting a stronger focus on the social perspective of learning, also requires an increased focus on, and importance assigned to, human interaction and collaboration. Knowledge needs to be treated as something people do, and stress the importance of the relationship between knowledge and action (Neve, 2015). Further Neve, (2015:13) states that *"If we are to learn from knowledgeable people, we need to search not only for their more abstract knowledge but also for their practical knowledge."* This addresses the need to continue to invest in the interprofessional dialogue in construction projects. It is during this dialogue the tacit, in contrast to the explicit, knowledge is in focus.

The findings in Paper D express that if the project culture and competence is present a knowledge and experience transfer is fostered and supported. So, how is this situation created? What in the project set-up renders an ideal culture and competence in a project? Looking back on the key-features it is suggested to render in the conclusion that it depends on the right people and their skill to communicate and interchange experience.

Evaluation of research approach

A large part of the conducted research relies on the foundation created in Paper A and Paper B. Even though we have only combined already validated research, both from team/group theory, as well as organization/management theory, there is always weaknesses which can relate to both our own evaluation of the results and our preconceptions. Not to forget the possible weakness in the already established research. Although, there several models existing in research similar to the one used here, e.g. (Ginnett, 2005), which gives the research more credibility.

The research also heavily relies on the results from evaluation in Paper B. Besides the peer-review process before publication, no other proper verification or test where conducted for the framework. The framework could have undergone a conceptual test in order to strengthen it, but the research group made a deliberate choice to focus on the results from the evaluation in this case.

Interactions of individuals subjected to psychological, social and contextual influences make the subject difficult to research in live business settings (Emmitt, 2010). Most of the studies in this thesis deal with gathering the perceptions of how participants perceive, understand or think under particular situations. Even though, for example Emmitt, (2010) highlight that this can be useful insights, he also give notice that the *perceptions of how people think they behave and how they actually behave can be quite different.*

4.6 Concluding remarks

There is a need to establish a deeper understanding that many possible choices, for example for a structural engineer, lies in the hand of someone else, such as a contractor or a client. There is a clear interdependency between professions in the construction process. Thus, it is important to see that these actions create a chain of dependencies between professions and that this requires a continuous dialogue to find the most suitable solution for each situation. The progression of sustainability as a driving force in society, see for example (fib Bulletin 71, 2013), states that the overall loser is on a totally different level when compared to when economy is the governing parameter. Economy as a driver instead tends to only praise the winner.

From that perspective it important to develop a better understanding for other disciplines and their challenges. Further it is important that we learn how to operate in the other profession's domain. Including the contractor earlier in the projects consequently means that the contractor needs to gain or increase knowledge of the design stage and project planning, which many contractors highlight as a shortcoming, and find ways to reduce risks from participating in constructive interprofessional dialogues. This has been highlighted many times in previous research, but most aspects need to be addressed earlier and then the contractor also needs to learn how to plan production procedures in collaboration with the structural designer. This may require engaging competent and decision-making individuals during much earlier sages where they are not used to working. It is important to make buildability a team task with shared responsibility.

5 Future work

Applying technology can clearly support the social processes by managing and establishing more sound and reliable support for decisions. All forms of planning include working with preliminary results. It is not possible to do a complete analysis of a design until fully finished and all parameters involved are decided. In design, there is a search for something that is optimal, design includes optimizing constructions. There is a risk that it is just this action that makes the industry to believe that it is so unique. Something can only be optimal within certain, very clearly stated circumstances, and to find that optimum is cumbersome and here technology can aid. To use approaches such as Set based design (e.g. Mathern, 2019) within structural engineering is something relatively new. Still, the use of parametric computation needs to be valued against computational cost, and the result from the parametric computation needs to be clearly visualised and honestly evaluated. The risk in trying to optimize may be losing in the other end. Optimization is always done based upon specific pre-conditions which in construction can be unique. Making something unique of course narrows the opportunity to repetition. It might be important to apply optimization from a holistic point of view, for example keeping the same dimensions on a beam intersection despite varying length and instead using varying amount of reinforcement, i.e. optimizing only the reinforcement. Still, it is important to treat the design process as a combination both a social and technical process.

Based on the aim and purpose of the presented research and previous conclusion, the following point summarises the suggested future work

- Continue to study and investigate the performance stage to further strengthen the activities performed within the projects.
- Create further understanding of roles and responsibilities within the interdisciplinary project setting as enforcing sustainability and buildability issues.
- Further strengthening the need for a greater upstream-downstream understanding amongst construction industry participants. We need to minimize risk to dare participate in stages outside our own domain.
- Create further understanding of how a technical environment can support the project team decisions and aid in prioritizing challenges to avoid cost being the only considered factor.

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Paper A

Study of approaches to meet the ends in bridge design and construction— It's time to walk the talk

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Study of approaches to meet the ends in bridge design and construction – It's time to walk the talk

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Transforming bridge design and construction by adopting a more process-oriented and integrated approach has received large focus in research over the last two decades. Despite reoccurring benefits highlighted in research, the construction sector has been slow to embrace to this new thinking, and has certainly not undergone a major transformation. The authors review relevant research and development of approaches developed from the increasing demand for more efficient and competitive ways to design and construct bridges. The concepts are found to be linked by a number of common features, both technical and non-technical, which also influence the adoption to a more process oriented and integrated approach. Also, the non-technical parameters linking the features out-number the technical parameters. For example, transition may start from the construction industry reducing its knowing-doing gap and change its prevailing ad-hoc approach to design and construction. By putting customer value and the end product first, creating the organisational support to such a culture, as well as reflection on what we know we can do better gives the opportunity to start to walk the talk. Still, how to accommodate these non-technical parameters in integration and how they affect the integrated teams are overlooked and needs further attention.

Keywords: integrated design, concurrent engineering, industrialized construction, constructability, integrated team

1 Introduction

There are several specific characteristics claimed to be connected to the construction process. For example, ¹ identifies that traditional construction is connected to with at least three major features: separation of design and construction, procurement through bidding, and institutionalized roles and division of work. All these features have been given large attention in recent research, yet the construction sector has been slow to embrace new thinking, and has certainly not undergone a major transformation ²⁻⁶. The separation between design and construction processes has been specifically emphasized to be related to this slow development in construction industry^{7,8}. This separation has also been an issue recognized in research for long^{3,4}. As cited in Ref. [9], "*design and construction must be considered together and that in the traditional contracting situation, the contractor is too far removed from the design stage at which his specialized knowledge and techniques could be put to invaluable use*"; the same problem was pointed out already in the Banwell-report written as early as 1964. The promotion to use integrated construction and facilitate the benefits from integrated teams and early contractor involvement is, based on the literature, still not significantly put to practice more than 50 years later.

The key for change is commonly said to be new innovative techniques and increased digitalisation, for which the sector is generally seen as a slow adopter, but there is more to it. Many of the problems in construction are related to structural shortcomings within its organizations, and the performance of the construction industry will not be changed just through the introduction of new technology, see e.g. Ref. [10, 11]. Over the years, academia and practitioners have provided several approaches and theories to meet the challenges the



construction industry faces. The development and progression in manufacturing has functioned as a role model for construction and this is where many of the concepts originate. Still, construction uses rather conventional methods, and there has been ambition for a long time²⁻⁶, to increase the level of industrialization in construction and to convert construction into a modern and highly effective industry.

Even though progression has occurred, especially on the technological side, no significant change is to be seen in the industry regarding e.g. customer value, and productivity. Despite the, in literature, “proven” benefits by applying aspects such as buildability and constructability into design and the use of industrial processes and collaborative methods, there has been a strong inertia from industry practitioners to adopt these approaches to the fullest. This is partly evidenced by the numerous articles regarding implementation problems. One of the reasons for this can be that there has not been sufficient attention paid to the shortcomings in the design process¹², and how this needs to be adapted to fit to what should be constructed. Traditionally, the general model for design in the construction industry has been sequential rather than concurrent and the organisation of architecture, construction and engineering companies has been fragmented rather than integrated¹³.

The research reported here, aims to establish a comprehensive, although far from complete, review of literature concerning the development of the construction process. The authors review important research and development of project delivery, design teams, and industrialisation of construction. The purpose is to identify some of the distinctive theories in literature which described to transform construction, which then are categorized and compared regarding similarities and dissimilarities, both in Swedish and international construction research. For this research the design and construction process is identified to consist of three major stages, pre-construction, construction and post-construction, see Figure 1. The focus of this research is from a design perspective in the pre-construction stage and how activities undertaken in this stage best facilitate both the construction and post-construction stage. The research departs primarily from the prevailing situation in Sweden, although the work is internationally relevant. Moreover, the project focuses on short- and medium-span road bridges.



Figure 1: The construction project process can be divided into three main stages.

The performed research explores a large amount of existing research literature and by the observation of previous studies describing the multifaceted problem in generating a more effective bridge construction process. The literature was chosen with the preconception that integration of disciplines and a collaborative working environment enhances project success. For the review, a multi-step procedure was employed beginning with an initial review of interesting views and aspects in relation to the development of construction followed by a more in depth exploratory review.

The exploration of the literature was approached at three levels. The first established what the core principles are and where they originate. The expected outcome from all concepts is generally the same when aiming for lower costs, shortened lead time and improved quality and safety. Although from which perspective and at what stage they originate, differentiate the approaches. The second, describes the approach towards integration and the distribution of responsibilities to create such an integration. The third and final step defines similarities and dissimilarities between the different concepts and links pre-construction and construction activities. For the exploration of the literature, some guiding questions were established to aid the identification of common key features in the studied concepts.

- What does integration mean during the construction stage?
- What does integration mean during the pre-construction stage, and specifically in structural design?
- What is the integrations representation in the bridge construction process?
- Who is responsible for generating that integration?

2 Theories and concepts of construction development

The research identified four main theories/areas of effective bridge design commonly discussed in literature, see Figure 2. In the following sections, the results of the review of the four concepts are presented. The presentation of each concept consists of four parts, (i) results from international literature, (ii) results from Swedish literature, (iii) conclusions and finally, (iv) each chapter ends with the main key findings or key features of each concept.

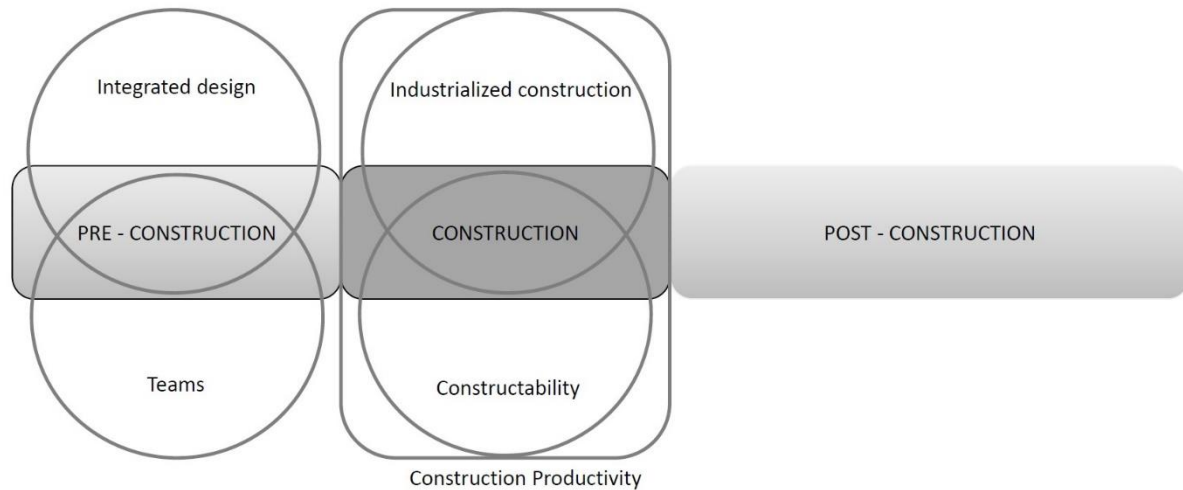


Figure 2: The studied concepts and their main point-of-departure in the design and construction process

2.1 Industrialised construction

2.1.1 International

Historically, industrialization has been associated and identified as a mass-production concept. As the development of industrialized construction is inspired by and has its foundation transferred from the process-controlled environment of the manufacturing industry this view has, in line with the manufacturing industry, evolved over time. Today, the concept is more consistent with philosophies representing a new way of thinking, organizing and utilizing industrial processes. Consequently, mass-customization is one of the major-drivers in the industrialisation development today. The main difference between new and old philosophies is basically the perception of project success. Emotionally charged factors such as value for money, zero defects, minimum waste and environmental impact are becoming more and more frequently ranked very high by both clients and the public¹⁴. This shift in view also influences the perception of, and consequently, the content in design.

Construction is often assigned with some special features when compared with other industries. These special features, such as one-off production, on-site production, long service life are often describe as one of the main reasons for the “problems” in the construction industry, see e.g. Ref. [15]. Construction industrialization has therefore mainly been a structural means in the elimination of these on-site activities, i.e. to utilize a high degree of pre-fabrication and modularization. Expected benefits have usually included saving in manual labour on site, faster construction process, and higher quality of components.

Ref. [15] suggests that the failure of implementation of industrial construction is related to the lack of a comprehensive theory of production. In Refs. [6, 16] the TFV theory of production is presented, meaning that production needs to be looked upon from the perspective of transformation (T), flow (F) and value (V). In construction, a single focus on transformation and a lack in focus on flow and value is usually apprehended. By neglecting flow and value the elimination of the special features of construction leaves construction in the same place as manufacturing was before addressing waste explicitly. Before concepts like lean production and quality management were introduced, a large amount of waste existed also within manufacturing¹⁵.



2.1.2 Sweden

In Swedish research, there has been a huge interest regarding the concept of industrialized construction, especially within industrialized housing, see e.g. Refs. [17-20]. For infrastructure structures, and particularly bridges, the research efforts have been less even though there are some, see e.g. Refs. [8, 21-24]. The interest in industrialized construction re-appeared at the end of last century after some time in dormancy and several of the major contractors in Sweden focussed on developing their housing business towards a more industrially customized production²⁵.

In Swedish literature, different views have emerged concerning the attempts of introducing industrial processes into construction. Debates regarding whether it should be called industrialized or industrialization of construction have been heard; it's been asked if it is the same as lean construction, or if it is all about prefabrication and off-site production? There is no clear consensus to these questions, neither in academia nor in the industry, but the attempt to distinguish the two made in Ref. [26] is appealing, even though this is directed towards housing and not construction of infrastructure, see Figure 3. If there will ever be a consensus or not is difficult to say and may not be particularly important. The real challenge the industry faces is probably how to implement the key aspects and benefits that are related to the change.

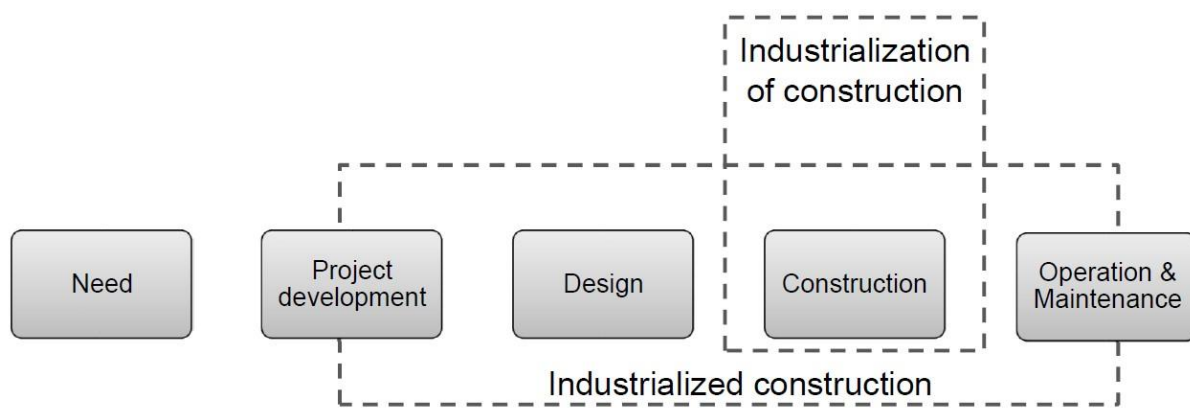


Figure 3: Different perspectives on how to adopt industrial processes in construction, redrawn from ²⁶.

These separate views indicate that industrial processes in general can be implemented in two different ways, incrementally or transformatively as highlighted by Refs. [27, 28]. The incremental approach draws on current practices and adds industrial approaches, such as off-site fabrication, mechanization, automation, to current work to generate expected benefits, i.e. industrialization of construction. Adoption of an approach of a more transformative nature requires a completely new perspective on projects and relies very little on current practices. The latter approach is the most common among industrialized housing companies²⁶.

From a strategical point of view, industrialised construction can be regarded as a production strategy aiming to create an efficient and productive production line. Industrialised construction needs, in contrast to traditional construction, a production system adopted to industrialised manufacturing²⁵. This will alter the company's requirements regarding organisation, business model, and product and production system. The most successful industrialized housing companies are therefore those who also fully adopted views and philosophies of lean. They have strategically chosen a well specified customer segment and exclusively operate under contracts where they control the entire process²⁶.

Several of the successful housing companies^{19,26} started off by taking control over the building process. In some sense, this means turning construction into production as far as possible. There is a large focus on minimizing the special features in construction by transforming construction into a manufacturing process, e.g. factory-produced modules which are later mounted at the site²⁵. This strategical view, automatically gives the customer or client a very important position. A market for industrialized construction needs to be present to create the drive for change.

In Ref. [21], a foundation for 'industrial bridge construction' is presented. Based on the TFV-concept presented by Ref. [6], which is one comprehensive theory for the construction industry, Ref. [21] presents three cornerstones of industrial bridge construction as process development, productivity development, and product development, which he refers to as the three P's. Serving as the natural link and generating a continuous circle of development between these three P's is information and communication technology, (ICT). The framework

stands in both an organizational/managerial domain and a technical domain. As process development has its main emphasis in the organizational/managerial domain, product development has its emphasis in the technical domain. Productivity development, which in some sense is a result of the two previous domains stands with equal shares in both domains, indicating that all parts need equal consideration.

Ref. [29] investigated drivers for and barriers to an increased industrialization within infrastructure projects. In the study, which was limited to the Swedish infrastructure construction sector, several key areas were identified and stated to act as core elements and barriers to increase industrialization in the sector. By the answers given from industry practitioners, the five most significant core elements were identified to be prefabrication, automation, planning for efficient production, continuous improvement, and integrated design and construction. Integrated design and construction originated out of statements regarding cooperation and communication amongst project participants. By that, it would be tempting to say that the other four elements are highly dependent on this single element. In other words, to be successful in the application of prefabrication, automation, continuous improvement and planning for efficient production we need cooperation and solid communication between project participants.

2.1.3 Conclusion of industrialization efforts in construction

One clearly important and central part of industrialised construction is pre-fabrication and modularization. But as stated by several authors, to establish a strong industrial concept, it is crucial that an approach with a holistic view together with systems thinking is adopted. The contemporary concept of industrialized construction is identified to consist of several sub-areas that need to be in place to achieve a more efficient, qualitative and reliable construction process¹⁹.

Inspired by Ref. [19], also Ref. [29] reports a model consisting of several characteristic sub-areas representing industrialized construction in infrastructure. A similar model can also be found in Ref. [22]. Although the models are somewhat different, there are clear similarities: that industrialized construction consists of continuous improvement, standardization of products and processes, distinct focus on customer value, and exploitation of ICT.

The flexible and adaptable organizations commonly seen in construction is also something valuable³⁰. These features generate an ability to mobilise on short notice. This can be discouraged by the one-sided topology that literature indicates that industrialized construction needs^{19,31}. To become an industrialized construction company, and to meet the challenges it requires, an organizational transformation is needed. This organizational change is mainly believed to be connected to the construction phase, the “production line”, and changes concerning the contractor. The demands and strains on the market and pre-construction stages that this change implies are usually over-looked or neglected in scientific literature.

