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Improving productivity in design and construction of bridges

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Abstract

Building new infrastructure is an essential part of developing society. The construction industry is also an important part of economic growth, accounting for 13% of the world's GDP. At the same time, the construction industry lacks behind in increasing its productivity. With more and larger infrastructure projects to be built, it is important that design and production could be performed in a more productive way. Increasing productivity is important both in terms of being more responsible with the economical and natural resources, and to be able to execute the project with the available personnel resources.

To increase productivity, this thesis focusses on standardisation of bridges. Standardisation in this thesis could be of the whole bridge, as well as standardisation of different parts of a bridge. By standardisation, the idea is that repetitive work tasks should give higher productivity as the number of similar bridges/parts increases.

This thesis examines which parameters are important to address to be able to increase productivity. It also examines how the different incentives of the three major actors' (contractor, client and design engineer) in the industry could be obstacles for increased productivity through standardisation.

The results in this thesis are based on a quantitative study consisting of a self-completed questionnaire that resulted in two appended papers. The main findings are which parameter to address to be able to increase productivity, and that the organisational structure of the contractor company could be an obstacle for long-term increased productivity.

This thesis provides further knowledge about how standardisation could increase the productivity and which incentives are important for the actors to work for this.

Keywords: Productivity, Standardisation, Early Contractor Involvement, Design-Build, Design Bid-Build, Lean Construction, Bridge design, Bridge construction

Preface

This thesis is the results of the work carried out from September 2020 until Mars 2023 at the Division of Structural Engineering at Chalmers University of Technology. The work is part of an Industrial PhD project, financed by the Swedish Transport Administration.

I would like to thank my group of supervisors, Associate Professor Rasmus Rempling, Professor Petra Bosch-Sijstema, Professor Ola Lædre, Dr Peter Simonsson and Professor of the practice Mats Karlsson, for all their support during this work. A special thanks to Peter Simonsson for believing in me and giving me this opportunity. I would like to thank my manager Anna-Maria Edvardsson for accepting me when I needed to change department at the Swedish Transport Administration to be able to accept this opportunity of being a PhD student, and for being very supportive during this time. Furter, I would like to thank all the other PhD students at the Division of Structural Engineering for support and interesting discussions.

I would like to thank all my present and former colleagues at the Swedish Transport Administration and Chalmers.

Finally, I would like to thank my wife and kids for all the support. Going through this time partly during a pandemic has been challenging from time to time, but we have made it so far. Let's hope that the second part of this PhD education runs more smoothly.

Johan Lagerkvist, Gothenburg 2023

List of publications included in this thesis

Paper A — Lagerkvist, J., Karlsson, M., Rempling, R., Bosch-Sijtsema, P., Lædre, O., & Simonsson, P. (2022). Important parameters for increased productivity in bridge design and production. Published in *Proceeding of IABSE Congress Nanjing 2022, Bridges and Structures: Connection, Integration and Harmonisation, 80–88.*

Paper B — Lagerkvist, J., Bosch-Sijtsema, P., Lædre O., Karlsson, M., Simonsson, P., & Rempling, R. Obstacles for improved productivity in design and production for bridges. *Submitted to Journal of Civil Engineering and Management, October 29, 2022*

Additional publications by the author

1 Lagerkvist, J., Simonsson, P., Karlsson, M., Rempling, R., Bosch-Sijtsema, P., & Lædre, O. (2021). Climate impact estimation – from feasibility study to handover. In H. Snijder, H, B. De Pauw, S. Van Alphen, & P. Mengeot (Eds.), Published in *IABSE Congress Ghent 2021, Structural Engineering for Future Societal Needs (pp. 622–628). IABSE.*

2 Antonsson, F., Lindvall, D., Lagerkvist, J., & Rempling, R. (2022). Optimal time for contractors to enter infrastructure projects. Published in *Procedia Computer Science, 196, 990–998.*

3 Lagerkvist, J., Berrocal, C. G., & Rempling, R. (2022). Climate-smarter design of Soil-Steel Composite Bridges using Set-Based Design. Published in *Current Perspectives and New Directions in Mechanics, Modelling and Design of Structural Systems (pp. 2001–2006). CRC Press/Balkema, Taylor & Francis Group.*

4 Lagerkvist, J., Berrocal, C. G., Carlsson, F., & Rempling, R. Probabilistic Risk Analysis of local verification of Load Model 1 in Eurocode for Soil-Steel Composite Bridges in Sweden. Submitted to *Engineering Structures, March 16, 2023.*