Key findings: Holistic view, systems thinking, continuous improvement, standardization of products and processes, distinct focus on customer value and exploitation of ICT.

3 Constructability and Buildability

3.1 International

Constructability is an approach with the intent of linking the design and construction processes. The increasing complexity of many construction projects makes it more and more difficult for designers to be fully aware of all the implications of their designs³². During the late 1970's and early 1980's, two separate concepts were developed with the intention to increase the focus on details of production during the design process and to generate the missing link between design engineers and contractors³³. In the US, the term of constructability was stated by the CII Task Force as "the optimum integration of construction knowledge and experience in planning, engineering, procurement, and field operations to achieve overall project objectives"³⁴. A similar term, buildability, was defined in the UK by CIRIA in 1983 as "the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building"³⁵. Both concepts are a result of the increased awareness of the importance of the design phase and to what extent it influences operations during the construction stage. The overall aspect is to describe the importance to have a comprehensive view over the construction process and therefore not overlook project activities³⁶. Throughout the years, a vast number of studies have been done concerning the two terms, but in general, buildability



concerns to what extent the designer may influence the “ease of construction” on site, while constructability includes management issues and should describe “the optimum use of overall construction knowledge”^{9,34}. Making use of construction knowledge, from the earliest stages of a project where the ability to influence cost is at its greatest, makes sense from both practical and financial viewpoints³². This view is shared in other research, e.g. Ref. [37] states that to benefit from construction experts in construction planning, the contribution must be made from the first day of the project.

It is well known that the possibility to influence the properties of a structure is at its largest during the different pre-construction design stages. The choices made in these stages may also have an impact on the choice of construction method. The clear focus and intention by implementing constructability concept is to ease the construction stage, but the time for most the decisions to be addressed are concentrated to the design stages. How these critical decisions are made during design are influenced by perceived customer value by the decision maker.

3.2 Sweden

In Sweden, research concerning constructability and buildability as a concept has been scarce. When aspects of construction, such as the manufacturing, assembly, and on-site construction, are considered in the design, it can of course be referred to as considering buildability/constructability of a structure. Buildable structures is always something that is requested by the contractors, and to generate designs that facilitate this is a challenge for the designers. Ref. [38] conducted a survey among construction industry practitioners to map the transfer of construction knowledge. In design companies, which are knowledge enterprises, stored knowledge usually is available in reference documents from completed projects, and in the form of knowledge at the individual level. With inadequate management of information along with staff turnover there is a high risk of losing valuable knowledge if this is not handled properly. It is widely known that the ability to influence a structure and its future properties is at its greatest in early stages, i.e. the project preparation phase followed by the design phase. Ref. [38] concluded that even though there is an obvious need for construction knowledge in design work, there is a lack of a consistent and structured transmission of experience between the constructor and the designing engineers.

In a project initiated by the Swedish Transport Administration, STA, Ref. [8] makes an effort to combine the theories of buildability and Lean Construction in order to generate a theory more applicable to the Swedish infrastructure sector. The combination of creating buildability during the pre-construction stages and adoption of lean philosophies during the construction stage was adapted to improve civil engineering concrete construction work. The project had its primary focus on in-situ concrete bridge structures and how the use of industrial thinking could enhance the rate of productivity during construction. One, among several results from the project was that an early involvement from the contractor during the design phase was found to be a success factor. By studying full-scale projects, several improvements regarding productivity were made by adopting an alternative design process, production methods and choice of materials. In this case productivity was increased mainly through shortened time for construction. These improvements were made by simple means after applying a more general and holistic view and putting the finished product in the front room. The main important factors for increased productivity derived by Ref. [8] were;

- early project involvement of contractor and construction knowledge during design;
- project design in 3D and virtual work instructions for workers;
- thorough planning of the construction work tasks and material supply using lean tools;
- adequate attention to the working environment early in a project.

Unfortunately, as the project consisted of pilot studies, no long-term change was accomplished⁸. Even though significant improvements were made during construction, without the economic stimulation given in the pilot studies, short-term success in the next project had higher priority than long term business success. This behaviour is also highlighted by Ref. [30] and also highlights that there is a difficulty in balancing the short-term price consciousness and long-term resource consciousness. Long term competitiveness suggests resource consciousness, due to the fact that the lower-resource alternatives have a greater potential to result in lower prices later.

3.3 Conclusion of constructability concerns

The reasons to introduce buildability or constructability concepts into construction is generally to achieve reduced construction time and construction cost, and to obtain increased quality and safety. But this construction-related focus is not enough, there is a need to reclaim control over the design and construction processes. If the industry continue focusing on what can be done merely in the construction stage, success will continue to be occasional, but not introduce any long-term change.

It is clear, that constructability is intended to bridge the gap between different stages. It is equally clear that the potential and benefits from the investment in constructability efforts lie in the construction stage, it is an early involvement of construction knowledge during the pre-construction stages that is stressed to be crucial. Even though the technical knowledge is available, as well as the importance of addressing constructability issues are well established in the industry, the possibility to influence the properties of a structure during pre-construction design stages are unfortunately seldom fully utilized. To get the full benefit from constructability, literature often stress the importance of establishing constructability teams, and to work in a collaborative manner between all project participants to generate appropriate designs to facilitate construction.

Key findings: Holistic view, integration, critical design variables, waste reduction, teams

4 Integrated design and concurrent engineering

4.1 International

Integrated design (ID) or concurrent engineering (CE) are both concepts referring to a multidisciplinary concurrent work process³⁹. This is an approach intended to facilitate the relation between design and construction and is the contrary to the sequential and fragmented work flow which is characteristic for the construction industry of today^{39,40}. Concurrent engineering generally aims at reducing the duration of engineering time, increasing the value of the product, while at the same time reducing the cost.

The integration and concurrency in design is a way to address issues related to fragmentation and the traditionally sequentially divided process of engineering. According to Ref. [41], the construction industry is still governed by silo mentalities and cultures together with document-based information exchange across professions. The conventional design process is usually linear in character with limited possibilities in optimization or iterations⁴². Today's specialization of functions, i.e. silos mentalities, tend to be counterproductive⁴⁰, and this approach leads to poorly supported decisions, usually in the absence of holistic or comprehensive and accurate knowledge⁴¹. Addressing all life-cycle issues up-front in the design stage and ensuring that the design is 'right-first-time' should therefore lead to cost savings, products that precisely match customers' needs, and are of a high quality¹³. The intention with the integrated concurrent design, as in constructability and buildability, is to overcome the missing link between design engineers and contractors^{39,43}. That link should be established through the whole process of a construction, meaning from early planning, design phases, construction and finally use and demolition.

Ref. [6] found in his studies that the approach of concurrent engineering was very similar to the theoretical foundation of lean construction. The various methods, tools and practices of concurrent engineering could be directly explained by his TFV theory. Adopting a lean philosophy to design, means eliminating activities not contributing to the conversion to the final design⁴⁰. An adapted definition of concurrent engineering (CE) to construction is stated in Ref. [13]: "an attempt to optimise the design of the project and its construction process to achieve reduced lead times, and improved quality and cost by the integration of design, fabrication, construction and erection activities and by maximising concurrency and collaboration in working practices".

The nature of design, contrary to construction, is a qualitative, subjective and in some sense related to a high degree of uncertainty. The appropriate methods and practices to use are therefor also slightly different from those in construction⁴⁴. The benefits of concurrent engineering derive from the fact that it is focused on the design phase⁴⁵, which determines and largely influences the overall cost of a product¹³. Explained in relation to TFV, Ref [6] states that transformation view is used to map what tasks are needed and getting them done. From the flow perspective elimination of waste in the design process is primary, including reduction of rework, adopting a team approach, and to release information for downstream activities. Value generation is basically to generate the best possible value by the chosen design from the point of the customer. Such value generation



usually needs a proper customer requirement analysis and the development of design needs to be pulled from an end user or client perspective. Instead of maximization of output from each specialization or structural component level, a holistic approach needs to be adopted to maximize optimal performance on a systems level. Although, such an approach relies on an iteratively and incrementally developed design⁴², which within today's structures is difficult, or at least rarely achieved⁴¹. By adjusting how cross-functional and inter-organizational communication and collaboration is conducted, inaccuracies and mistakes from design affecting construction activities can be prevented to higher extent.

4.2 Sweden

Integrated design and concurrent engineering in construction is, to the authors knowledge, relatively unexplored in Sweden, at least at a conceptual level. When studied, the subject has mainly been elaborated on in relation to procurement issues or from a management perspective. It is recognized that methods with collaboration as a foundation have great potential for project success and have been shown to lead to improvements concerning time, quality, and costs⁴⁶. The foundation of such collaborative work is usually identified with the involvement of key participants early in the process, clear routines for conflict solving and teams selected on certain criteria with common goals. This view is supported in Ref. [47], where a successful collaborative design process is claimed to be a combination of the following constituents: early involvement, focus on value, measurement of performance, and long-term relationships. To produce and deliver high-quality and aesthetic structures, teams should consist of all the key-players, including the client and suppliers, together with the structural engineer and the contractor. Such a collaborative environment enables engineering input and knowledge of the construction procedures and materials science¹¹. Equally important, upstream activities need to establish a flow of constraints effecting downstream activities, from construction to design. How to establish such requirements and constraints in an integrated environment is studied in Refs. [48, 49], and how the active involvement of the client in design development and the use of visual management can positively effect the outcome for integrated design. These results are derived from teams which, supported by structured methods and visual means to improve the mutual understanding, worked in a collocated environment for one full-day per week. The need for collocation are both favoured and questioned in literature, and in practice sometimes difficult to obtain. Although, from studies of project teams in virtual settings, Ref. [50] shows that trust, clear communication, technical support, and overall corporate support are the four most important conditions for getting the work done in virtual settings. These success factors don't deviate from those derived for any collocated settings.

4.3 Conclusion of design integration in construction

The trend still, both indicated in literature and seen in practice, is that the relation between the structural engineer and contractor is established only in the later stages and in close relation to the construction phase^{27,42}. At this stage, all major decisions regarding the structural design and detailing have already been taken and the experience from the contractor which may generate an improvement to the design is more to consider as damage control than real transfer of knowledge. To include a collaborative approach, linked with an effective knowledge management system would facilitate options in design and engineering, based on alternatives which build both on prior knowledge and on topical alternatives⁵¹. In principle, to apply an integrated and concurrent design, there is a need to share information affecting downstream activities at early stages, even though the information may still be preliminary⁵². To do so, this requires trust among and between individuals. The integrated design approach, and concurrent engineering generates the environment to start the development of technology, product and manufacturing sooner than in sequential development. In addition, it requires large efforts in integration of teams, tools, and product information

Key findings: Holistic view, early integration, critical design variables, exploitation of ICT, teams

5 Integrated teams

5.1 International

How can we best benefit from an integrated and concurrent design approach? Among others, Ref. [53] states that the field of bridge design has become too complex to be handled by one person, or one role. The objective of the integrated design approach is to bring together the structural design and construction profession in one

“discipline”, comparable to the old role of a master builder. It is clear, in these days more and more industries have embraced the trend of using integrated design and integrated teams^{54,55}, so also within the construction industry. As a response to the construction industry’s lack of productivity and poor performance, use of teams are often identified to be needed even in construction⁵⁶. The use of teams generates an opportunity to use complimentary skills in reach for project success and to achieve high productivity, which cannot be achieved individually^{57,58}. Summarized from various definitions, Ref. [56] stated that integration can be defined as "bringing together different requisite and contributory functional disciplines to work in a continuous collaborative and cohesive manner to achieve more efficient and informed desired collective objectives."

In construction, integrated teams usually represent a coalition of individuals from different organizations⁵⁴, which might unintentionally increase the possibility of divergence between project participants and consequently, leading to time waste and rework⁴³. As a prerequisite for such teams to be successful, getting the right people, as well as securing their team’s development, is critical⁵⁹⁻⁶¹. The teams should, according to ⁵⁶, consist of personnel from owner, design-engineering, and contractor organizations, and these key members are recommended to be hand-picked and involved early in the projects as well as consistent through the different project stages. In design and construction, teamwork is usually not a mere option, but a prerequisite for successful delivery of a project. Efficiency for effectiveness within the team in a construction project is consequently necessary and always needs to be improved, and management of activities performed by individuals and groups of individuals within the organisation needs to be coordinated to ensure a value flow and an organised flow in the work schedule. Involved actors need to share information and knowledge to generate optimum decisions. By that, these individuals act as a “carrier of knowledge” and a bridge between, not only project stages but also, between different projects. Here lies a great responsibility at the client’s role. In the end, the client holds the main beneficial role of enhanced project performance, and should also establish the required and favourable environment for integrated teams⁶².

To develop a common understanding among all the team members, and to what is valued as critical for the project, affects how decisions are made concerning design issues. Successful teams in manufacturing are teams which have multiple-project experience, and have developed a shared culture and organization of work and design processes. Therefore, due to the short-term perspective, there is always a significant risk that design coalitions in construction will not perform well, or might even be dysfunctional^{54,55} if not well managed. Unfortunately, in most cases and projects, it is not possible for the constituent organizations to freely choose team members within the projects. The teams will consist of, at the time, available resources. In contrast to the manufacturing industry, integrated project teams in construction are normally brought in together for the first time and are assigned to the project on a temporary basis⁵⁴. Furthermore, in most cases, the team members work in several different other projects during the duration of the project. A fully integrated team⁶³, has developed a single project focus and objectives; boundaries between individuals are diminished and team members work towards mutually beneficial outcomes through the free sharing of information.

5.2 Sweden

That the composition of an organization is extremely important to achieve good results, is of course acknowledged also in Sweden³⁰. The integration of a team with knowledge that can contribute to the design, construction and management is critical to develop and achieve project value for the client and stakeholders²⁷. With a team approach to the design and construction process, this generates a common commitment amongst team members from early stages until the end of the project. Ref. [64] states that the establishing of a design team is a decisive part of the design process, and that the chosen team members need to represent all relevant stakeholders and should work closely with the client.

Ref. [30], uses a sport metaphor to stress the well-known importance of individual skills and how individuals are combined to form a team. As mentioned previously, for the project teams in construction the possibility to choose individuals is limited. Yet, the individual competences and composition of project teams are as decisive for the outcome, and e.g. Ref. [65] shows a clear link between an organization’s composition and rework cost. By establishing long-term relationships and aligning teams, both regarding work teams and project organizations³⁰, projects have lower defect costs than projects carried through by groups and individuals that have not worked together earlier.

The effects on the outcome of team-work is dependent on the established relation among team members. The importance of the physical presence of the client for success in collocated teams was studied in Ref. [48, 49]. Although, it is equally important to acknowledge the attitudes and the potential for improvement of all



individuals in the team³⁰. In the end, to reduce waste, is about understanding one’s role in how to increase customer value. But even more importantly, Ref. [30] stresses the ability – and the desire to develop the ability – to understand what adds value and what does not.

5.3 Conclusion of teams in construction

In most projects, the work is done in teams or groups, in one way or the other. The outcome of a construction project is in most cases dependent on the individual skills to collaborate and communicate. To establish teams requires investment in time, and all tasks or problems do not require fully developed teams to solve them. It is therefore important to utilize team-work approaches to the degree that it is necessary. For teams to be successful, getting the right people is critical together with the team development including a shared culture and organization of work and design processes. Based on established communication in and between teams, both risks and uncertainties are commonly reduced. The client holds the main beneficial role of an enhanced project performance and should establish the required and favourable environment for integrated teams to operate in.

Key findings: Appropriate members and team skills, sharing knowledge, culture, common goals.

6 Discussion

The discussion of the concepts is performed in four steps supported by the questions stated in the Introduction. Firstly, discussion concerns the construction stage, and how the production oriented concepts of industrialized construction and constructability are related. Secondly, the pre-construction stage is targeted and concepts mainly related to the design. Thirdly, interfaces between structural design and construction are highlighted, and finally the responsibility for generating the integration in construction is discussed. The discussion evolves around the idea to generate and condense the concepts into a few common features.

The reviewed concepts; Industrialized Construction; Constructability and Buildability; Integrated Teams; and Integrated design, are derived with different perspectives and origins, see Figure 2. However, the expected outcome and benefits from implementing any of the concepts are quite similar. In Figure 4 some of the definitions of the different concepts are displayed.

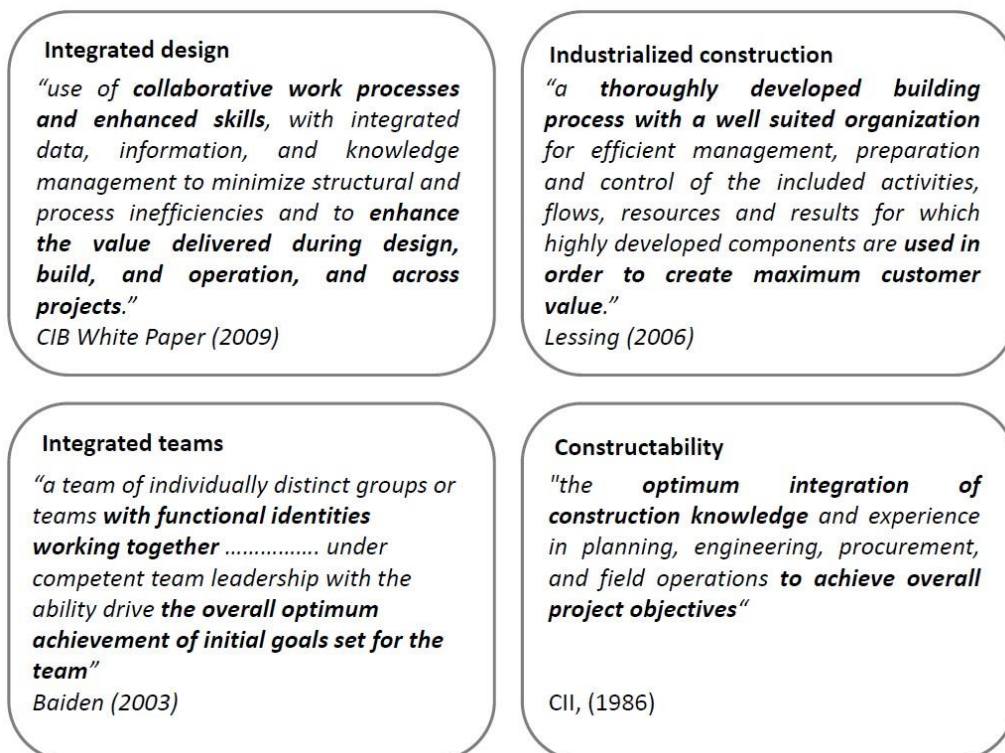


Figure 4: Some established definitions from literature for the different concepts.

6.1.1 Similarities between industrialization and constructability

There is a strong focus on facilitating the production system i.e. activities during construction. Both concepts include and utilize different production system techniques and such as standardisation, modularisation, prefabrication or off-site fabrication, on-site fabrication, pre-assembly, mechanisation, automation, and the use of different building systems. The primary focus of both concepts is, thus, at the construction stage and the importance to include production issues in design. However, the question of how to undertake design is not necessarily treated. Core elements derived in research strongly links important aspects of industrialization and constructability, see Figure 5, and most are also closely related to issues and activities made by the constructor in the construction stage.

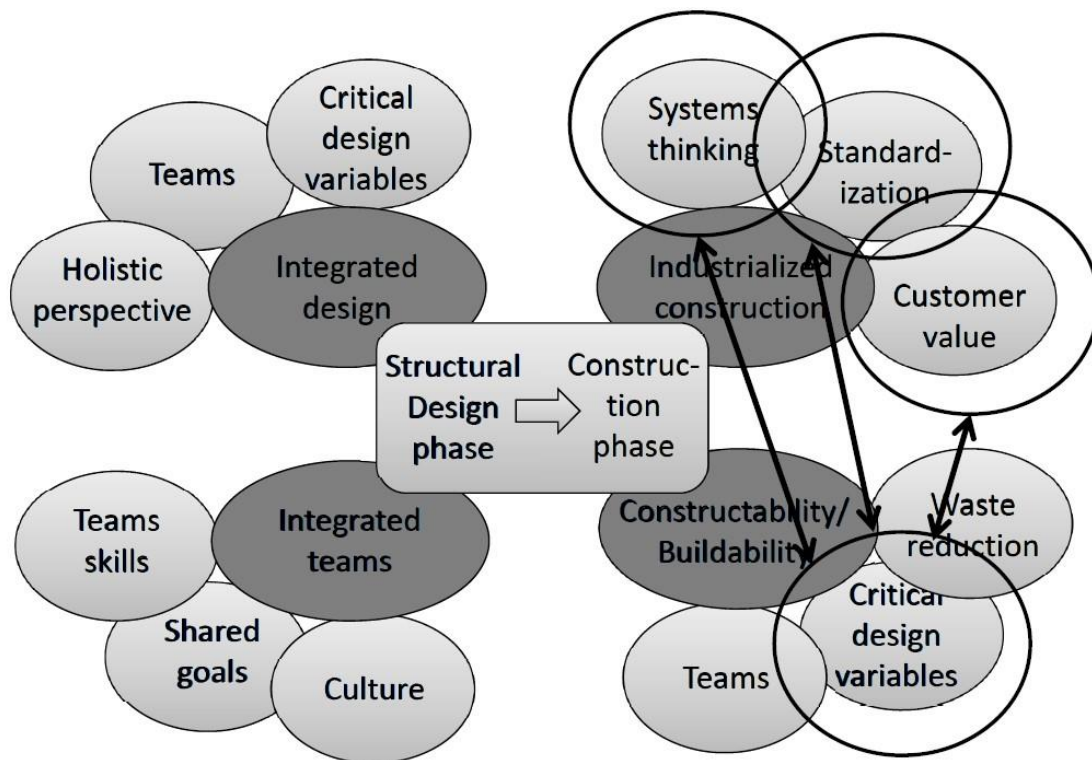


Figure 5: Core elements link important aspects of industrialization and constructability.

Industrialized construction has naturally, by e.g. value flow management for production, taken constructability into consideration in the process. Both concepts are separately striving for efficient use of its resources e.g. through the reduction of waste. To succeed, the concepts are also heavily influenced by both the design and operability of the structures. To reach the desired output, often measured in customer value, it is a necessity to clarify these values early, and to continuously monitor and follow up possible changes. In design, it is important to identify requirements and critical design variables affecting downstream activities. It is usually impossible to change the choice of production strategy, so when entering the detailed design phase, constructability should have been implemented as design constraints to reach a good final solution. This becomes even more important when having a fixed and well-defined construction method or production system.

6.1.2 Similarities between integrated design and integrated teams

The adoption of an integrated design approach automatically requires a holistic view to design. The intention with the integration is to overcome the linear and fragmented design which normally is undertaken. Ref. [66], stresses that the integrated team should be an ambition in construction due to expected improvements in delivery process efficiency, cost effectiveness and increased profitability. Most project teams in construction are short-termed and consequently, a sufficient level of trust might be difficult to develop. Yet, to realize the benefits from integrated design, this comes with the change in culture, and in the way team members relate with each other⁶⁷. In practice, given the holistic approach needed in concurrent engineering, this is often equated to establish and develop teams. As follows, the suitable environment to establish such a team is necessary, see



Figure 6. To summarize the essential aspects of Concurrent Engineering in construction, Ref. [43] chose the following:

- The identification of associated downstream aspects of design and construction processes. (Holistic perspective)
- The reduction or elimination of non-value-adding activities (made by teams according to Ref. [15])
- The development and empowerment of multi-disciplinary teams.

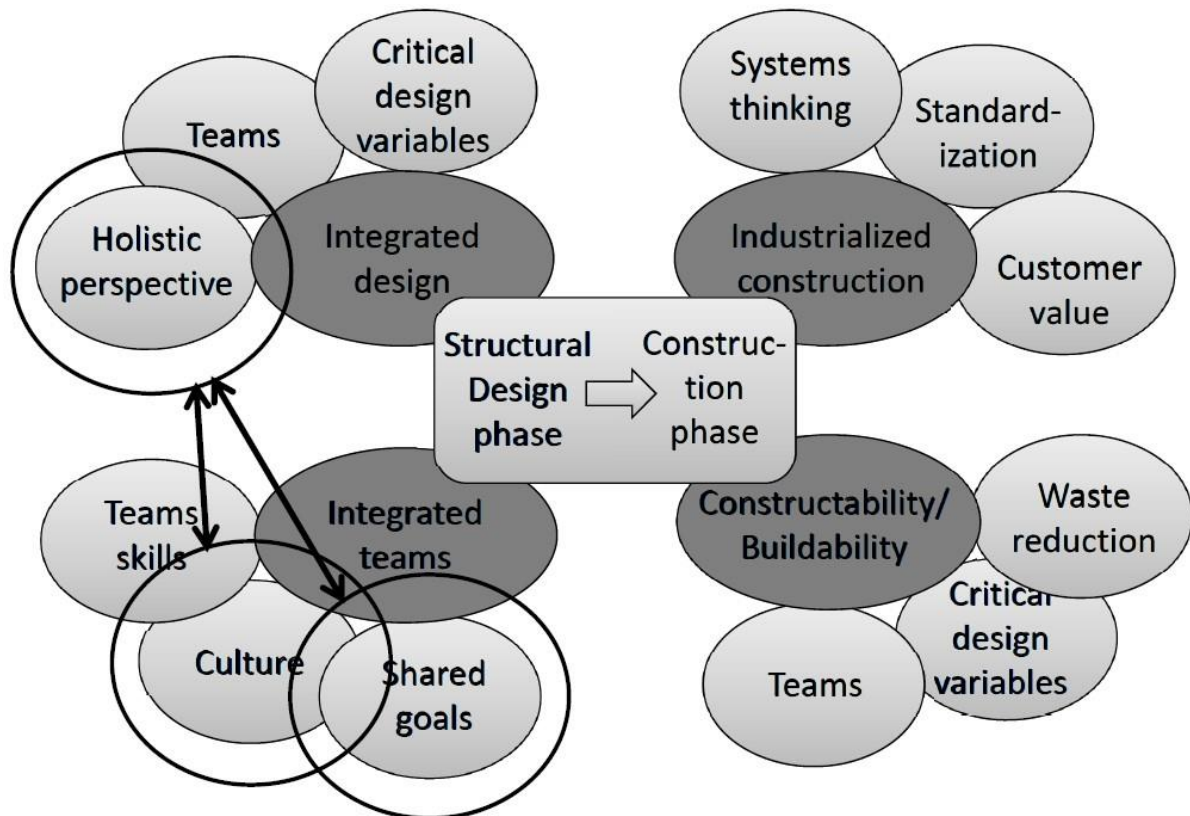


Figure 6: Core elements link important aspects of integrated design and integrated teams.

6.1.3 Interfaces between structural design and construction

To improve the relation between the structural design and construction, it is necessary to identify the common interfaces between the disciplines. With the complexity in construction today, it is important to consider the construction process as different stages with various outcomes as the primary objective, where structural design is one such stage. There are several and obvious aspects where choices in the structural design stage have a direct impact during construction. Some examples are listed below:

- Type of bridge, structural system
- Foundation
- Production method; phasing or sequencing
- Detailing, (e.g. reinforcement, connections, formwork)
- Safety
- Format of delivery
- Quantities (Optimization)

These aspects are also subject to uncertainty and risk in tendering for the contractor, e.g. Ref. [69]. To establish a collaborative and integrative environment in pre-construction activities would be an opportunity and one

natural way to minimize these factors of uncertainty and risk. By addressing how constructability issues already in early pre-construction stages the factors of uncertainty may in large be reduced. In industrialized construction, the process control provides just that through predictable and repeatable operations.

A large portion of the shortcomings that appears during construction can be related to design errors. The errors may vary, from being delivered late, incorrect, or even worse, non-existing. These design errors are due to many factors, but the most common factors are²⁷ (1) lack of communication between the client and the design team, (2) lack of understanding the production needs and that (3) construction documents are not ready when production begins. To overcome such inefficiencies, the designer or the design team needs to generate an understanding for site activities and core elements in construction, see Figure 7. By adopting a holistic view to design, and also a clear idea of how the work at site will be conducted, and by which tools and equipment¹¹, critical aspects for the design can be established.

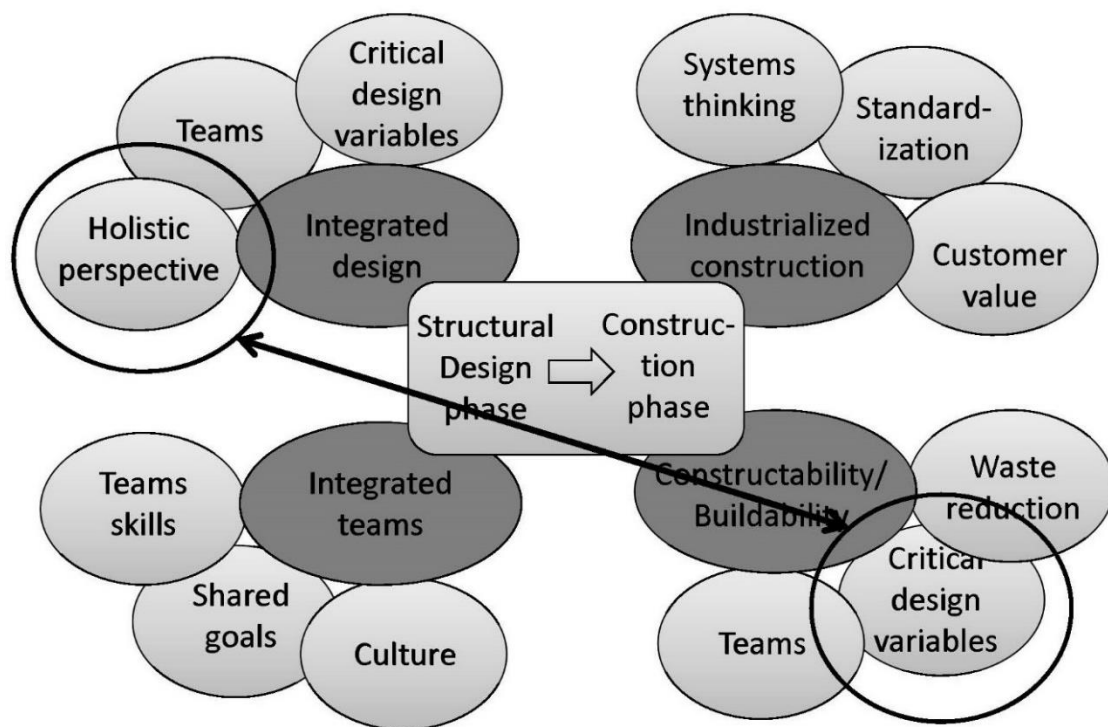


Figure 7: Core elements link important aspects of structural design and construction.

Is there any difference between organizational structures for the design consultant? Is there any way to adopt a design approach that considers all the special features that occur in construction? Probably not, and the reason for that is that we cannot predict the future. The aim ought to be to generate a support for sound decisions. How these pre-construction activities should be undertaken though, is rarely discussed in literature. One strategy for consultants to be competitive is to be flexible and adaptable to any kind of project and project organization. Up to date, implementation of approaches in design to meet the requirements of industrialized construction or constructability issues is scarce. Adapting to e.g. lean theories in design is difficult, and the literature is also very vague in this area⁶⁹.

To make a change to the prevailing way to work, the activities which occur early in the pre-construction stage need the attention proportionate to their importance. All stages are of importance, but focus needs to be put at doing the right things before doing things right. Consistently, the literature reports that the possibility to influence the properties of a structure is at its largest early on, i.e. during the different stages of design. These choices may also have a great impact on the choice of construction method. It is clear that timing of decisions is essential and according to Ref. [71], decisions regarding constructability are taken too late in the process in 20-70% of the cases. In which stage these interfaces acts and where the decisions are most efficiently taken, is not equally clear. Listening to advocates for the integrated design and construction process, though, it is easy to visualize that this still commonly occurs in very close relation to the construction phase.



As a parable, we can consider the constant battle between uniformity and variation in the discussion about standardization, between maximum standardization and flexibility. Standardization in production refers to both ease of construction, but also to ensure that components match. The most important part of standardization is the interface between the components rather than the component themselves¹⁴. For integration between design and construction, the same analogy applies, the interface between the processes is more important than the processes themselves. Here, we decide if we do the right things.

6.1.4 Responsibilities for integration

Integration is one clear and common denominator in the studied concepts. Integration as such can be relatively subjective and its content can have various meaning depending on who is sending and who is receiving. The general perception in the construction industry is, that the later the changes are made, the more they will cost. This is not unique to the construction industry and can be seen in any industry involving any sort of production. With that as a condition it seems obvious that time needs to be invested in the conceptual design phase to sufficiently clarify what the customer needs and values before narrowing down into possible options. Yet, even with this knowledge, the common projects are still typically end loaded.

To support integration, the use of information and communication technologies (ICT) is believed to play an important role by generating a continuous flow of information through the project life cycle, with increased transparency of projects and minimized risk for loss of information. The expected benefits are related to how things are built, to minimize the deficiencies and errors, and to create higher productivity and profitability for all involved parties. Unfortunately, this implementation has never materialized to the fullest potential, and many existing advantages and benefits that BIM can provide are left unused⁷¹. These claimed benefits from ICT have been available for quite a while, and according to a study by Ref. [73], at least some of these benefits were real. These benefits seemed to mainly be related the project level, whereas the benefits at both the individual and organizational level are still unclear

The importance of technical support activities is highlighted, together with the need to involve all actors to ensure an effective construction process. The communicated information between the actors and the possibility for integration is governed by the organizational level which the integration is made. Three hierarchical levels: macro-, meso- and micro-level are defined by ⁴⁴ to represent different social constructions. The macro-level incorporates the organizational level of all involved participants of a construction project. The meso-level represents the project team responsible for generating the design solution. Finally, the micro-level represents the collaborative space between individual project team members. Ref. [39] recommends that the integration is implemented mainly at the project level. This is supporting the use of integrated project team structures.

7 Conclusions

The adoption of a more process oriented and integrated approach in bridge construction offers many benefits, but industry practitioners still hesitate to adopt these approaches to the full. The development in construction of small and medium sized bridges has not been very progressive in Sweden over the last decades, and new techniques and methods are rarely presented. To adopt to an integrated approach in construction requires a change in the upstream activities of the design process. For construction to be more 'industrial', also design needs to be aligned with this process oriented approach. Industrialization of bridge construction of today is still a concept with highly unclear support from structural design and other pre-construction activities.

The presented work is the result of a review of approaches developed as a response to the increasing demand for more efficient and competitive ways to design and constructing bridges. Given by the vast amount of existing literature, to make a significant change in the industry and especially when a transformative change is asked for, is perceived as difficult and cumbersome. Changes of such category requires time and continuity to sufficiently monitor and measure the effects of any implemented changes. A detailed review of literature identified that the reviewed concepts are very similar, not only in their expected outcomes, but also in its governing features. Although the concepts are developed from different perspective and stages, the review suggests that there is a variety of factors influencing the adoption of each concept that are previously not connected to implementation difficulties. In this paper, the authors address this identified gap by adding a holistic interpretation to the governing features in each approach. The result of this detailed review identified a few main features that commonly influence the adoption to more process oriented and integrated approach in bridge construction. Besides the similarities between the main features which constitutes the different concepts, these main features can also be divided into (1) technical parameters: standardization of products and processes, critical design

variables, systems thinking and exploitation of ICT; and (2) non-technical parameters: holistic view, focus on customer value, continuous improvement, early integration, appropriate members and team skills, sharing knowledge, culture and common goals. The number of governing non-technical parameters linking the features out-numbers the technical parameters. Still, how to accommodate these non-technical parameters in integration, and how this affects the integrated team have been overlooked. How to sufficiently undertake design and how to facilitate a team approach during pre-construction stages are relatively unexplored in Swedish literature and needs to be addressed further.

As a contribution, the presented result provides an insight to both practitioners in the construction industry, as well as researchers, to the highlighted main features to consider towards the implementation of process-oriented and integrated approaches in bridge construction. It was identified that many of the main features are common to the concepts, and particularly that non-technical parameters outnumber technical parameters. To address these features requires an understanding normally over-looked in construction and constitutes a challenge in the transition towards change.

In this transition, it is of great importance that there are designers and constructors with the sufficient knowledge and tools to adopt to an integrative and collaborative approach. It is, however, equally important that the client takes its share of responsibility, creating the opportunity and space for the designers and contractors to operate in. This could include changes to regulatory framework, norms and design codes, choice of procurement practices, as well as actively taking part in, and supporting a collaborative environment. Within the sector of infrastructure, the main client, normally a public authority in most countries, acts as the single most important client. This monotony also generates great responsibility to the client in eliminating barriers that might hinder application of a collaborative and integrative environment.

Basically, all construction projects involve objectives that needs multi-disciplinary attention to be successful, intentionally or unintentionally. It is clear that it is difficult to separate one concept from the other. Also, when implementing change, the effort may not differ between them. As shown here, the concepts rely to a large extent on the same foundation, and therefore the key is not to carefully decide which concept to follow or adapt to, the importance is to decide to actually do something. If we expect to realise the benefits of an integrated design approach, the construction industry needs to face the challenge to reduce its knowing-doing gap. A change to the governing ad-hoc approach may very well start with the separate individual by putting customer value and the end product first, as well as the organisational support to such a culture. For example, there is no, and should not be any, conflict between prefabrication and on-site construction. Both are needed, and mostly in combination and they both need to continuously improve their performance. The construction industry itself needs to reflect and admit that we can do better. Instead of sitting waiting, it is time to walk the talk!



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Paper B

Integrated project team performance in early design stages performance indicators influencing effectiveness in bridge design

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Integrated project team performance in early design stages – performance indicators influencing effectiveness in bridge design

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ABSTRACT

To create multi-functional and integrated project teams, and to adopt a team perspective in the early design stages, it is recognised in the literature that a more effective process is required; one that reduces the probability of costly changes and difficulties during construction. This paper presents an evaluation of project team collaboration during early design and development of construction documents for bridges in Sweden. The purpose was to study key variables influencing the performance of integrated project teams by using importance performance analysis (IPA). A self-evaluation questionnaire addressed clients, contractors, and structural engineering consultants in the Swedish bridge construction industry. The questionnaire addressed three essential cornerstones of value-creation during the engineering design process; culture, structure and competence. These were addressed at three organisational hierarchy levels, the organisation, project, and the individual level. Our results show that increased support and resources are required at the project level for better project team performance. Results further identify that project culture needs to be developed including both collaboration and social relationships as well as project competence, especially the ability to solve mutual issues. This research offers a 'generalised' and prioritised view of the challenges in the Swedish bridge construction industry in terms of creating integrated project teams.

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Importance performance analysis (IPA); integrated project teams; organisational hierarchy; organisational structure; project competence; project culture

Introduction

The overall performance of construction projects has long been questioned and research frequently suggests that there is room for improvement (Egan, 1998; SOU, 2012). Due to its nature, construction projects are affected by several external factors such as; the environment, climatic effects, cost of energy, regulatory controls (Forbes & Ahmed, 2011), but also project performance is greatly affected by factors closer to the project setting and by the parties and individuals involved during the design stages. The construction industry is by tradition exposed to fragmentation within its delivery stages and with a relational short-term perspective (Anumba, Baugh, & Khalfan, 2002). This traditional approach creates several interfaces and deliveries between different professions during the process. Such deliveries and interfaces are often identified in the literature to be inefficient and the sources of waste (Forbes & Ahmed, 2011; Josephson & Björkman, 2011).