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1 Introduction

1.1 Background

Transport infrastructure enables the transportation of people and goods, and it is a crucial part of a country's development, both in economic and social terms. At the same time, it has a huge impact on the environment through the use of natural resources, the barrier effect for people and wild land-living animals, disturbing noise during operation etc. Globally, the construction industry is responsible for 37% of the total CO_2 emissions [1]. With this amount of impact, it is of great importance that the industry uses natural resources in a responsible way, and thereby contributing to a more sustainable society. The construction industry is also important for the economy, accounting for 13% of the world's GDP [2]. Simultaneously, the productivity in the construction industry is low [3], only increased by 1% during the last 20 years, according to [2], and there is even research that indicates that there has been a decrease in productivity [4–6]. If the productivity in construction could reach the same level as the rest of the economy (2.8%), more value is added to the projects [7], and the total value added in the industry could be increased by $1.6 trillion each year, which is the level of the GDP of Canada, or half the cost of the world's annual infrastructure need [2].

The problem with a lack of increased productivity is also well-known in the bridge construction industry and has been identified by several researchers [8–11]. The value-added time during rebar installation has been shown to be as low as 32%, while 29% is a pure waste [6]. In Sweden, it has even been indicated that the construction industry has a cost increase which is twice as high as for other industries [12]. The importance of increasing productivity and innovation in the industry has been recognised by the Swedish government. In 2018 they gave The Swedish Transport Administration (STA) a mission to measure and present their productivity for three years [13]. In the productivity report, standardisation was mentioned as one way to increase productivity. For standardisation, and for bridges in particular, it is important to understand how they could be standardised in a way that actually increases productivity.

Except for standardisation, there are several ways that have the potential to increase productivity. Digitalisation, lean design and lean construction are some ways to increase productivity [11, 14]. Except increasing productivity, digitalisation also has the potential to increase the collaboration between the actors in the construction industry [11, 15]. In the work done by [9], lean philosophy, lean construction, standardization and prefabrication are identified as possible solutions to increase productivity in the transport infrastructure industry. Another possible way to increase productivity is by increasing buildability, which could be achieved by involving the contractor earlier in the project [16–18].

Striving to increase productivity is to be responsible with society's common resources. With increased productivity, society will get more value for the money spent. To increase productivity, it is also important to be able to build what is intended to be built. In the northern part of Sweden, STA is building the North Bothnia Line, which is a 270 km new coastal railway line. Except for the railway, there will be approximately 550 km of roads and about 250 bridges [19]. With an estimated building time for one team to build a single concrete bridge in Sweden of 4-6 months, this would end up with 83-125 years to only build the bridges for one team. The first part of the line should be open for traffic in 2033, and in that part, there are about 140 bridges. To be able to build these 140 bridges for ten years, it would mean that there would need to be 5-7 teams consisting of 4-6 persons in each team.

Even though research has shown that there exists a potential to increase productivity, this has not yet been realised to a large extent. Reasons for this could be a lack of labour experience as described in [20, 21] and/or a lack of financial incentives for the workers [22, 23]. There is little research that has looked at how the different actors' incentives could underly the lack of long-term increased productivity. In this thesis, incentives are what drive the actors to strive for improved productivity, and it does not have to be financial incentives. Financial incentives have been shown to be less important compared to motivation and performance compared to relationship enhancement incentives [24]. However, financial incentives have also been shown to be one way to increase productivity [5, 25].

In this thesis, the focus will be on the design and construction stages. This is because, in the land acquisition plan, there are a lot of things that could affect the outcome that lies out of the project's control. The difficulties with things that lies out of the control of the project were noticed in the work reported by [26]. The different stages in a project are shown in Figure 1, where cost- and climate estimations during the different phases also are presented.