With a constant demand for resource efficiency together with an increased understanding of customer value, it has over the years become evident that the design and construction process need to be understood in another way to facilitate all the elements essential in delivering a construction

project. Many project-based industries have recognised that multidisciplinary teams can reduce the probability of costly changes and production difficulties. This is normally enabled by addressing design and production decisions earlier in the process (Anumba et al., 2002; Crowley, 1998). Activities in construction, both at the construction site and during the design stages, are normally performed by individuals with different skills belonging to different companies, all compounded into multidisciplinary and temporary organisations or groups. Here, these actors need to share information and knowledge for optimal decisions (Salas, Reyes, & Woods, 2017; Stewart & Barrick, 2000), an area where the construction industry is often found to lacking. To meet the challenges to achieve the desired integration of professions as well as to generate a more effective process within construction, the adoption of a team perspective is often a suggested approach (Egan, 1998; Larsson, Eriksson, Olofsson, & Simonsson, 2014; Latham, 1994; Oakland & Marosszeky, 2006). A large amount of research findings have also presented support for that integration, and especially for the potential benefits from a high degree of multidisciplinary involvement in early stages of design (Baiden, Price, & Dainty, 2006; Moore & Dainty, 1999; Simonsson, 2011).

As in most countries, in Sweden, a public authority acts as the single most important client in the sector of infrastructure, and in Sweden this is operated by the Swedish Transport Administration (STA). In addition to the STA, the Swedish bridge construction industry consists for the most part of approximately six to seven contractors and ten engineering consultancy firms active in bridge engineering design. Apart from very large projects, architects are very rarely used. Although these businesses have mutual differences, as a profession it is generally quite a homogenous industry.

Over the years the Swedish infrastructure market has been characterised by the traditional Design-Bid-Build (D-B-B) contract, but for bridge construction projects a modified version of Design-Build (D-B) contracts has been in use for quite some time, leaving the contractor with larger, yet limited, control of detailed design. During recent years the STA has offensively introduced more D-B-B contracts, but more collaborative approaches are sparingly tested in large scale infrastructure projects. Design and construction integration has been discussed in the literature for a long time, together with the ambiguous questions of contractual relationships and how to benefit from collaborative approaches between companies during long term relationships e.g. (Bygballe, Jahre, & Swärd, 2010). This challenge is still not completely understood and very little has been adopted within projects in the Swedish construction industry to date.

Adopting an integrated design approach and establishing integrated project teams (IPT) in the early stages intends to facilitate the configuration of an end-product with a structural design based on well-substantiated and reasoned decisions. By including clients, contractors, and structural engineers, these teams can promote improved cost effectiveness and productivity. The expected effectiveness in design is also commonly connected to what is referred to as highly functional teams (Baiden et al., 2006; Salas et al., 2017). However, how to best create and benefit from these teams is still not clear. For example, there are several interfaces in the everyday project setting where experience feedback and knowledge transformation are possible to use, and there are opportunities to take important steps to create effectiveness over time. But the long term business relations within project teams, including experience feedback over time, are scarce today and any systematic experience feedback or knowledge transformation is seldom or never utilised, e.g. (Gadde & Dubois, 2010). So, despite all previous observations, the mechanisms of how integrated project teams are established within projects and how to influence performance are still areas that need further clarification. Even though a lot has been done, previous studies fail to describe the effects in the teams, and especially from an engineering-contractor relationship.

The purpose of this research was to investigate the key variables influencing the performance of integrated project teams in Swedish bridge construction projects.

As a result of one of their internal productivity initiatives the STA identified several product categories within its operations that are considered particularly suitable for industrial and/or serial construction (Trafikverket, 2014); and one product category consisted of bridges. Bridges in this product category are generally characterised to be smaller bridges with a span length shorter than 20 m, and

to have low geometrical complexity. This category of bridges is the most commonly built bridge in Sweden and therefore this survey focused on the performance of teams in such everyday projects, thus limiting the scope to this product category. The aim of the research was to identify critical areas for improvement of team performance to support effectiveness within the Swedish bridge design teams. Team performance, though, is a multifaceted area so it was also crucial to identify factors that are perceived as critical and most important regarding team performance in this context.

This paper presents an evaluation of project team collaboration during early design and development of construction documents for bridges in Sweden. To support the team performance evaluation a theoretical framework was created to inform the questionnaire survey. The questionnaire addressed three essential cornerstones of value-creation during the bridge engineering design process; culture, structure and competence; and at three organisational hierarchy levels, the (macro) – organisation, (meso-) project- and (micro-) individual-level. The self-evaluation questionnaire addressed clients, contractors, and structural engineering consultants in the Swedish bridge construction industry. An effective method to set priorities is importance-performance analysis (IPA), introduced by Martilla and James (1977). The IPA provides a useful tool to identify the most critical attributes regarding the need for managerial measures, thus informing the objectives of this study:

- (1) to provide practical guidance for resource allocation for project team performance improvements by proposing focus areas based on the results of the importance-performance analysis, and
- (2) to use importance-performance analysis to identify how different disciplines perceive and perform on various project team aspects, thereby classifying the aspects according to their managerial priorities.

Findings highlight that the greatest potential for overall improvement is at the project team level. Also, our results propose three prioritised areas to support integration for construction project organisations; project culture, organisational structure and project competence.

Selected theoretical framework for studying team integration in construction

In the following sections relevant literature related to teams in construction, driving forces for customer value and organisational hierarchy is presented to support the development of a framework to evaluate project team performance.

Teams in construction

In modern construction, management interest has increasingly shifted towards teams. For example, (Salas et al., 2017; Stewart & Barrick, 2000) assert that teamwork is not an option, it is a prerequisite for the successful delivery of construction projects. In fact, the general view is that teams are expected to deliver better results than the average collection of individuals (Katzenbach & Smith, 1993; Wheelan, 2016).

Examples of successful teams in manufacturing are teams sharing experience from multiple projects, and who have developed a shared culture and organisation of work and design processes. Project teams in construction on the other hand, usually work together only for the development of a single project and consequently rarely work together on more than one project (Anumba, Kamara, & Cutting-Decelle, 2007; Senaratne & Gunawardane, 2015; Senaratne & Hapuarachchi, 2009). As a consequence of the prevailing short-term perspective in construction, there is always a significant risk that, if not well managed, design coalitions in construction will not perform well, or might even be dysfunctional (Forgues & Koskela, 2009; Sumner, Domingue, Zdrahal, Millican, & Murray, 1999).

Integrated design teams, as used in construction, serve to remove the traditional separation between design engineering and construction planning. Bringing together individuals and organisations with different knowledge and skills also creates a culture of efficient and effective collaboration to enhance the outcome of construction (Anumba et al., 2002; Owen et al., 2010). This integration normally requires overlap of domains, for example, that a contractor takes part during design development and in the conceptual discussions or even to compete with different bridge concepts, or the structural engineer gets involved in upstream activities to support in the architectural design (Uihlein, 2015).

In their research, Forgues and Koskela (2009) found two opposing transition paths from traditional design practices towards new collaborative approaches; a development from a linear and sequential to an iterative design process; or a change in how projects are procured. Furthermore, when discussing integrated projects, it is normally the contract or the way of procurement that is given the primary focus (Kadefors, 2002; Mosey, 2009; The American Institute of Architects California Council, 2007). This limited focus is usually not enough and therefore a far too narrow interpretation for moving from fragmented to integrated design (Forgues & Koskela, 2009). Problems with project performance of integrated design teams are in general related to the context and not necessarily the process itself, i.e. they are not technical but socio-cognitive (Baiden, Price, & Dainty, 2003; Forgues & Koskela, 2009; Moore & Dainty, 1999).

Collaborative procurement approaches, such as Partnering (Bygballe et al., 2010; Kadefors, 2002) or Integrated Project Delivery (The American Institute of Architects California Council, 2007) for example, function to stabilise and formalise the patterns between the client and its suppliers and improve the environment for integrated design team performance. Yet, Forgues and Koskela (2009) also bring attention to the need for change in relational patterns. The lack of socio-cognitive attention in design is supported by the results from (Cross & Clayburn Cross, 1995), who concluded that, especially in the engineering domain, the design process is normally treated as a technical process: a rationalised approach as a sequence of activities to solve a technical problem. Team work, however, is not only a clearly social process, the outcome of design is also limited to the cognitive skills and limitations of the individual designer/engineer. Cross and Clayburn Cross (1995), recommended treating the design process as an integration of a technical, a cognitive, and a social process.

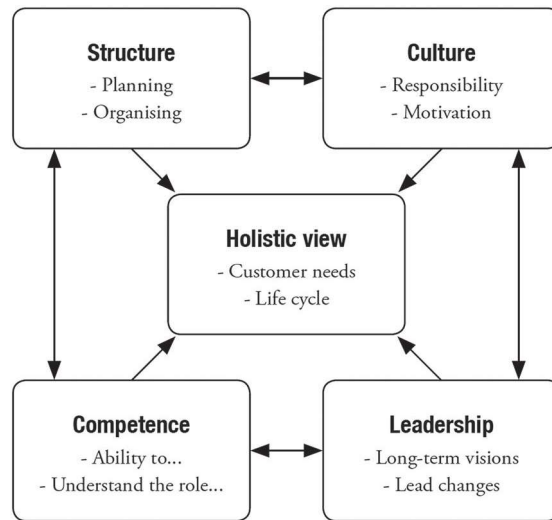
Driving forces for customer value

To address the shortcomings in construction, Josephson and Björkman (2011) suggest a holistic approach to minimise waste in construction and ultimately generate higher customer value. The recommendation is derived from a comprehensive study conducted within the Swedish construction industry. The authors formed several discussion groups consisting of experienced people to list root causes of waste in construction. Waste as a concept is a commonly used term, both in industry and academia, but can be interpreted very differently. Josephson and Björkman (2011) support their framework and recommendations by stating a definition in line with Womack and Jones (1996) and address waste as predominantly considered as activities and tasks that are performed but that do not add any value to the customer.

Josephson and Björkman (2011) presented waste as a complex system of several causes, ultimately categorised under five main groups of characteristics for effective operations: (1) holistic view, (2) culture, (3) structure, (4) competence, and (5) leadership, (see Figure 1). The four cornerstones (2)-(5) are of equal importance. If any of the cornerstones, which act as driving forces in minimising waste are neglected the pyramid will be skewed, and the full potential of waste reduction not obtained.

Organisational hierarchy

From a study of the interaction between architects and engineers, Moum (2006) presented a framework consisting of three hierarchical project levels: macro-, meso- and micro-level. Many different authors besides Moum (2006) have clearly indicated the importance of a flow of information also through the organisational hierarchy, e.g. (Hughes, Ginnet, & Curphy, 2013; Moum, 2006; Josephson & Björkman,



(a)

- | | |
|----------------------|---|
| <i>Holistic view</i> | - By an inadequate overall view, we mean partly the inability to understand the purpose of all activities carried out and partly to understand how the different sub-processes in a project are linked together. It also implies an inability to identify what is of optimal benefit to the customer, to the product, and to all contributing actors. |
| <i>Culture</i> | - A set of attitudes and values shared by a group of people leading to a certain behaviour within a group. |
| <i>Structure</i> | - Includes planning, co-ordination, procurement, and the management of resources at all stages of the project. |
| <i>Competence</i> | - Described as the ability of organizations and individuals to both carry out their tasks as well as understand how value can be passed on to the end customer. |
| <i>Leadership</i> | - How executives and project managers influence the group's attitudes and values. Leadership thus has a large influence on group culture. |

(b)

Figure 1. Value pyramid - Characteristics of effective operations (Josephson & Björkman, 2011).

2011). This multi-level perspective originates from group development literature as an integration of several research models into a unified approach on groups. The multi-level perspective suggests that understanding of group development and success requires attention to all levels (Forsyth, 2014). For example, Hackman (2003) stresses and describes that group behaviour can be broken down into three different levels: the organisational or societal level (macro), the group level (meso) and the individual level (micro). Also, the framework presented by Moum (2006) indicates that even within small projects the relations between project participants can be complex and that a design team is influenced by many other parameters. Such parameters are normally outside the team's control and at many different organisational levels. Moum (2006) was also able to identify that different social constructions and non-technical parameters also influence the integration in construction.

A similar concept is also presented by (Ginnett, 1993; Hackman, 1987) cited in (Hughes et al., 2013), which they call organisational shells. Their model is derived and presented from a leadership perspective and describes the dependency between the team (cockpit crew) and its surroundings as different layers of a concentric circle with the team at work as the core. The team is in critical need of

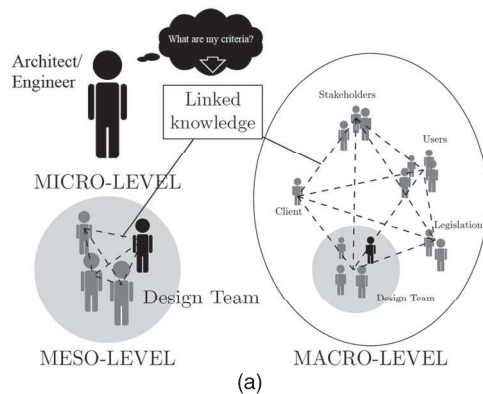
information and input from the surroundings to perform, and for a team to work effectively, information regarding four variables needs to be in place: such as task, norms, boundaries, and authority. The content of these variables are similar to the four driving forces described by Josephson and Björkman (2011) for reducing waste.

Method

In this section, the development and execution of the framework, data-collection, IPA and survey-analysis are presented.

Framework

To examine how the collaboration between different disciplines works during the planning, design, and development of construction documents for new bridges in Sweden, the authors established the framework presented in Figure 3. The framework was developed by combining the theoretical references, previously described in Figure 1 (Josephson & Björkman, 2011) and Figure 2 (Rempling, Fall, &



Macro-Level	Organisational Level	<ul style="list-style-type: none"> Qualities, characteristics, and processes of the larger collectives of which a group is a part of (i.e., the organization or the community). (Hackman, 2003) Incorporates all participants of a construction project: architects/engineers, contractors and users. (Moum, 2006)
Meso-Level	Project Team Level	<ul style="list-style-type: none"> Qualities, and characteristics of the group as a whole, such as how cohesive the group is, what is its size, how is it structured, etc. (Hackman, 2003) A conglomerate of stakeholders with separate interests and expectations is boiled down to a design team with the mandate to uncovering the mutually beneficial expectations of the stakeholders (Moum, 2006)
Micro-Level	Individual Level	<ul style="list-style-type: none"> Personal qualities and characteristics of individual group members, as well as their actions. (Hackman, 2003) The collaborative space between the architect and the engineer. (Moum, 2006)

(b)

Figure 2. Organisational hierarchy (Rempling, Fall, & Lundgren, 2015) modified from (Moum, 2006).

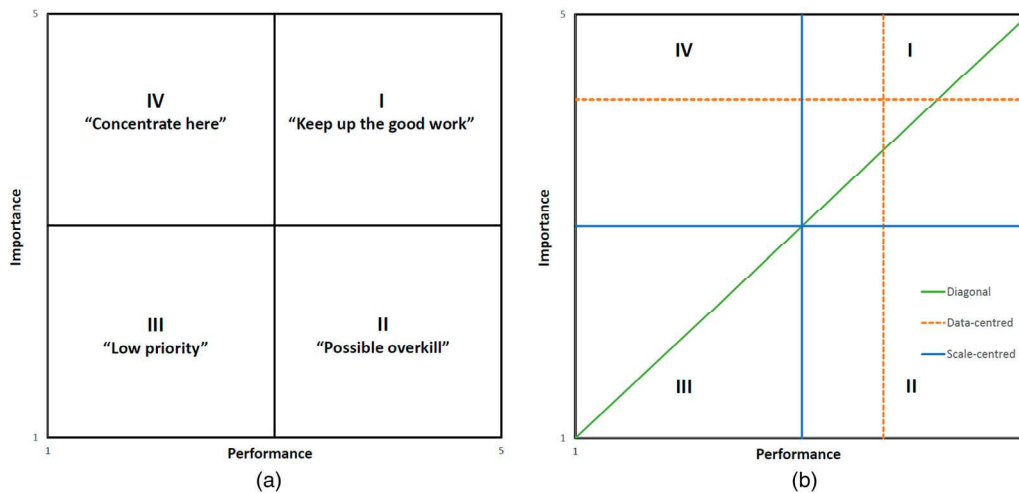


Figure 3. Left: Traditional IPA Right: Scale-centred or data-centred crosshair point.

Lundgren, 2015), and was designed to evaluate prevailing attitudes and identify possible opportunities and obstacles for more integrated cooperation between different professions. The framework consists of a vertical and a horizontal dimension to form a matrix-analysis. From the matrix, it is possible to identify different areas of measurement in the crossings between the vertical and horizontal dimensions. To follow the framework questions were developed with inspiration based on a self-assessment questionnaire (Wheelan, 2016). This type of questionnaire is commonly used in team literature as an indicator to provide aid to identify how to develop a group of individuals into high-performance teams (HPT). The questions were sorted and organised into the three different levels of organisational hierarchy: organisation, project, and individual and finally to the driving forces for customer value: culture, structure, and competence, see Figure 3.

The design of the questions for each level; organisation, project and individual, was made as statements, such as:

- *My organisation encourages ...*
- *The project team has ...*
- *I support ...*

Unlike the original questionnaire, (Wheelan, 2016), the number of statements were limited to 15 for each organisational level (45 statements in total). Also, some statements were altered to better fit the situation, although the initial meaning of the statement remained unchanged. Reducing the number of statements was an attempt to minimise the risk of exposing respondents to survey fatigue. For the same reason, the variable of leadership in the model, see Figure 1, was not addressed in this part of the research. The importance of good leadership for the success of a team cannot be stressed enough, which is also reflected in the vast amount of research done in that area. However, for these reasons, the influence of leadership was left out for the benefit of the other measurements.

Data collection

The respondents were presented with 45 statements and were asked to answer to what extent the statement agreed with their way of working (performance) and to what extent this was important for the degree of project success (importance). Each statement was measured on a 5-point Likert scale, see e.g. (Bryman & Cramer, 2011), where 5 represents a high degree of conformity and 1 no

conformity. By adopting a Likert scale to the responses it is possible to assign a numerical value to something that is a subjective opinion (Bryman & Cramer, 2011). In addition, for each statement, the respondent was given the opportunity to add additional text to support their answers.

The respondents were given a short written introduction to the aim and scope of the survey. The introduction was given to support coherence amongst the respondents regarding a target case, which they were asked to relate their responses to.

The survey was administrated to clients, contractors, and structural engineering consultants in the Swedish bridge construction industry, and distributed electronically. A total of 134 persons completed the survey. Besides the major client, STA, the respondents represented some of the largest construction and consultancy firms in Sweden. Of the 134 survey respondents, there were 20 representing the client, 52 a contractor, and 62 a consultant. The majority of the respondents were working in either detailed design (50) or in the construction stage (49) and the work is in general performed in relation to a design-bid-build contract (65) or a design-build contract (46). 64 of the respondents (50%) had 16 years or more of industry experience and 81 had some sort of management position whereas 28 managed 16 people or more.

Importance performance analysis

The Importance-performance analysis (IPA) model was initially presented and introduced by Martilla and James (1977) with the intention of providing a simple and graphical tool for the development of business marketing strategies (Abalo, Varela, & Manzano, 2007). Supported by literature, Martilla and James (1977) defined customer satisfaction as a function of two components: the importance placed by customers on a product or service and the performance of that product or provision of service. The key objective of IPA is diagnostic in nature: the technique aims to facilitate identification of attributes for which, given their importance, the product or service underperforms or overperforms (Abalo et al., 2007). Combining the importance and performance measures allows for the IPA to be presented as a grid divided into four quadrants that offer a visual understanding of overall user satisfaction (Bruyere, Rodriguez, & Vaske, 2002). The four quadrants are normally interpreted as 'keep up the good work', 'concentrate here', 'low priority' and 'possible overkill'. Here, the importance measure is represented on the vertical axis, and the performance measure at the horizontal axis of a two-dimensional graph, see Figure 4.

IPA is a popular and widely spread method used in many different fields, both in academia and practice. The health care and tourism industries are the most frequent users, but the method is well documented also in the field of construction management (Albaloushi & Skitmore, 2008; Chang et al., 2017; Eom et al., 2008; Eom & Paek, 2009). Similar approaches also exist, for example in (Jergeas & Van der Put, 2001) to evaluate potential benefit and the effectiveness of applying constructability principles in the Canadian construction industry. Also, (Al Mousli & El-Sayegh, 2016) assess the design-construction interface problems in the United Arab Emirates construction industry. However, difficulties in IPA application have become apparent and have prompted several IPA versions that generally differ from Martilla and James' original version. From two recent reviews, (Azzopardi & Nash, 2013; Feng, Mangan, Wong, Xu, & Lalwani, 2014), four different approaches can be

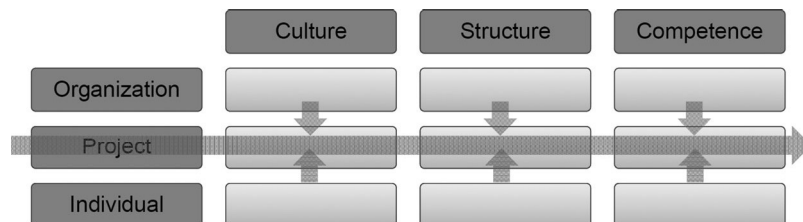


Figure 4. Survey evaluation matrix.

clearly distinguished from the literature as most selectively used regarding IPA; (1) Traditional IPA, (2) Gap 1 analysis, (3) Gap 2 analysis, and (4) three-factor theory.

The most apparent differences can generally be divided into two ways. First, the grid partition into areas with distinct significance for decision-makers. Where to place the crosshair point, normally scale-centred or data-centred, and to generate the axes in a four-quadrant grid then becomes rather subjective and depends on the researcher’s objective. Second, the measurement of both importance and performance, where in traditional IPA the assumption is that performance and importance are two independent variables. Oh (2001) on the other hand, argues that the IPA graphical representation implicitly assumes at least some form of correlation between importance and performance. Also, Martilla and James (1977) indicated that importance and expectations are potential antecedents to performance. When using IPA, according to Matzler, Bailom, Hinterhuber, Renzl, and Pichler (2004) the user needs to be aware that a change of performance can be associated with a change of importance.

In IPA literature there is limited empirical evidence to support which of the derived and direct importance approaches performs best in assessing the relative importance in IPA application. IPA literature does not identify any approach that distinguishes itself in addressing validity concerns, but a few empirical studies have provided some guidelines for applying IPA (Azzopardi & Nash, 2013). For example, Feng et al. (2014) show that somewhat varying and conflicting results can be provided by the different approaches. The value of using IPA is to evaluate relative importance and performance scores (Martilla & James, 1977). To use an absolute evaluation significantly limits the discriminatory and predictive power of stated importance measures (Azzopardi & Nash, 2013). The analysis used here follows the procedure proposed for the traditional Importance-Performance Analysis (IPA) together with the Gap 1 analysis, described by (Feng et al., 2014).

Survey analysis

Five statements are presented within every area leaving the range of score in each block between 5–25, and the total score for each organisational level in the range of 15–75, see Figure 5. In the analysis, it is possible to generate a mean value for each indicator leaving the final total score for each organisational level on a range of 5–15. By using this kind of multiple-item scale it is more likely that the generated responses give a broader view of the concept measured. This also makes it possible to draw finer distinctions between the different indicators and also minimise the error from questions being misunderstood (Bryman & Cramer, 2011).

Research has established that from the characteristics of a team it is possible to determine a team’s development level, and also a relationship between a team’s level of development and its performance. The concept of team development has over the years been well documented and multiple

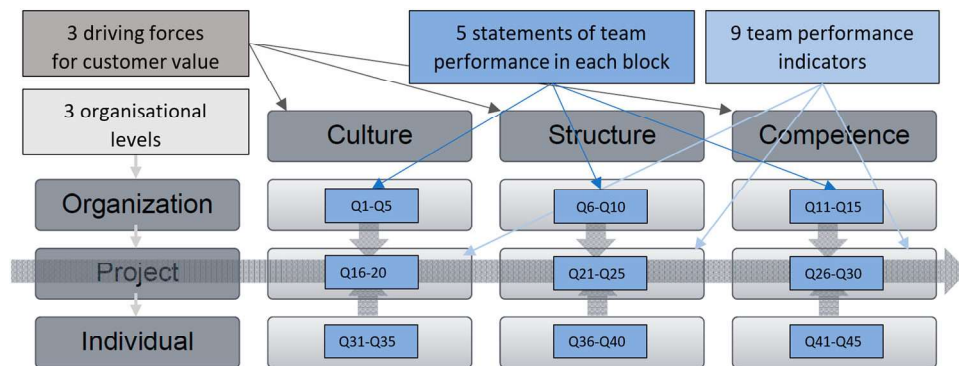


Figure 5. Survey evaluation matrix, explanation.

authors have established theories in the field of team formation and its performance e.g. (MacMillan, 2001; Tuckman, 1965; Wheelan, 2009). Teams functioning at the higher stages of development are found to be more productive (Wheelan, 2009, 2016). Scoring high on performance in the evaluation would indicate a highly mature and effective group, a so called high-performance team (Wheelan, 2016). Wheelan (2009, 2016) divides her integrated model of group development into four stages described as, (1) dependency and inclusion, (2) counter-dependency and fight, (3) trust and structure, and (4) work, a stage of intense productivity and effectiveness. In addition to determining performance, the respondents were asked to evaluate the importance of each statement regarding project success.

Results

The scientific framework applied generated three units of analysis, one for each organisational level: organisation, project, and individual, with three attributes corresponding to the driving forces for customer value studied: culture, structure, and competence as described previously in the *Driving forces for customer value* section. The results were treated and analysed within each of the three levels and its three attributes, which correspond to the nine blocks of the evaluation matrix in Figure 5. Each block serves as a team performance indicator. The mean values and the standard deviation of individual responses were calculated for each of the nine blocks, and this data is presented in Table 1. The gaps between the presented importance and performance from utilising a team approach in project settings were also calculated.

Based on the performance ratings, the respondents consider the average project team to range from a low to a moderate level of maturity in performance, see Table 1. The total score, 10.65 out of 15, indicates that the average everyday infrastructure project team only reaches stage 1 or possibly 2 [(1) dependency and inclusion, (2) counter-dependency and fight] according to (Wheelan, 2016). This low maturity level within construction teams is common knowledge and often highlighted within the literature, either as shortcoming in project outcomes (Egan, 1998; SOU, 2012) or more specific as dysfunctional teams (Forgues & Koskela, 2009; Oakland & Marosszeky, 2006). The underlying reasons for the shortcomings in team development, or what to do about it are not clearly stated or understood. Following the same analogy when evaluating importance ratings from a team perspective, the respondents are expected to perform at the higher level in order to be successful in projects. Still, this score only reaches level 3 [(3) trust and structure] according to (Wheelan, 2016) in team performance. So, the teams are not perceived as high-performance teams by the respondents.

Level of importance

In general, as shown in Table 1, there are very small differences on the total scores between the three assessed organisational levels indicating them being valued equally important by the respondents.

Table 1. Overall summary of survey results (mean values).

	Culture	Std	Structure	Std	Competence	Std	Total
Organisation							
Performance rating	3.82	0.601	3.69	0.630	3.64	0.730	11.14
Importance rating	4.32	0.467	4.29	0.524	4.12	0.693	12.73
Gap	0.50		0.60		0.48		
Project team							
Performance rating	3.38	0.717	3.75	0.597	3.53	0.611	10.65
Importance rating	4.08	0.619	4.25	0.614	4.13	0.614	12.46
Gap	0.70		0.50		0.61		
Individual				0.702	4.16	0.556	11.75
Performance rating	3.91	0.535	3.68	0.702	4.16	0.556	11.75
Importance rating	4.15	0.604	4.19	0.595	4.31	0.576	12.65
Gap	0.24		0.50		0.16		

Note: Std: Standard deviation.

The score ranged from 83% to 85% of the total where organisation was the level with the highest score for *importance*, 12.73 out of 15. While looking at the different attributes, the mean values, as can be seen in Table 1, the *importance* varied within a fairly high range from 4.08 to 4.32. The three most important team performance indicators according to the survey respondents were *Organisational culture*, *Individual competence*, and *Organisational structure*.

Level of performance

For the performance ratings, in contrast to the importance ratings, there was a larger spread in the total score ranging from 71% to 78%. In general, the *performance rating* generated lower values on the total score, and also with a wider range compared to the *importance rating*. Here, the organisation level generated the highest total score with 11.12 out of 15, whereas project team level was marked with the lowest level of performance amongst the respondents. In Table 1, the mean values for *performance* vary within a range from 3.38 to 4.16. The three team performance indicators rated to be working the best today were *Individual competence*, which is the only performance average above 4, *Individual culture*, and *Organisational culture*.

Importance-performance analysis

The mean values of importance and performance scores for the three disciplines were calculated separately and the scores of each team performance indicator were compared against the grand mean value. The results, when mapped on the IPA grid, positioned the nine indicators for the three disciplines, see Figure 6(a)–(d). The diagonal indicated in the graph represents points of equal importance and performance ratings. Consequently, points above the diagonal are rated to have higher importance than performance. Attribute importance is represented on the y-axis and its corresponding attribute performance is presented on the x-axis. The four quadrants in the analysis are generated by the crosshair placed at the mean rating from all respondents. This data-centred placement is one of two common ways to place the crosshair in IPA literature (Azzopardi & Nash, 2013). When presenting the result in the IPA, importance shows a small spread in average values. This small spread gives an indication that the respondents have a high level of awareness of important team characteristics.

For average performance ratings, the spread is larger, indicating a clear gap between respondents' awareness regarding the critical team performance indicators and their actual behaviour in everyday work. Given that the importance scores are higher than performance scores indicate that there is room for improvement in all areas regarding team performance. When plotting the team performance indicators from all the respondents in the IPA grid, Figure 6(a), the result is quite densely situated around the average value, except for individual competence, (circle with red edge). In general, all indicators are underperforming, i.e. all indicator values score lower in performance than in importance.

For the clients, Figure 6(b), all the average values for the indicator located are above 4 in importance rating, which means important, but only one indicator is higher than 4 in performance rating which means good. According to Figure 6(b), all indicators are underperforming but 6 out of 9 are located above average for both performance and importance. Even though the values for the client show the largest spread of the indicators they are still quite close, and slightly above the overall average. For the client, 6 indicators fall in Q1 'keep up the good work', 0 indicator in Q2 'possible over kill', 3 indicators in Q3 'low priority', and none of the indicators fall in Q4 'concentrate here'.

For the contractor, Figure 6(c), the results show that 7 out of 9 indicators are ranked above average performance, while 6 out of 9 attributes are above the average importance. The result for the contractor shows the smallest spread in indicator averages, but with the main point above the grand mean. Here 6 indicators fall in Q1 'keep up the good work', 1 indicator in Q2 'possible over kill', 2 indicators in Q3 'low priority', and none of the indicators fall in Q4 'concentrate here'.

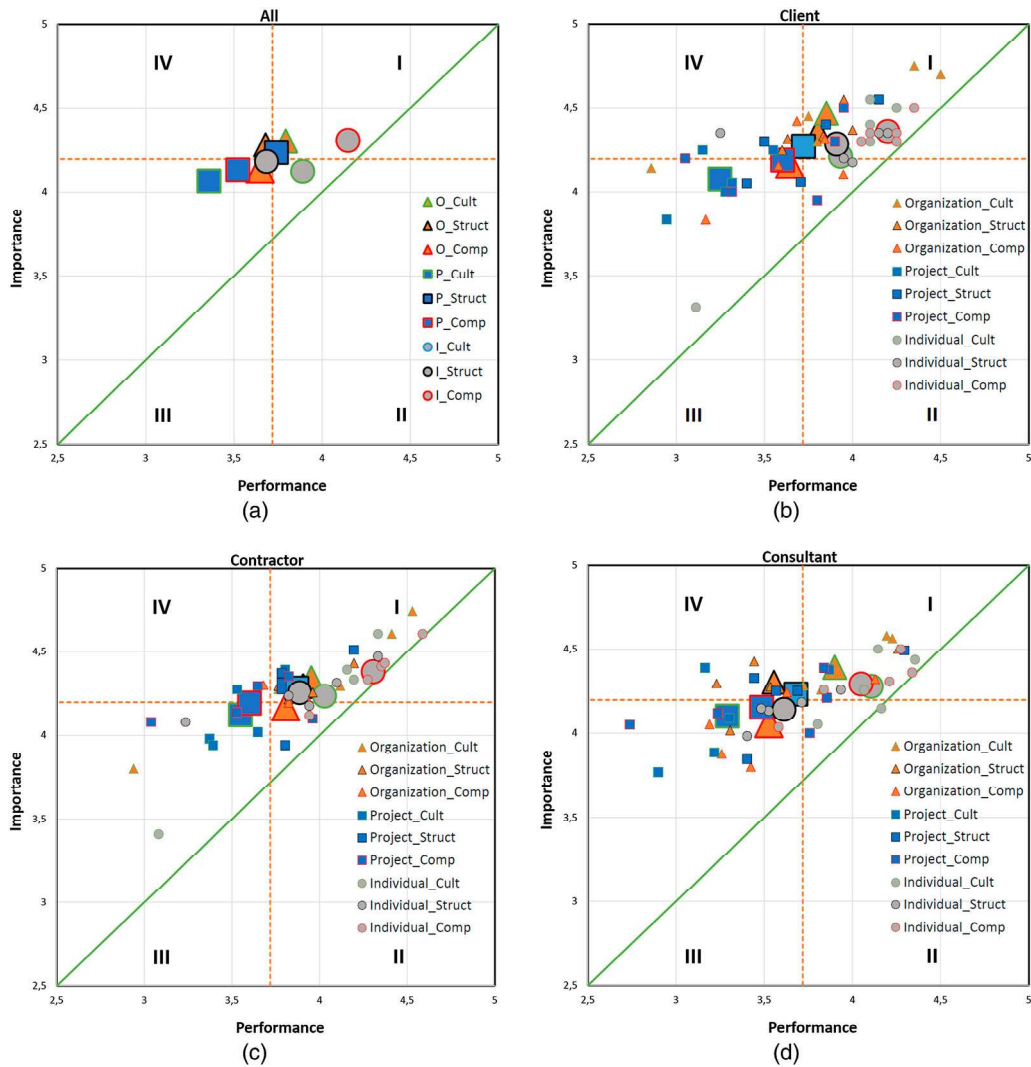


Figure 6. IPA for all and divided by profession.

The consultants, Figure 6(d), responded with the lowest score of the three professions, and only 3 out of 9 attributes are above average performance. 5 out of 9 attributes are above average importance. Here, there is a small spread in the average score of the performance indicators, but in contrast to the contractor with the main point below the grand mean. Here 3 indicators fall in Q1 'keep up the good work', 0 indicators in Q2 'possible overkill', 4 indicators in Q3 'low priority', 2 indicators in Q4 'concentrate here'.

Performance gap analysis

The performance gap analysis intends to reflect the urgency of performance improvements for each indicator. The performance gap is calculated as the mean importance rating minus the mean performance ratings, with a negative gap (performance exceeds importance) suggesting satisfactory performance and positive gap (performance is lower than importance) indicating an area requiring management attention (Taplin, 2012). However, a low performance gap in an aspect does not mean that there is no need for improvement on that aspect. Rather, it can mean that the importance

and performance levels on these indicators are evaluated equally. When studying the response from all respondents, Figure 7(a), 7 out of 9 indicators have a performance gap larger than the grand mean. The largest gap is found for *Project culture*, *Project competence*, *Organisational structure*, all values above 0.6.

For further comparison across the different professions, performance gaps of the 45 questions were calculated for each profession Figure 7(b)–(d). The average performance gap amongst Clients, Contractors, and Consultants are 0.50, 0.37, and 0.53; respectively.

Figure 7(a)–(d): Performance gap analysis overall and by profession. For the clients, Figure 7(b), 6 out of 9 indicators have a performance gap above the grand mean. The largest gap is found for *Project Culture*, *Organisational Culture*, *Project Competence*, 0.83, 0.62, and 0.59. Project Culture is the indicator perceived to need the most urgent attention, while indicators connected to the individual are all perceived to be well below the grand mean performance gap. Results from respondents representing the contractor, Figure 7(c), generate results that only 2 out of 9 indicators have a performance gap

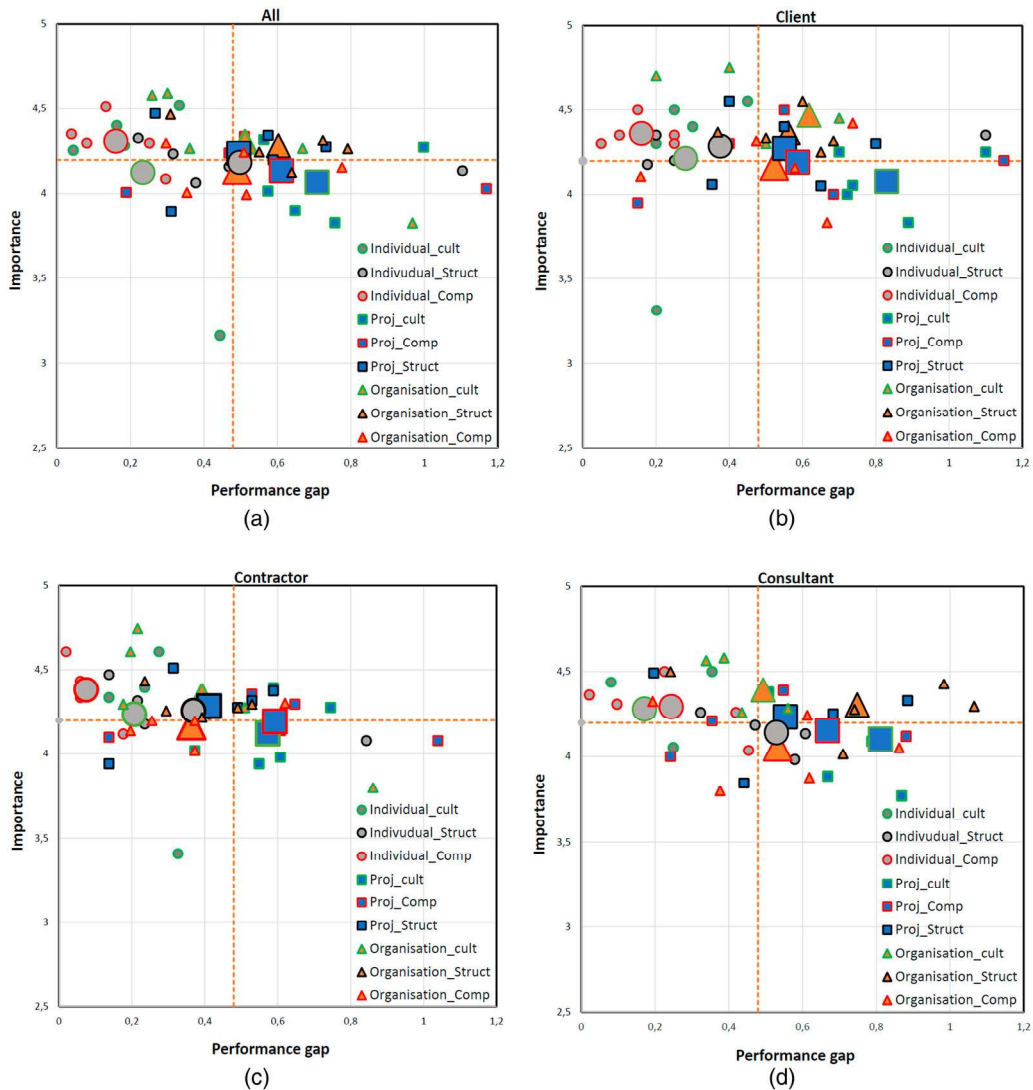


Figure 7. Performance gap analysis overall and divided by profession.

above the grand mean. The largest gap is found for *Project Competence*, *Project Culture*, both with performance gaps above the grand mean, and *Project Structure*. The calculated performance gap is 0.59, 0.57, and 0.41, respectively. The profession contractors get the lowest self-perceived performance gap in the study. In large contrast to the contractors, the consultants, [Figure 7\(d\)](#), ranked 7 out of 9 the indicators to have a performance gap above the calculated grand mean. Here, the largest gap is found for *Project Culture*, *Organisational Structure*, *Project Competence*, with values 0.81, 0.75, and 0.67, respectively.