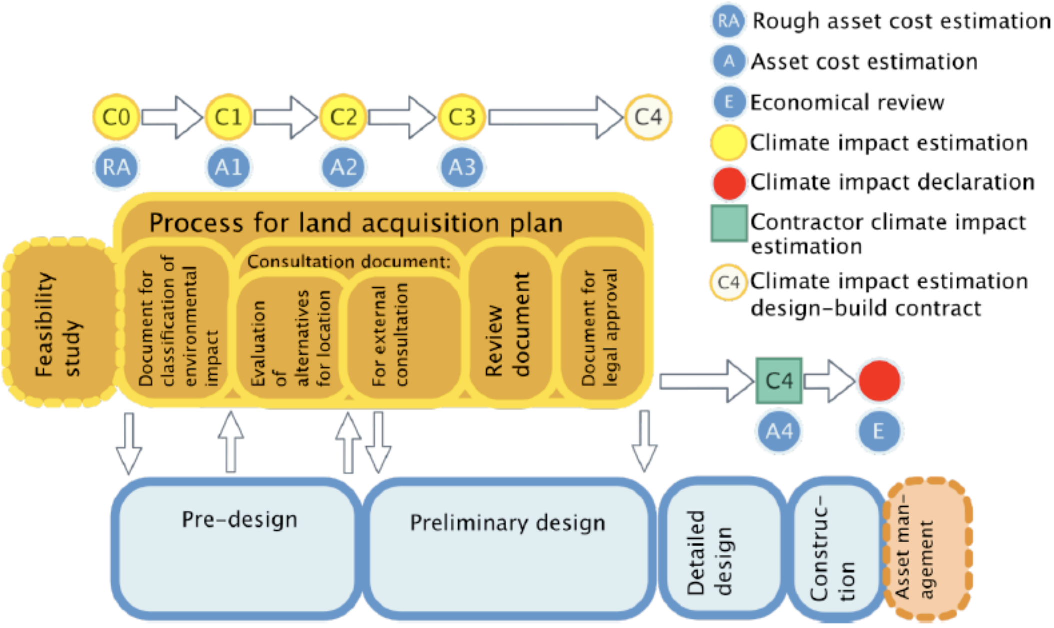

Figure 1. Different stages in a project, Figure modified from [27]

1.2 Purpose

The primary purpose of this thesis is to find out which potential the three major actors (client, contractor, and design engineer) identify as important to increase the productivity in the bridge construction industry in Sweden; in technical as well as organisational aspects.

In a longer perspective, the ambition is that results from this thesis could guide clients to improve the procurements with better conditions to build transport infrastructure projects with higher productivity.

1.3 Aim and research questions

To be able to fulfil the purpose, the work in this thesis is based on one study that addresses different parts. The first part focusses on the technical aspects that need to be addressed to give the right conditions for increased productivity. This is presented in Paper A.

The second part address the organisational aspects that give important information about potential obstacles for increased productivity from the three major actors point of view. This is presented in Paper B.

The overall aim of these two studies is to contribute with knowledge about how to increase productivity in the bridge-building industry.

The following research questions define the aim:

- **RQ 1:** What are the important parameters that could increase productivity in the design and construction of bridges?
- **RQ 2:** How could the different actor's incentives be obstacles for improved productivity in the design and construction of bridges?

1.4 Limitations

This thesis is limited to only study the contractor, client and design engineer perspective.

This thesis focuses on the second part of the definition of productivity given in [28]: "Productivity means that the value added to the product increases despite the same amount of resource being used as before, and/or that the need for resource decreases to produce the same value".

This thesis has been done mainly with concrete bridges in Sweden in mind.

Even though much of the literature studied is international, the focus in this thesis is on Sweden. However, since many of the developed countries are struggling with the same problem, I believe that results from this thesis could be applicable in an international perspective.

1.5 Outline of the thesis

This thesis is a summary of two scientific papers, the first was published in 2022 and the second was submitted in 2023. Chapter 2 deals with the frame of reference used in this thesis. Chapter 3 presents the research method and Chapter 4 deals with the discussions. In Chapter 5 conclusions are presented, and finally, future work is presented in Chapter 6.

1.6 Summary of appended papers

1.6.1 Paper A

There is great potential for increased productivity in the production of bridges in terms of optimising material use, time and cost for design and production. Hence, the environmental impact and cost can be optimized. To find out how standardisation of parts of bridges and which parameters are of most importance for increased productivity in the production of bridges, a quantitate study was performed on the Swedish bridge construction industry. The questionnaire received 151 responses. The results show in which aspects and parameters the industry's three major actors – design engineers, contractors, and clients – see greatest potential in order to increase productivity. By standardising parts in bridges, there is great potential in making the construction of bridges more productive.