Discussion

Both in research and practice, the adoption of an integrated design approach in construction has been suggested to offer major benefits. Our review of the literature suggested that multidisciplinary constellations in construction are rarely viewed or evaluated as integrated teams. With the help of a combination of the existing framework, this paper addresses that gap by exposing professionals in construction to a self-evaluation questionnaire and providing a snap-shot of participants' perception of team performance today. Using Importance-Performance Analysis (IPA), supported with gap analysis, the results provide a reciprocal ranking of nine team performance indicators. Focusing on these indicators support the transition towards integration of professions in structural design.

When using traditional IPA to support prioritising between different indicators, placement of the crosshair to generate the four quadrants is of importance. The placement of the crosshairs directly affects the result when evaluating whether performance and importance values are high or low (Oh, 2001). As elaborated on in section *Importance-Performance Analysis*, it is possible to use scale-centred or data-centred measurement or using importance to benchmark performance in a gap analysis. These gaps can then be compared against zero, as an absolute measure, or the mean gaps of all the indicators, as a relative measure. When strictly following the traditional IPA approach, very few indicators fall into the quadrant of 'concentrate here' which suggests limited managerial attention to all the indicators. In such cases, gap analysis can provide aid in determining which indicators to prioritise. For example, Bacon (2003) held gap analysis superior to the traditional IPA analysis. Traditional IPA is therefore often supported by a gap analysis (Azzopardi & Nash, 2013; Feng et al., 2014), since gap analysis provides a type of benchmarking where performance is measured against importance. The calculated gap between the perceived level of performance today and the importance of that same action can be interpreted as a measurement of the potential of improvement.

The analysis also inherently implies that higher performance is more desirable for performance indicators which received higher importance. This assumption requires that performance and importance are independent measurements as well as measured on the same scale. This assumption is often questioned in literature and for example, Matzler et al. (2004) even claim IPA to be an insufficient tool for resource allocation since importance and performance cannot be considered as independent. The survey for this study was assigned with the same scale for statements on both performance and importance, from 'high degree of conformity' to 'no conformity'. The respondents were presented to the performance and importance statements simultaneously which may have violated the expected independence of attributes. Yet, this exemplifies that results from IPA may be more appropriately interpreted as relative rather than as absolute measures. For example, indicators with a gap above the average (taken over all indicators) of the gaps, may be interpreted as requiring management attention (Taplin, 2012).

The largest gaps, and thereby also areas identified with the largest potential for improvement for all professions are: *Project team culture* and *Project team competence* [Figure 7](#). The largest potential for improvement perceived by the respondents is therefore identified to be within the project team settings. Looking at the total score, this perception is mirrored as the level of project team scored the lowest total score of the three organisational levels as described in [Table 1](#). In the project team section of the questionnaire, the statements are for example targeted at communication, goal statement and goal perception, collaboration, and team composition in order to evaluate how well the

general project team is developed. The results presented here, indicate that the Swedish bridge construction industry still struggles to get the most out of its project teams, and consequently construction as such.

For construction works, normally considered as an activity, both the inputs and outputs are generally physical entities. In structural engineering, in contrast, the inputs, in general, are considered human and psychological factors (Baiden et al., 2003; Hughes et al., 2013). Such input may be knowledge, as for a team design, provided at different levels from individual members, groups of members, and even the surrounding environmental level, as previously described (Ginnett, 1993; Hackman, 1987). These different organisational levels cannot be overlooked or neglected. The literature repeatedly states, that getting the 'right people' is one of the most critical issues when building a project team (e.g. Radtke & Jeffrey, 1993; The American Institute of Architects California Council, 2007; Zimina, Ballard, & Pasquire, 2012). Individuals are appointed as a key-factor and a lot is required from both the individual team member and the surrounding organisation in order to generate the expected outcome (Hughes et al., 2013).

It is well-established that developing a high-performance team requires both time and effort. But what maturity level is a common Swedish bridge design team able to reach with the prevailing conditions? Are design teams most of the times in the initial stages of level 1 or 2 (Wheelan, 2016)? Are teams ever able to get past the 'storming' part, see (Tuckman, 1965), in the projects? Regardless, the construction industry is of a multidisciplinary nature, and within the projects team developing processes will be present. These processes are completely natural and instead of offering resistance to them, these stages can be embraced to generate clarity of the behaviour in project teams. Team performance and the corresponding processes are rarely included while evaluating project performance, and therefore 'how' things are done is usually left unmeasured. Therefore, there is a risk that lack of performance is mistakenly blamed on the leader, specific individual shortcoming for instance, instead of being related to group or team issues. In psychology, this is referred to as a 'fundamental attributional error' (Wheelan, 2016). As an analogy used in (Hughes et al., 2013), this would be a doctor who diagnoses the symptom of an infection and then treats the symptom rather than attacking the underlying cause. As an inadequate process can still generate successful outcomes, it is important to measure both the process and its outcome, and at all levels of the organisational hierarchy. The fact that both culture and competence are attributes which are closely related to an individual's personal traits and values strengthens the view that the organisational levels should not be separated and that all need to be monitored. The root of the problem may very well be already at the inputs.

Conclusion

The purpose of this research was to study key variables influencing the performance of integrated project teams in Swedish bridge construction projects. With the data from the questionnaire, the authors were able to identify how respondents representing different disciplines perceive and perform on various project team aspects, identify critical areas of improvement, and classify the aspects according to their managerial priorities. Findings highlight that the greatest potential for improvement is at the project team level, as well as the need for involved parties to focus on supporting efforts to improve project culture, organisational structure and project competence.

However, the findings of this research offer implications for both future studies, and construction project teams, mainly in two ways. First, the results offer a 'generalised' and prioritised view of the challenges in the Swedish bridge construction industry in terms of creating integrated project teams. Second, the established framework would be useful for similar research, both in Sweden and internationally as well as a sufficient tool for specific project evaluation to increase project team integration.

Because this study is based on a questionnaire with a relatively modest number of respondents (134), there are some limitations to the generalisability of the findings. When respondents answer

the questions themselves, the researcher has limited opportunities to check if the respondent understood the target case or the questions and answered them as intended. Also, to determine the total population is difficult, and there is a risk that the numbers of respondents are too few to be representative. However, for the authors, the results are used as a means of identifying and prioritising areas for future research.

To generate significant gains from the application of integrated project teams (IPT) in the Swedish bridge construction industry, reliable measurements are needed at all organisation levels. To sufficiently capture the true project performance and to fully benefit from the potential of a multi-disciplinary project team, the individual contribution, as well as the organisational support to the project team's performance, cannot be overlooked or neglected. The natural next step in this research is to create a deeper understanding of the findings and further support the results through interviews. Future studies should also address not only the perceived gap between importance and performance but also the obvious gaps between professions. Such enhanced understanding would probably further support the understanding of how to create successful project team integration.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Paper C

Closing the knowing-doing gap in the feedback loop – A study of experience and knowledge transfer in bridge construction projects

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Closing the knowing-doing gap in the feedback loop – A study of experience and knowledge transfer in bridge construction projects

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Experience feedback and solid knowledge management are crucial steps in any project's life-cycle, yet shortage of time or money or just the individuals' aspirations to move on to the next challenge in up-coming projects, often results in leaving out this crucial step. This behavioural shortcoming limits the ability to develop an integrated collaborative environment and to fully utilise the already gained knowledge and experience. This research explores the feedback from participants in a series of interviews of professionals engaged in the Swedish bridge construction industry. With the purpose of increasing understanding of the problem of transferring knowledge of constructability concerns to and within structural engineering teams (design teams), we designed and conducted semi-structured interviews to probe participant perception and behaviour. Findings are presented in form of observations which are based primarily on the interviewees statements, together with the authors' own experience from the field of structural and construction engineering in both academia and industry domains. The main contribution of this paper is the presentation of a few insights and a picture of how knowledge and experience feedback is undertaken in practice and what difficulties that are associated to the action. Drawing on the observations made during the interviews the authors conclude that experience and knowledge transfer rarely handled in any structured way. Further it is clear that both structural engineers and contractors needs to establish a deeper understanding about each other and learn how to speak a common language to support the interprofessional dialogue and in the long run the performance of integrated project teams.

Keywords: Inter-disciplinary; Interprofessional dialogue; Experience feedback; Knowledge transfer

Introduction

The construction industry today is distinctly project-oriented leaving the divided and sequential construction process with no clear ownership. Construction projects usually consist of several independent organisations, including varying roles and responsibilities, and consequently conflicting goals and objectives. As projects are finalised, also their organisations are dissolved, and the members regroup to other tasks and assignments.

Construction site activities and design activities are regularly performed by multidisciplinary and temporary organisations or compositions. These actors need to share information and knowledge for optimal decisions (Salas et al., 2017; Stewart & Barrick, 2000), but due to loosely coupled connections between project participants, it is difficult to capture a project's full complexity and context. Consequently, there are several interfaces in the every-day project setting where experience feedback and knowledge transformation are necessary to take important steps to create effectiveness over time. However, deliveries in these interfaces are often identified in the literature to be inefficient and sources of waste (Forbes & Ahmed, 2011; Josephson & Björkman, 2011). Experience feedback and solid knowledge management are crucial steps in any project's life-cycle, yet shortage of time or money or just the individuals' aspirations to move on to the next challenge in up-coming projects, often results in leaving out this crucial step. So, long term business-relations within project teams including experience feedback over time are scarce today, and systematic experience feedback or knowledge transformation is rarely or never utilized, (e.g. Gadde & Dubois, 2010).

The area of experience and knowledge transfer has been a topic of concern in the construction industry since the late 90s and shortcomings are well documented in the literature (Josephson et al., 2008; Love et al., 2015; Meiling, 2010; Sverlinger, 2000).

Also, industry individuals themselves frequently highlight inadequate performance of experience and knowledge transfer.

There are several consequences identified as caused by poor knowledge management and experience feedback within construction. Such consequences appear both during the design and construction stage and usually include the sense of “reinventing the wheel”, recurring errors, design errors, rework etc. (Dave & Koskela, 2009; Love & Sing, 2012). The most evident driver to improve is usually quite short-term and focused on minimising such errors or mistakes. So, instead of trying new things, already proven methods are regularly used to minimize any risk for individual responsibility (Josephson et al., 2008). Yet, besides avoiding mistakes, an additional dimension of learning is included in the process - to foster individual learning, and to further understand our adjacent professions and their targets and driving forces including how these relate to project team performance.

To evaluate the final outcome of a project is a complex activity since it relies heavily on project team performance, which in turn is linked to the effectiveness established by a project team (Salas et al., 2017). A proper project team evaluation requires including several of the basics contributing to how project team members work together and what they produce based on their actions (Salas et al., 2017). By adopting a multilevel approach, and including the individual, project, and organisational levels, (Ekström et al., 2019) evaluated perceived project performance amongst Swedish bridge industry participants. Cross-mapping organisational levels towards attributes concerning culture, structure, and competence, they showed that, out of nine evaluated key areas, more immediate attention is crucial concerning *project culture*, *project competence*, and *organisational structure*. When addressing the individual statements within each

category, statements concerning experience- and knowledge transfer individually stood out from others to be rated low in performance whilst ranked high in importance.

The present study, therefore, explores feedback from participants in a series of interviews of professionals engaged in the Swedish bridge construction industry. With the purpose of increasing our understanding of the problem of transferring knowledge of constructability concerns to and within structural engineering teams (design teams), we designed and conducted semi-structured interviews to probe participant perception and behaviour. Although problems may arise connected to the intra-professional communication, this study focuses on the interface between the structural design engineer and the construction engineer, i.e. towards the inter-professional dialogue concerning the *what* and the *how*, (e.g. AIA, 2007).

Due to the magnitude of the data and the specific knowledge sought, for this paper, we prioritise to report only a portion of the results from the interviews . The questions supporting the evaluation for this paper are stated as:

- How is knowledge and experience feedback perceived and handled in bridge construction projects?
- How can knowledge and experience transfer between the interprofessional interfaces be strengthened?

The main contribution of this paper is the presentation of a few insights and a picture of how knowledge and experience feedback is undertaken in practice and what difficulties that are associated to the action. To set the stage, the following section presents some recurring consequences, highlighted in literature, as connected to the shortcomings of the construction industry to learn and benefit from earlier experiences. A brief overview presents how learning is described as an action in the literature and how this learning

relies on capturing experiences from previously completed projects. Further, some observations are provided concerning how the interdisciplinary dialogue occurs within the industry today, and how to handle knowledge and experience feedback. The observations are based primarily on the interviewees statements, together with the authors' own experience from the field of structural and construction engineering in both academia and industry domains. Lastly, a discussion of some needs for developing future conditions to better support construction already at the design stages.

In the following, a literature review provides context for this study and reveals concise views on aspects of learning in construction projects.

Challenges with experience feedback in a construction context

To be competitive, all organisations face the challenge to constantly develop better and different models, strategies, and processes in the effort to benefit from their cumulated knowledge (Olsson Neve, 2015; Styrhe, 2009; Sverlinger, 2000). Experience feedback is a linchpin in any learning organisation and in learning, as such, it can assist both an organisation and individuals to improve its operations and activities (Meiling, 2010; Nonaka, 1994; Nonaka & Toyama, 2015; Senge, 2006). The evident driving force to improve learning in construction is connected to delivering better products to customers, reducing both construction and management costs, as well as developing the individuals working in the projects (Josephson et al., 2008). In construction, the challenge of knowledge and experience transfer is often mentioned as one of the largest as well as one of the most important, for example (Josephson et al., 2008; Nonaka & Toyama, 2015). Even though there is an obvious need for knowledge of construction in design work, there is a lack of a consistent and structured transmission of experience between the construction and the structural design engineers.

An established view in both literature and practice is that one key to improve construction efficiency is by capturing construction experience from finished projects, feeding it forward and using it during the design (Chen & Mohamed, 2007; Pathirage et al., 2007). To accomplish learning in the construction industry is challenged by the fragmented and often short-term and project specific perspective. The very nature of construction projects is, thus, considered to limit the opportunities for learning (Styhre et al., 2004), and to capture, store, share, and re-use all the information and knowledge created in a construction project (Shelbourn *et al.*, 2006), is evidently found difficult.

The challenge to capture information and knowledge in construction projects often refers to a project's lack of a so-called organisational memory (Argote & Miron-Spektor, 2011; Fiol & Lyles, 1985). Project teams in construction usually work together only for the development of a single project, and, consequently, rarely work together on more than one project (Anumba *et al.*, 2007; Senaratne & Gunawardane, 2015; Senaratne & Hapuarachchi, 2009). This practice creates concerns how knowledge and experiences can effectively be transferred between individuals and how these insights can be "stored" within each organisation's memory (Josephson *et al.*, 2008)

Individuals learn within the context of the project and bring these learnings "home". The interconnection between individual and organisational learning assumes that learning starts with the individual and is thereafter established at the collective level (Hogan & Warrenfeltz, 2003; Huber, 1991; Senge, 2006). So, essentially organisations rely on the experiences and knowledge creation of individuals (Nonaka, 1994). For example, team learning occurs when individuals engage in sharing experiences with each other and create an environment for collective learning to occur (Knipfer et al., 2013)

One of the main reasons often suggested why companies experience these problems, is that too much focus is put on the technology itself, (Garavelli, Gorgoglione, & Scozzi, 2002). Technology has clearly an important role to play in the evolving construction industry, yet research shows that knowledge management cannot be implemented using technology alone. The way technology is utilized is more important to support knowledge management. To only codify information and knowledge and to use databases generates avoidance of its social dimension and its capacity to be exploited to create new knowledge (Love et al., 2015). Shelbourn et al., (2006), even question if there is any information or knowledge to ever be fed-back from a project since *“much of it is never ‘produced’, since no mechanisms or processes exist to foster the social interaction required to give any shape or form to it.”*

Method

In this study, qualitative interview methodology (Kvale & Brinkmann, 2014) was applied in order to explore how industry professionals, within the Swedish bridge construction industry, perceive knowledge and experience feedback as well as their abilities to collaborate and to share information and knowledge. The study explores how these actions are perceived both within the professional’s own organisation as well as in relation to other interorganisational team members. The study was conducted with representatives from some of the largest construction and consultancy companies in the Nordic EU-countries. The interviewees were geographically spread over Sweden, but the main part was situated in the Gothenburg or Stockholm areas.

Interviews

All interviews have been based on a semi-structured interview guide that constitutes a checklist of issues to discuss. This means that the interview was not constrained by any

specific script or time limit. Although the interview guide acted as a structure for the interaction, the discussion was allowed to evolve as appropriate for the participant. In total, 17 interviews were conducted with personnel representing a client's organisation (2), contractors (6) as well as structural engineers (9). The interviews were conducted in the form of conversations that lasted between 55 and 105 minutes and all took place at the participant's place of work.

All interviews were recorded and transcribed. Notes were kept during the interview and used as a support to debrief each interview. The interviews are not completely comprehensive, or representative for the Swedish bridge construction industry in general but highlight several issues sufficiently that are generic and therefore not only of interest for the individual case. Anonymity was guaranteed to the participants to encourage as much frankness as possible during the interview. Any direct quotes that appear in this paper will be attributed only to profession and the number assigned to each participant—*Structural Engineer#IP7* for the Structural Engineer assigned to the number seven, for example. The language, while at times conversational, is that of the participant.

Selection

The chosen participants were originally identified through a selection of individuals who previously completed a questionnaire survey (Ekström et al., 2019). Purposeful sampling (Bryman & Bell, 2011; Flick, 2014) was chosen for the study to get as wide and accurate description as possible of the phenomenon to be studied. Selected professionals have both different roles in their professions as well as a breadth of experience to ensure a wide spread of angles towards the phenomenon. A common factor amongst the individuals chosen is that they are all individuals expected to have a

lot to say about the area to be described. Determining the size of the sample in a qualitative study is not entirely self-evident, and the starting point is to continue to interview people until no more new comments appear (saturation) (Kvale & Brinkmann, 2014). Numerically determining the degree of saturation is usually not necessary, nor is the selection aimed at statistical generalisability, the number of interviews is considered to be sufficient when saturation is achieved and verified.

Analysis

Qualitative content analysis is a method to stepwise analyse written or verbal communication while focusing on differences and similarities. There was no predetermined theory being investigated in the interviews, but rather the responses were examined for key points. The interpretation process results in one or several themes. A theme acts as a common thread which runs through each meaning-unit, code and category (Graneheim & Lundman, 2004).