1.6.2 Paper B

Increased productivity is necessary to reduce economic costs in future bridge projects. The design and production of bridges have great productivity potential. A questionnaire with the purpose of identifying what incentives clients, contractors and design engineers require in order to increase productivity in bridge construction projects received 151 responses. The responses show that the incentives vary. One finding is that the contractors' employees find profit in single projects more important than the company's long-term business development. Then, they do not invest in standardization that could benefit future projects and thereby increase the accumulated company profit. The design engineers and the client did not show the same pattern regarding the benefits. The design engineer and client place most value on the quality of delivered products. None of the actors found reduced climate impact as an important incentive to work for increased productivity.

2 Theory

The work done in this thesis deals with areas of lean production, productivity, and different compensation models for contractors and design engineers.

2.1 Lean

Lean production could be traced back to the Toyota Production System (TPS). In the first oil crisis in 1973, Japan suffered from a recession and after that followed years with very low or even negative growth. Many Japanese companies were suffering, and they could no longer function based on the American mass production system. The crisis led to a need for a new production system. Taiichi Ohno looked at the possibility of producing many different models in small quantities [6]. Two principals were defined in the TPS: Just-in-time and Automation.

When Jeffrey Liker published his book "The Toyota way" in 2004, he contributed to the spread of Lean information.

The bridge industry could probably have a lot to learn from lean. Transport projects could benefit greatly from the use of Lean techniques for delivering projects faster and with higher quality [6]. By delivering projects faster and with higher quality, the projects will also be delivered with less environmental impact [10]. A simple way to think of lean production is: deliver what the customer wants, when the customer needs it and in the required quantity [29]. It could also be added that it should be delivered with the right quality.

Especially the elimination of waste should be of great interest for the bridge building industry. Liker pointed out that there are eight types of waste in any process, according to [29] these are:

1. Overproduction
2. Waiting
3. Unnecessary transport of materials or people
4. Over or incorrect processing
5. Excess inventory
6. Unnecessary work steps
7. Defects
8. Unused employee creativity

When looking at each of these wastes, it may not be obvious how they relate to the bridge construction industry. By studying the root cause of too many delays in the construction industry, it is evident that many of these wastes are a common occurrence and are even considered best practices in some situations [6]. One common example could be the mass delivery of storm sewer pipes on day one of a road project [6]. This kind of waste could also be common in the bridge construction industry, i.e., more material than necessary is delivered on day one, and this material needs unnecessary movement during the project. Except for unnecessary movements, it will also need unnecessary inventory since a location for storage needs to be created for the material that will be used later in the project. There is also a risk of defects of the material since it is harder to protect the material on site.

There are a number of different lean tools, and those of interest in this work are:

- Standardised work tasks
- Kaizen
- Digitalisation

<u>Standardised work tasks:</u>

Standardised work tasks are a way to organise parts and operations so that all tasks are carried out in the most productive way. Tasks produced or used in one project should then be applied to other projects [6]. In the first place it should at least be used in the same project for another structure. One example where this was implemented was during the construction of the Modena bridge in Italy [30]. Serial production of bridges has been mentioned as one way to increase productivity [31]. Workers and management should develop standardised work tasks together. For bridge construction this could be done by the use of work preparations in 3D so that the workers working on site could find difficult parts and perhaps improve them in a more productive way than what was first prepared by the designer. To gain the full potential from this, the designer should participate in this part to learn from the workers and bring this experience back to the office. When the designer is present in this part, they could also explain the need for some reinforcement to the workers and discuss possible solutions and effects of changes. If each project uses the same standard techniques, these can become standardized and can reduce the learning curve on each new project [6].

Kaizen:

Kaizen stands for continuous improvements [6]. This is achieved through the participation of all the workers. The fundamental idea is that continuous improvements should be a natural part of everyday work [10]. Through the incremental improvements that are achieved through Kaizen, an activity creates more value with less waste [6].

Digitalisation:

Digitalisation has a major potential to increase the efficiency in the building sector. Digital tools allow a more efficient collaboration and a more detailed design earlier in the process. This will contribute to making the right decisions and also better planning of coming work [32]. Digitalisation also has a potential to improve the waste reduction [14].

2.2 Different project delivery models for contractors

The chosen project delivery model is of importance to avoid cost overruns, time delay and quality [16]. Together with the definition given in Chapter 1.4, the project delivery model the is of importance to increase productivity.