The first step in the analysis is to generate an understanding and overall view of the collected material. Each interview is therefore listened to after it was finished, and then transcribed. All interviews were transcribed by the authors, and the interviews were imported to a qualitative analysis program and, in accordance with content analysis (Graneheim & Lundman, 2004; Maguire & Delahunt, 2017; Nowell *et al.*, 2017), and broken down into meaning-units. These sentences were subsequently further condensed into shorter phrases and finally concluded into a code describing the content of that meaning-unit. Codes with similar content are grouped into subthemes and further, the subthemes finally were grouped into larger parent themes which constitute the final observations (Graneheim & Lundman, 2004). This step in the process also included sorting and excluding material outside the themes in the interview guide and not

relevant in this study. The remaining text comprises the analysis unit. In this study, main categories were formed by the codes formed by our transcription material. A number of subcategories were also created, which gave rise to subheadings in the research findings chapter. The participants were numbered in the transcribed material with numbers 1-17 to distinguish them during processing of the data. All data were captured and coded using NVivo 12 software.

Research findings

Reported in the following sections are observations that emerged from interpreting and analysing the interviews. The main themes that emerged were: *Lack of time and value for the project*; *Knowledge management as a technical dimension*; *Early involvement in design*; *Culture of silence and Interprofessional interfaces*. Each observation is thus presented as a result from actions and behaviours which are contextually explicit. They are not individually exclusive, but instead act to jointly summarize an environment evaluated based on learning and performance improvement in projects with a special focus on collaboration

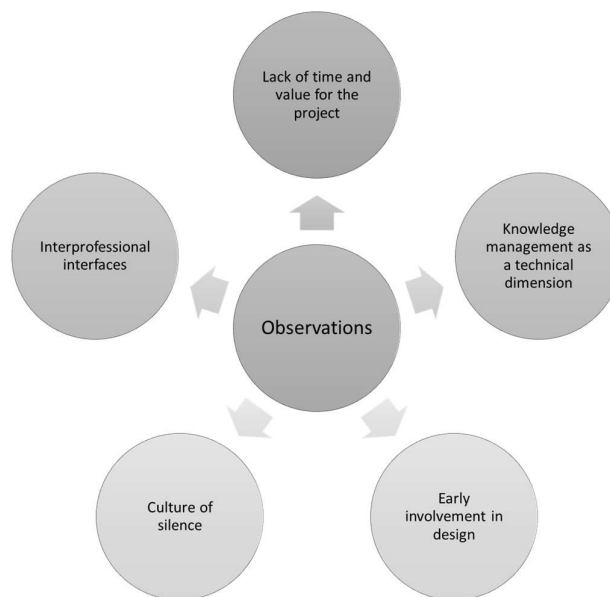


Figure 1: The interviews emerged into five observation.

Observation 1: Lack of time and value for the project

The interviewees express that the opportunities for knowledge and experience feedback in projects are clearly limited. Although being considered of utmost importance for the job, experience feedback is something considered more of an administrative character than other design activities. As something added on to everything else and with no benefit for the work itself, and only managed if there is any time left at the end. When a task is perceived as administrative, there will be situations where priority is required relative to construction or design related tasks and where administration will end up short. One interviewee [Engineer, #IP1] answered in a very short and definitive way, ” *Time and available resources*”, when asked if there was something missing to engage more in the matter. Interestingly, when that answer is further challenged, the ones to provide the missing time and resources were usually the persons themselves by prioritizing and self-management.

[Draft engineer#IP13] ”*Of course, you control this partly yourself. Sometimes you have to put your foot down and say..., but it’s about how you yourself prioritize of course. If you are in a project and you need to deliver, and you are working nights and weekends, then you do not prioritize such things. At that point the project comes first. Maybe it’s just me, no, it is really like that.*”

The profession of engineering largely involves independent work and of course implies engineers to control and manage their own time. But, the collective picture from the interviews also reveals that even project management considers experience feedback as a separate question, i.e. there is no time or resources allocated to deal with the actions within the projects.

[Site Manager#IP4] ”*You might get the feeling that you don’t have time. When one*

project ends you're on to the next one. What's in the past, you don't really bother to deal with."

This time is expected to be "found" outside project budgets. Consequently, project management plays a crucial part in showing that experiences and knowledge are important. As human beings, it is easier to prioritize things asked for, something shown important. For example [Draft engineer, #IP13] says: " *We have all the support we need of course but it is never asked for. No one ever checks if we have done it.* " Although no one believes it would take very long time to implement a meeting to reconcile, at least not within the project group, still this rarely happens. [Draft engineer#IP13] continues, "...it might take an hour" and clearly meaning this would be something manageable.

Observation 2: Knowledge management as a technical dimension

Most respondents fall into a discussion about technical systems as help when they are asked how they normally handle knowledge and experience feedback. It often refers to some form of system for enabling the collection of data / information / knowledge / and experiences from previous projects. This gives a clear indication of a notion that knowledge is something that can be held or owned, that knowledge is in a form that is possible to formalize and code. Many things are naturally documented during the design and construction process today in terms of calculations, reports, drawings and models. Still, to gather information or data is significantly easier than to create a well working system and how to later use that information.

[Site Manager#IP4] " *I had an experience feedback meeting with my previous project, were all site managers or block managers and all higher managers sat down and raised issues. Some sort of document was created from that I guess, but I hardly know where that document is today.* "

The construction industry is constantly perceived to be relatively slow in adopting innovative solutions offered by the developments in the ICT sector. However, in the last decade the construction industry has made significant efforts to embrace ICT solutions. (Dave & Koskela, 2009). Yet, there are many ongoing initiatives to enable ICT solution to support working in construction projects, and by the late advances in AI, IoT, machine learning etc. there are great opportunities to find the support, even though we are not quite there yet. If one can find systems that clearly support the work of project teams, it is also expected to strengthen both design and construction. Still, the aspect that emerged from the participants was that creating and maintaining such systems usually are difficult activities and that they have not yet seen a system that works.

[Site Manager#IP4] *"We have had different kinds of systems, computer systems, lessons-learned and such, but it never really works. We haven't been able to get it to work. That something relevant is put in and creates an actual source to lessons-learned."*

Instead, most of the participants highlight the importance of including the human element in the process, and that it is by socialising we are able to transfer knowledge and not only by use of technical systems.

[Design Manager (Contractor)#IP11] *"Above all, I believe that many people go and wait for it, for something that will come and solve everything. But I do not think it does. It's not possible to create such a system. Instead you have to work with networks and find the right people. I think it is difficult to get any system that works over time."*

[Structural Engineer (Project Manager)#IP8] *"[] I don't think you can rely on formal systems and structures, culture is really important. It doesn't matter how good systems you have if you don't take the time to help each other at the moment when questions arise."*

Observation 3: Early involvement in design

One clear driver from the contractor is the ability to be innovative, finding new, smarter and quicker ways to build. To be able to do that usually implies being introduced in the process early to influence and create smart solutions. As a part of that early involvement, most contractors express a desire for a structural engineer that is equally creative and innovative in thinking about how to support the process of finding new and possible ways to improve construction work. Although, this desire is often perceived to be inhibited or limited by normal contract relations (the traditional design process) and the way clients choose to interpret available possibilities. Yet, contractors given the opportunity to be involved at an early stage found this way of working very attractive.

[Block Manager#IP2] *”When we were in a partnering project, we all sat together. Then you felt involved from the beginning. When you sat next to the designer and discussed how to build a bridge from here to here and is 76 m, crosses five-six railway tracks. How do we build that? We knew steel was one option, but do we build like this , or like this? Then you were involved from the beginning and had the chance to influence. That was fun.”*

Although the collaboration between structural engineers and construction personnel can be productive, there may appear conflicts of interest between the two which can threaten a positive outcome. To overcome this, one contractor emphasises the importance of engaging in the dialogue with both structural engineers as well as construction workers in order to facilitate the work.

[Site Manager#IP3] *“But then you must dare to be at site, dare to be questioned, dare to ask uncomfortable questions. Play the fool sometimes. Always question things and gain trust. The tools and methods are already there, now people with key positions also need*

utilize them in the right way. Try to, to get the best results.”

Getting the right people, with the right competence into projects is something commonly addressed for when aiming for high project performance. Usually this entails both a technical and practical competence but also the ability to work within a team, the ability and an understanding on how to work in a team.

[Site Manager#IP3] *”It isn’t easy. You need to have those with practical knowledge as well as theoretical knowledge. Then, we need to remember that we are working with humans. So, there is different carrots, different driving forces, different everything. You can’t find a standard solution and just go with that. There is an individual solution for every person.”*

Further, the respondents express that there is a need to ensure that the different organisations have the ‘right’ people in the projects at the same time. The opportunity to receive and benefit from early feedback on construction documents due to staff shifting between design and construction personnel.

[Structural Engineer#IP8] *”Sometimes, there is no proper counterpart. We can be in such an early stage that we are working with a tender document and then there is no contractor appointed. But even when there is one, we might even be working with one, there organisation isn’t really awake, or how I should put it. There might only be a calculation office, a purchaser and perhaps an intended construction manager, then there isn’t much more. Then it’s difficult to get someone to discuss construction issues with.”*

Such shifting creates a problem since late error detection or changes lead to further time-rushed revisions or re-work that further increases the risk of errors. When the

structural engineer needs input concerning, for example, reinforcement layout or intended construction sequencing, these issues have normally not yet come to light for the contractor.

Yet, as another contractor puts it, the early involvement also involves a higher degree responsibility for the final product which is not equally attractive. There is a conflict between the desire is to increase influence while still avoiding responsibility beyond contract. Even when there are obvious improvements to be made in design these may not be communicated.

[Block Manager#IP2] *"Well, we haven't told them. They have done what they have been told by us [the contractor]. There's no point saying anything because they will only say that we [the contractor] said that it should be this way."*

Observation 4: Culture of silence

Especially from the designer's perspective there is a clear culture expression that the "sound of silence" is a sign of success. The general attitude is that if you do not hear anything from your customer, you have succeeded in your task. Below is an excerpt of a dialogue between the interviewer and one respondent giving a typical view:

[Interviewer] *"When you work in project and receive feedback, from the contractor or client, concerning things which are good or bad, how actively do you work to change your way of working during the time?"*

[Engineer#IP_14] *"Sometimes we get feedback, but usually when something has gone bad. Positive feedback is something we rarely get. If a project is silent, if you don't hear anything, then it is a fantastic project."*

[Interviewer] *"That's what you assume, you mean?"*

[Engineer#IP_14] *“Yes, but I think it is like that, because then you don’t hear anything. Then everything is perfect.”*

To rely on the “sound of silence”-approach requires an established procedure of handling complaints. Yet, research has shown that very few customers complain (Bergman & Klefsjö, 2010), so in practice this means that many solutions are created at site instead without the supplier's (structural engineers) knowledge.

[Draft Engineer # IP13] *”Usually, when construction starts, the only time we get to hear anything is when something doesn’t work. We don’t know what they say otherwise. Somethings they solve at site of course, and such things we’ll never hear about.”*

In construction, the ultimate test of the structural solution (construction documents) is of course done in the pit. One interviewee [Site Manager #IP_3] described a situation with a reinforcer which never saw any real change and therefore stopped to complain about “bad solutions”. It emerges that it is a rare occasion that construction staff take the opportunity to discuss with the designer when given the chance, for example during visits or construction audits. This dialogue is, however, expressed by many of the interviewees to be very rewarding as structural engineers can explain directly to construction staff why, for example, the reinforcement is arranged in a certain way (norms, rules and regulations). Still there does not seem to exist any natural form of communication or feedback loop between the professions except when things go wrong enough.

[Draft Engineer, #IP1] *”They call when something is wrong! Then you hear about it instantly! But otherwise? Not if I don’t ask. But if I ask, there are many who really enjoy talking, and explaining. Well, telling me how things worked, or how it should be or*

work. I think there is a great benevolence, especially from those which you have worked with several times. But it won't happen if I don't address it first."

The interviews confirm that the main part of the individual knowledge usually remains as tacit since none of the interviewees maintained any systematic documentation of their own gained experiences. The things you learn, you expect/rely on to keep/store in the back of your head until needed. Sharing of your own knowledge and experiences to others are also dependent on the fact that "others" find you and ask the question. Further reinforcing the culture of silence, there are also statements that indicates that much importance is attached to the relevance and correctness of what is to be transmitted. Especially within the inter-professional dialogue where the contractual relation seems to inhibit dialogue where there seems to be an underlying concern among many to expose one's lack of knowledge.

[Structural Engineer,#IP6]" *We ordered a job from you, you should know this. [] You can also say something really stupid. Something which isn't right, or at least you have that attitude sometimes. Don't say too much now, because you might say something wrong and they'll hold it against you. Make you stick by your word, what you have done. I've made such mistakes and learned from that."*

Observation 5: Interprofessional interfaces

When the interviewees are asked how often they work with setting common goals within the project team, their thoughts almost exclusively end up in the mother organisation, i.e. the structural engineer relates to the team back at the office and the contractor to the team during construction. Even after sharpening the question to force the interviewee into the state of mind, they have difficulties to see or create the situation. This implies that the interviewees are untrained to naturally be involved and

work with other disciplines and maybe even lack the mental manoeuvring space (P-E Josephson *et al.*, 2008; Senge, 2006) to do so. Individuals in this industry are highly trained to work with "their" own assignment, finish it with no specific external involvement, submit for review and then adjust accordingly. When asked what opportunities are given to develop common goals in the projects one [Structural Engineer (Project Manager) # IP8] answers.

"Unfortunately, the opportunity is often limited and usually the time schedule, well it doesn't allow much room for reconsideration of the structure and most of what to design is already decided. [] Well, there is not much of a dialogue or collaboration. We do our thing and then we send out to review. We get some comments, we adjust accordingly and then we have done our part..."

Many of the interviewees consider setting common goals is very important, but what that includes seems to lack a clear line and the answers are scattered. The answers diverge partly in how to engage in such a dialogue to set common goals, as well as how the finalised product or service is supposed to look at the time of delivery.

[Structural Engineer (Project Manager) # IP17]" *but a contractor building a bridge with a lump sum contract wants the effort from the structural engineer to be minimal, spot-free and the best in every way. Setting high standards is a way to increase both quality and lower costs and that is good of course, but the occupational environment, and the feeling in the project can be strained in my opinion. When I communicate with the team, I always have at the back of my head that this takes too long, or we need to do this faster."*

Also, at the greatest simplicity, quality is a clear measure of a common goal. Creating a common understanding on what we are trying to achieve together in the project, what are the technical requirements, when are we supposed to be finished and to what cost are we expected to deliver? From that perspective it is also possible to see a diverging perception of what quality represents. When the interviewees are asked what quality is, the answers are quite broad and express different expectations. For example, one [Structural Engineer (Project Manager) # IP14] answered:

"The right quality? That's a question not so easy to answer. I think, in general, we work in relation to a feeling of what is "good enough". Of course, we need to follow the code etc. and we try to fulfil those requirements but, no, that's not an easy question to answer. What is the right quality for the customer? It's related to cost as well, but the right quality, I think it's more of a feeling. What's good enough."

Without a common view concerning quality led to further questioning how well-developed the understanding is for other disciplines and their needs. When asked, if the interviewee's think there exist a general and mutual understanding between the different professions driving forces within the industry, the answers were somewhat scattered.

One client expresses a desire for increased coordination within a project, the greatest root cause to errors in design was usually related to insufficient time for coordination.

[Client # IP12] *"After all, many would benefit from being at site more and see how it is. Many more need to understand each other's work, to understand and to respect. The contractors are usually very quick to point this out, the need to drag the designer to site so they can see what we are dealing with. Well, this goes both ways. The reinforcer could really benefit from a week at the office. To understand the designer, when you have so much to deliver in a very short time, and how much work there is behind. A*

little more understanding for each other's work would probably benefit the every-day dialogue.”

This lack of understanding of the design stage from the construction side was also verified by several of the contractors.

[Design Manager#IP11] *”I think you lack knowledge about what design, what they do and what it contains. I sometimes get the feeling that one has trouble in asking the right questions, and instead only scream for construction documents. In that, I have an important role in this project. To be that link [between design and construction]. To have one leg in each of the stages, you could say. Still, I belong to construction but with experience from design. I think it is important to have that link, that connection.”*

Further, another contractor states:

[Technical Manager#IP10] *“In general, what we need to improve, to be better in transferring experiences, is to understand each other’s parts in this. On the overall level, it is like that. A producer needs to understand, to better understand design and vice versa of course. That’s when it works, a collaboration, if you understand, you don’t do the other one’s job, but you understand each other’s challenges and can offer help.”*

Discussion

There are many expressions for increased knowledge within organisations. Yet, in most organisations there is a tremendous amount of collected knowledge, but the difficulties lie in transferring that knowledge and experience between individuals, between teams, and between projects. Multiple observations were identified from the interview responses and as expected, findings from the interviews support the vast amount of previous research stating that poor performance in construction is related to the

insufficient handling of knowledge and experience within and between project phases as well as between professions. The observations indicate the interprofessional dialogue within projects to be relatively limited. The discussion is structured around how the observations relate to the perception and handling of knowledge and experience feedback (RQ1) and how knowledge and experience transfer between the interprofessional interfaces can be strengthened (RQ2)?

A clear response from the interviewees was that the aspect of time is an important factor to support the interprofessional dialogue, and mainly in two ways. First, there is the immediate time available within the projects to engage in knowledge and experience feedback. Due to the [perceived lack of] available time within projects, tasks with a short-term benefit (within project) are frequently prioritized on behalf of task with long term benefit (between projects). Secondly, it is important to establish a project schedule allowing each organization to involve the ‘right’ people. This is specifically apparent to structural engineers involved in early stages of design, which often needs to rely on their own knowledge of construction and make qualified “guesses” and assumptions. A common expression from contractors is that solid knowledge concerning construction activities is something that the structural engineer usually lacks and needs to acquire more. This is on a general level probably true. Fully understanding the complexity in construction and its related construction activities, however, is not exclusively linked to the structural engineer. This shortcoming appears even within their own ranks, e.g. purchase, tendering.

A large portion of the shortcomings that appear during construction can be related to design errors (Claesson-Jonsson, 2013). Consequently, rework and disturbance during construction continue to be major problems in construction and engineering projects. To overcome such inefficiencies, the structural engineer or the structural design team needs

to generate an understanding for downstream site activities and core elements in construction, (for example buildability concerns). A clear benefit from reusing and sharing previous project experiences is that it creates an opportunity to align a specific task to be performed in a similar and repetitive way. To minimize the variation in how different structural engineers perform a specific production process is also a key to ensuring that the total product quality meets all customer requirements. Yet, there is also a significant risk to become prisoners of our own experience, i.e. we perform the next coming project in the same way as the previous one without really questioning or reflecting over the actual outcome of the same.

Yet, to improve the level of buildability on infrastructure construction projects requires a type of knowledge which is found to be primarily tacit and stored at an individual level. For example, (Nonaka, 2008; Nonaka & Toyama, 2015) states that a large part of what individuals know is in tacit form. Tacit knowledge is usually referred to as knowledge and experiences which cannot directly be communicated with words or symbols, but rather transfer when, for example, two individuals perform a task together or engage in collaborative problem solving. In the construction industry, much of the knowledge needed to carry out the professional tasks is learned by socialization (Sverlinger, 2000), and many key solutions are generated by knowledge tacitly held in the heads of the individual. Such key solutions are often the result from an individual's expertise and experiences which are applied to the current project. By highlighting and addressing the benefits of tacit knowledge, the process of socialization is also encouraged and strengthens the integration and interaction between individuals (Emmitt, 2010; Nonaka & Toyama, 2015; Olsson Neve, 2015). Socialization in turn also strengthens the development of the design teams, which in the long run also increases the possibility of further obtaining a successful project.