Traditionally, Sweden and other similar countries have often used Design-Bid-Build (DBB) contracts, i.e., the contractor receives complete design documents that they should bid on and construct after. In Sweden, it has also been quite common that the bridges have been broken out and have been procured as a Design-Build (DB) delivery in the DBB contract. A major difference between DB and DBB is where the responsibility for detailed design lies. For DB models, the responsibility lies with the contractor, while for DBB models, the responsibility lies with the client [33]. Another difference between DB and DBB is the contract form between the actors. In DB, the client has one single contract to perform design and construction [16, 34]. For a DBB, the client has two separate contracts, one for design and one for construction. Projects delivered with DB are often procured with a fixed price, compared with DBB which often are procured with unit prices. Research has shown that fixed price tends to give higher productivity [2]. With a fixed price model, in which the cost is the only criteria for the choice of contractor, the contractor receives a strong incentive to increase productivity [35]. Even though a lot of bridges traditionally have been built in DB contracts in Sweden, there is still a great lack of productivity increase and lean thinking in the projects.

A great disadvantage with DBB is that the knowledge from the contractor is not used since they do not get into the process until all the design documents are finished. Different contractors could also have different experiences which do not come to use with this kind of contract. In the work done by [36], they present a case study where the contractor changed DBB documents and redesigned the structure. Even though this meant that they lost time for redesign, the contractor was able to provide a more productive solution than what was proposed in the original design documents from the procurement. DB contracts could thereby be seen as a better way since the contractor then comes in earlier in the process and could contribute with their experiences from earlier projects delivered; this was also concluded in [37]. That DB perform better than DBB with regard to building time and/or cost was concluded by [38–41]. Regarding cost performance for DB and DBB, contradictory results could be found in the literature [42–44], which means that the performance could depend on the situation and not only the project delivery model.

Another project delivery model that has gained popularity in the last years, and then mostly in larger and more complex projects, is Early Contractor Involvement (ECI). In this delivery model, the contractor is involved earlier in the process compared to DB and DBB. In Sweden it has often been in the stage before they traditionally get into a DB contract, i.e., they are involved in the stage of designing the traditional DB documents. During this stage, the contractor and the client should agree on a target price for construction during the next stage. To the best of my knowledge, there has also been one project, in Sweden, where the contractor has been involved even earlier than in this stage. In this case the contractor was involved already in the evaluation of alternatives for location stage, see Figure 1, for a road should be decided. Experiences from this particular project are presented in [26], and in [45], experiences from this project and another six projects are presented. Early involvement of the contractor is an important factor for increased productivity according to [10].

By involving the contractor earlier, the buildability and the cost estimation will improve [46]. ECI has also led to reduced time for construction and better conditions for constructing projects in densely built-up areas [45]. For ECI delivery, there is often a possibility to have financial incentives, which is an important motivator for contractors to increase productivity [24].

2.3 Different forms of compensation for design engineers

Different compensation forms for design engineers and their ability to affect productivity is a research area that is not very well explored. However, research has shown that engineers tend to produce better quality and more innovative designs if they have financial incentives [47]. Fixed price has also been shown to increase productivity for design engineers. The reason for this could be that design engineers have a potential to increase the profit. Even though productivity would increase, it does not mean that the client will receive the best solution [48].

2.4 Buildability and constructability

Buildability and constructability strive to improve the production and safety of on-site production while reducing costs [49]. Buildability was coined by Construction Industry Research Information Association (CIRIA) in the UK. Constructability was coined by the Construction Industry Institute (CII) in the USA. Buildability or constructability has a potential to improve productivity, reduce construction time and give a higher profit margin [50]. With reduced construction time, the environmental impact is reduced due to factors such as reduced traffic and reduced energy consumption [10]. The difference between buildability and constructability is that the latest includes management functions, which buildability does not [46]. The definition of buildability given in [51] is: "The extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building", is the most cited according to [10]. For constructability, a well know definition is given in [52]: "The optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project design".

CIRIA has focused on the buildability of bridges in one of their reports [50]. Factors such as the shape of the bridge, choice of materials, and specific design details all affect the ease of construction of the bridge. The top six factors affecting the buildability of civil engineering projects in Sweden are, according to [10]:

- Early involvement of contractor
- Workplace structuring (e.g., 5S)
- Available space on construction site
- Production planning
- Prefabrication of reinforcement
- Simplicity during the construction phase

As mentioned in Chapter 2.2, [36] studied a Design-Bid-Build contract where the contractor wanted to change the original design to be able to have a more optimal construction regarding buildability and risk during construction. In that case, the most significant areas related to increased productivity were:

- Construction method, including sequence, production rate etc.
- Repeatability, simplicity, similarity in details
- Minimizing shear reinforcement, and choice of bar type

To minimize shear reinforcement has also been mentioned in [53] as a factor that could increase the buildability.