The interviews revealed an embedded “culture of silence” which strongly contributes to breaking the learning cycle in the construction process. This break/interference disables the opportunity to learn from the experiences gained by the individual (Senge, 2006). During the construction stage, it is usually too late for any major alterations and for any detected errors or possible adjustments, corrective measures are instead taken to solve the issue here and now and without consideration or reflection if this could have been done any other way. Instead, the challenge is to raise the questions between projects to engage in any opportunity to create long term learning. In the small project, typically single short to medium span bridges, contrary to large projects where you can benefit from the natural repeatability which creates the manoeuvring space to question used solutions and thinking patterns within the project.

Adopting a stronger focus on the social perspective on learning, also requires an increased focus on and importance assigned to human interaction and collaboration. Knowledge needs to be treated as something people do, and stress the importance of the relationship between knowledge and action (Neve, 2015). Further Neve, (2015:13) states that *“If we are to learn from knowledgeable people, we need to search not only for their more abstract knowledge but also for their practical knowledge.”* This addresses the need to continue to invest in the interprofessional dialogue in construction projects. It is during this dialogue the tacit, in contrast to the explicit, knowledge is in focus.

Conclusion

The study for this research began with the goal to better understand the interprofessional dialogue and how experience and knowledge feedback is handled and understood amongst construction industry participants. With the adopted interview methodology, it was possible to further understand the complexity of the interprofessional dialogue and

the research interviews offered an important means for the researchers to deepen their understanding concerning structural and construction engineering integration. The findings are presented in form of observations; *Lack of time and value for the project;* *Knowledge management as a technical dimension;* *Early involvement in design;* *Culture of silence and Interprofessional interfaces*, which together conjoin some of the challenges in addressing experience and knowledge transfer to and within structural engineering teams (design teams) in bridge construction projects.

Findings from this research supported the authors to conclude that there is a clear distinction between two situations where the interface between structural design and construction needs to be bridged. Unfortunately, at both these opportunities the structural engineer and contractor are normally separated which distinctly prevents the possibility for a constructive interprofessional dialogue.

Firstly, there is an interface during the development of construction documents, the actual input of knowledge to generate solutions (knowledge creation/knowledge transfer). During this stage, even when possible, there is no indication for any widespread effort for creating supporting activities, instead the projects team members are usually strictly bound to solve given tasks within their own professional domain. One important pillar in that development of aligned efforts is to understand the need of your project team-members. So, given that the environment of structural design (pre-construction design stage), contrary to the construction stage, is a qualitative, subjective and in some sense related to a high degree of uncertainty, the appropriate methods and practices used in pre-construction stages are, thus, slightly different from those in construction. Consequently, there is evidently a need to establish a deeper understanding for the essentials and important task during each stage.

Secondly, the very action to learn from the results from the first (experience feedback/knowledge creation), the actual effort for evaluation and retrieval of experiences from previously performed projects. The interprofessional dialogue seem prevented by a two-way continence. Instead of engaging in dialogue, both parties are expected to understand the implications from their own actions. This becomes more apparent for small projects where there is less opportunities to repeat the same action or solution within the same project.

Supported by the above it is clear that both structural engineers and contractors establish a deeper understanding about each other and learn how to speak a common language to support the interprofessional dialogue and in the long run the performance of integrated project teams.

This study is based on interviews with a relatively modest number of respondents (17), and consequently with some limitations to the generalisability of the findings. The interviewees answer and describe situation from their own perspective, and not from any given perspective or situation given by the authors. It was important to the authors to allow the interviewees to provide their general view and perception of the phenomena and not from the perspective of a single case. Instead, the interviews contain numerous project- or situation specific example, given by the interviewees, which are more related to specific and individual events.

Further, any interview situation is by nature exposed to the influence of the researcher, as it is impossible for the researcher to be completely objective. To establish validity to the findings, excerpt from the interviews were include in the article. Also, to determine the size of the sample in a qualitative study is not entirely self-evident, and there is a risk that the numbers of interviews are too few to be fully representative.

The natural next step in this research is to create a deeper understanding of the findings and further connect the findings to the performance of projects team in construction. Future studies should also address how to support and link non- technical and technical aspects of project team performance. Such enhanced understanding would probably further support the understanding of how to strengthen the interprofessional dialogue and further a higher degree of successful bridge construction projects.

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Paper D

Predicting project performance using pre-construction performance indicators - A case study evaluation

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Predicting project performance using pre-construction performance indicators—a case study evaluation

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Abstract

Predicting the outcome of a construction project largely relies on estimated targets of time and cost. Still, hitting the targets does not mean that the project is a success on all performance levels. Here, a retrospective case study was undertaken on a construction project identified as a successful project by the partners involved. The purpose of the study was to validate conceptual design indicators of a high-performance construction project as reported in the literature, by answering the following research questions: “What characterizes the dialogue between the different disciplines; (2) What is the dialogue about; and (3) When in the process do questions arise?” Findings indicate that the interprofessional dialogue within the project team was well established. The paper introduces a discussion that the dialogue benefited from the collaborative project environment as well as the early design intent. Further, the study also suggests that the interprofessional dialogue supported a sound project team development.

Keywords: Structural Design, Buildability, Constructability, Pre-construction indicators, conceptual design

1 Introduction

Predicting the outcome of a construction project largely involves relying on the estimates of time and cost calculations. Still, hitting the target does not necessarily mean that the project is perceived as a success on all levels. In the pursuit of a high-performing construction industry, the focus is often on early involvement of the contractor in the project and numerous studies have investigated the organizational and inter-organizational management tools, [1]. Instead, with a team performance perspective, [2] identifies three main areas of improvement regarding project team development in bridge construction projects and also shows a need for investigating the execution of

projects and the underlying mechanisms of collaboration; *Project Culture*, *Organizational Structure*, and *Project Competence*. Demonstrated by the performance-indicators, the inter-professional dialogue act as a linchpin in supporting project-team development. In this paper, we report on a retrospective case study undertaken on a construction project identified as a successful project by the partners involved. Unlike the stated conditions given in the literature regarding projects in collaboration, this project was not specifically procured in collaboration; it was initially procured as a Design-Bid-Build contract (D-B-B) with completed construction documents provided to the contractor by the client. Importantly, it was the experience from similar projects and previous successful

collaboration between contractor and engineer that prompted the collaborative design. The purpose of this study was to further evaluate reported pre-construction performance indicators of a high-performance construction project leading to the research questions of this research: (1) What characterizes the dialogue between the different disciplines; (2) What is the dialogue about; and (3) When in the process do questions arise?

2 Inter-disciplinary relations in construction

Inter-disciplinary methods in construction are best exemplified by multi-party contracting practices such as project alliancing, project partnering, and integrated project delivery (IPD). These contracting methods, referred to as ‘relational’, are based upon a relationship of trust between parties with fair division of responsibilities and benefits [3]. The American Institute of Architects defined IPD as a “method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction” [4]. The relational aspect thus helps enrich inter-organizational relationships to deal with unforeseen events difficult to capture within the dictates of the contract definitions. Thus, it encourages a flexible and speedy response to deal with the challenges usually associated with a risk event that has not been explicitly addressed in the contract.

However, contractual arrangements are only a part of the transition towards a more efficient and sustainable construction process and can only create the prerequisites for a project to be successful. The degree of success still lies in the hands of the project participants, i.e. the individuals involved in the daily work of engineering and construction activities. To reap success in a construction project, the project team should strive for an integrated project process, with a focus on the end-product, and formulate clear project goals and specify priorities regarding quality, cost, and time.

For contractors to operate construction activities both efficiently and competitively, they are directly

dependent by the design concept and the detailing. Consequently, it is important to understand the critical aspects which could cause problems on the construction site. The optimization of a structural member, for example to make a beam or a column as slender as possible will result in maximum economy of material but will certainly not minimize cost of the finished product. Simplicity and repetition are usually the keys to success and core conditions for efficient production. It is crucial for a structural engineer to understand governing site activities, and when designing to also have a distinct idea of how construction will be performed, and what equipment is available to the contractor. Further, a structural engineer needs key knowledge of construction operations [5] and an understanding of the advantages and disadvantages of a proposed solution. However, buildability considerations are normally based only on the structural engineers’ knowledge or experience from previous construction projects and without the input from the appointed contractor.

Construction projects increases in complexity and makes it more and more difficult for designers to be fully aware of all the implications of their designs. This complexity underlines the importance for the structural engineer to receive feedback from, and to have a dialogue with, the contractors who are experienced in construction engineering and meet the problems daily.

3 Method

The chosen approach for this study was a retrospective document analysis [6], to explore the interprofessional dialogue within the structural design team and how industry professionals use their abilities to collaborate and share information and knowledge, both within their own organization and to other interorganizational team members.

3.1 Case study

The case for this study was chosen with the preconception to be a generally considered successful project, including the perspective of the client, contractor, as well as the structural design engineer. The construction project was a train-depot for regional trains, located in Stockholm, Sweden. The studied part of the project included an approximately 320 m long concrete tunnel and was

executed in 2014, initially procured as a D-B-B-contract, i.e. complete construction documents were delivered by the client.

During construction planning, the contractor identified many time-consuming activities and other difficulties to improve. Together with the structural engineering company, the contractor had just completed the structural design of another project, including some long tunnels similar to this, and saw an opportunity to benefit from the experience of a previously successful collaboration and presented an alternative calculation to the client including a re-design. The date for construction start was fixed so there was time pressure to deliver the first construction documents. Within the original design there were several areas identified to improve and with the new design the intention was to optimize buildability and minimize risk during construction. The following areas were the most significant:

- construction method, including sequence, production rate etc.
- repeatability, simplicity, similarity in details
- minimizing shear reinforcement, and choice of bar type

3.2 Analyzed documents

The documents are notes of meetings and have therefore been reviewed and edited in accordance with common meeting documentation procedure. The meeting notes have been documented by the engineering office with the purpose of recording decisions and responsibilities as a project management tool. Consequently, a series of design meetings was arranged parallel to the original plan. Each meeting was documented including information concerning date; place; participants and affiliation; task and associated responsibility. All known protocols concerning the re-design were gathered and stored in a case study database [6]. The targeted audience is the project members as well as the mother organizations of the client, contractor, and engineering office.

3.3 Thematic analysis

The analysis of the project meeting documentation was made as a qualitative content analysis [7]. Qualitative content analysis is a method to stepwise

analyze written or verbal communication while focusing on differences and similarities. The interpretation process results in one or several themes. A theme acts as a common thread which runs through each meaning-unit, code and category [8].

The qualitative data consisted of 17 documents. Initial codes were generated deductively based on our prior research, the conceptual framework of integrated design, and our field expertise. Codes were first fit into a pre-existing coding framework of the main theme as meaning units. The coding was then revised interpreting the meaning units and condensed into condensed meaning units to provide a detailed analysis of aspects of the data. Codes with similar content were then grouped into sub-themes [8]. The following step in the process required researcher triangulation [9]. The triangulation included separate coding by a group of researchers. First, a group of two researchers made a preliminary coding of the documents by first theoretical and reflective thoughts were recorded as well as potential codes and themes. Finally, a third researcher coded the content identified as interesting in the coding structure of the themes. After the research triangulation, a review of the generated coding and themes were done, and the coded material was checked for referential adequacy by returning to the meaning unit. The theme naming was discussed as well as the sub-theme structure. Following this coding methodology [10] we strove for trustworthiness and credibility in approach and interpretation.

4 Results

When analyzing the project execution, the holistic parts of the project, such as presence of the client, engineer, and contractor at meetings; type of tasks and who was responsible for the task; and the task's category of what, how and realize were mapped and documented. Only those tasks clearly including the interprofessional dialogue were further evaluated and presented. In total, 20 tasks were identified, and from the thematic coding the tasks could be categorized into 7 themes representing the content of the interprofessional dialogue: Prototyping (1); Structural Design (6); Logistics (1); Rebar layout (5); Accessibility (5); and Staging (4), see Figure 1.

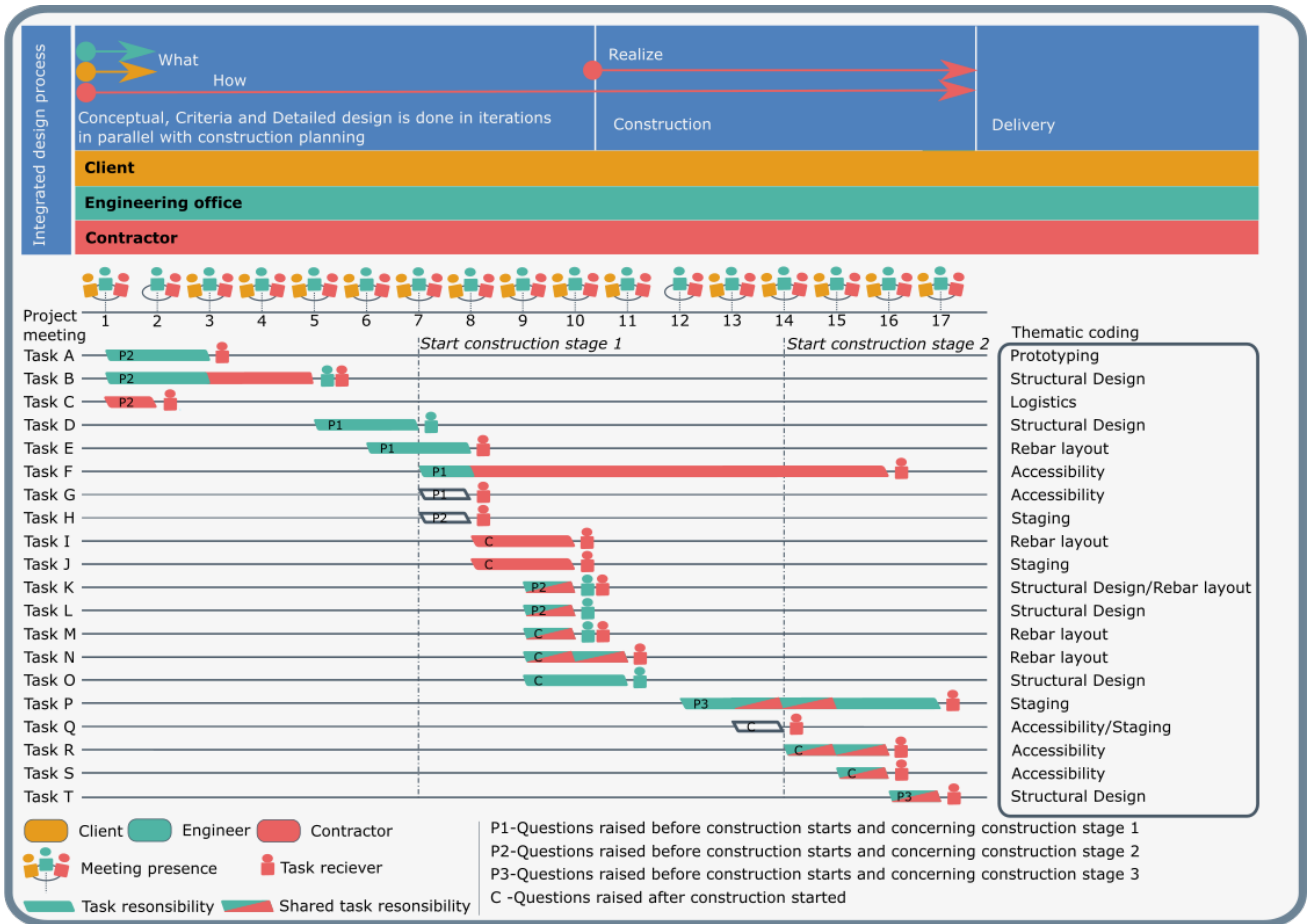


Figure 1: Final theme structure and corresponding definitions.

In the first delivery from the structural engineer, there was a design based on clear guidelines on improvements due to the initial agreement of buildability improvements. So, unlike the traditional process of D-B-B, this already contained much of the contractor's wishes regarding a design related to structural engineering constraints, which is reflected in the documents since few questions appear before start of construction stage 1, and questions that do arise mainly concerns construction stage 2. Following the dialogue, it is possible to identify questions concerning three phases to be included; construction planning, construction works, and experience from construction. Getting an efficient construction procedure is largely dependent of site conditions and what requirements have been set for the structural design. Dialogues that appear are both directly and indirectly linked to construction work. Examples of directly linked dialogues include accessibility at the construction site, or feasible and

available construction methods/equipment. Examples of more indirect related dialogues are further clarification of details or adjustments in reinforcement specifications. Interestingly, the dialogue indirectly related to construction works, such as Structural Design, 5 tasks out of 6 appears ahead of construction start, contrary to dialogues directly related such as: Rebar layout; Accessibility; and Staging, in which 8 out of 14 tasks appear after start of construction.

5 Discussion

The results of this study are examined from three perspectives governed by the previously raised questions; (1) What characterizes the dialogue between the different disciplines; (2) What is the dialogue about; and (3) When in the process do questions arise? However, due to space restriction, this discussion will only deal with the first question. Figure 1 illustrates the researchers' interpretation of the documents on how the interprofessional

dialogues evolved during the project. The figure clarifies some main topics that are affected during the dialogues and at what stage these topics appear. Further, it also describes the dialogues to appear in three loops originating from: (1) Initial structural design, (2) Construction -Planning/-Works/ and – Experience, (3) Updated structural design.

In most D-B-B construction projects, the possibility for any constructive dialogue between contractor and structural engineer is usually limited. For this specific case, finalized construction documents were provided to the contractor by the client due to a tight schedule. Although the construction documents were based on current codes and regulations, and assumed site conditions, the contractor saw great potential for improvements and wanted to re-design and remake the construction documents. While rethinking construction, the contractor established a clear picture of how they wanted to organize construction and could bring this input as new entry values to the new structural engineering company. In some way, there was a fairly completed "design intent" as an entry point for the contractor and the structural engineer dialogue.

The meeting documents distinguished that the interprofessional dialogue from the structural engineer to the contractor is much more difficult to identify than the opposite (Loop 1 and 3). This dialogue may be embedded within the project delivery itself and the structural engineer's dialogue is conducted through the product or service that is provided, in this case the construction documents.

Further, meeting documents revealed a high presence from all actors. All parties had the individuals needed present to be decisive at the meeting and were thus organizationally ready, which simplifies the inter-disciplinary dialogue. It is normally difficult to receive early feedback on construction documents due to staff shifting between design and construction personnel. Such shifting is a problem since late error detection or changes leads to further time-rushed revisions or re-work that further increases the risk of errors. When the structural engineer needs input concerning reinforcement layout and intended construction sequencing, these issues have

normally not yet come to light for the contractor. Further, when the contractor starts to think about construction procedures, the structural engineer has moved on to other projects.

The project was initially given very limited work-site area, so discussions about the possibility of utilizing the finished constructions became a clear issue. Questions such as: When and in what order can finished constructions be backfilled to make construction procedure more efficient? How is the access to and within the construction site and availability of cranes during staging? Can cranes be placed on top of finished construction works instead of alongside? The fact that these questions about construction procedures remain, highlights these issues as largely unpredictable. Yet, the project team demonstrated a strive to constantly improve and streamline construction procedures when solving them.

6 Conclusion

This research is still ongoing and conclusions for the parts studied so far are here limited to the following:

An environment for collaborative efforts needs to be established and supported by the client. Here, allowing for a re-evaluation of the structural design and construction planning created that environment despite the short available time and the established interprofessional dialogue enabled a sound project team development.

Further, to support the interprofessional dialogue requires some form of vehicle, it is important of have something to discuss around, otherwise the dialogue tend to fail. Allowing the contractor to establish a "design intent" created that vehicle to carry the dialogue.

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