The term "constructability" is used within construction projects when the different work tasks have low repeatability [54]. Constructability is often neglected during the early phases of a project, and this is controversial since it is in these stages that most decisions required to make the project constructible are made [49, 55]. Due to the fact that the contractor often is involved after the design has been completed, the design is seldom done with regard to the contractor's specific skills [10].

3 Method

In order to obtain a general and broad knowledge in both the field of research and the studied industry a literature review and a quantitative study were performed. With the knowledge from the literature review, it was then possible to formulate what could be done to contribute with new knowledge in the field.

The two studies on which this thesis is based on are quantitative studies that used a self-completed questionnaire for data collection. Collecting data through a questionnaire is a way to receive many responses in a time-efficient way [56]. With the number of responses that are possible to collect with this method, it was considered to result in objective conclusions.

The two studies have different foci. The first study focuses on the technical aspects and important parameters that could be addressed to be able to increase productivity in design and production of bridges. In this study, it was important to find out which parameters the industry finds most important to address to increase productivity and to find out what potential they see in standardisation.

In the second study, the focus is on the organisational aspects and how the three major actors' different incentives could be obstacles for increased productivity.

Both studies are about productivity and how this could be increased through different aspects.

3.1 Questionnaire design

The questionnaire used in the appended papers was developed by the authors of the two appended papers. The work was done during two workshops and the questions were based on the literature review. One way to increase the quality of the questionnaire, according to [56], is to test the questionnaire. Therefore, a pilot test was distributed to six representatives from the industry. Minor revisions were done after the pilot test, and the questionnaire was finally distributed in September 2021.

In the final version of the questionnaire, there were 24 questions, including answer-dependent follow-up questions. The first questions were of demographic character, e.g., discipline, age, and time in the industry. Thereafter the respondents were asked to what extent different statements influence productivity in the design and construction of bridges. The questions had different aspects, i.e., technical and organisational aspects. The two different aspects were then handled in the two appended papers.

For every question, the respondents also had the opportunity to add an additional alternative and to give comments. By doing this, it is possible to receive some qualitative data from the questionnaire which enriches the answer [57].

The respondents ranked the different statements on a 7-point Likert scale. The choice to have a 7-point Likert scale was made since this would give a more nuanced result compared to a 5-point Likert scale, and keeps it simple enough for the respondents [58].

3.2 Data collection

It was important to collect as many responses as possible for a statistically significant result. Therefore, it was decided to have a shorter questionnaire since this according to [56] improves the chances for a higher response rate. In order to improve the possibility of receiving a higher response rate, the questionnaire started with a short-written introduction to the aim of the survey. Finally, a last step to increase the response rates was to follow up on respondents that had not yet responded and to remind people that had not finalized the questionnaire. The questionnaire was distributed to 470 recipients from the Swedish construction industry, distribution between design engineers, contractors and clients. The response frequency is presented in Table 1. The questionnaire was available for the respondents during 19 workdays.

Table 1. Distribution of questionnaire and response frequency

	Distributed	Responses	Response frequency
Design engineer	175	76	43%
Contractor	246	37	15%
Client	49	38	78%
Total	470	151	32%

3.3 Analysis

The responses from the questionnaire were analysed by sorting the responses into categories by actor type, plotting Likert-scales of the results, and studying the average for each actor.

3.4 Reliability and validity

Reliability is an important factor for quantitative studies [56]. The replicability for the questionnaire was considered to be very high since all the questions will be available, so it would be easy for another researcher to replicate the study with another group of people. Replicability is considered as an important quality of quantitative studies [56].

The validity of the quantitative study will be higher when more respondents complete the questionnaire. In comparison to other quantitative studies that have used questionnaires within the Swedish bridge building industry, see e.g. [10, 59, 60], this questionnaire received more responses. With more responses, this means that the results will be easier to generalise and that the results could be a "microcosmos" of the population in the industry [56]. The validity of the results also depends on whether the respondents understand the questions; the pilot test of the questionnaire described in Chapter 3.1 was thereby considered to increase the validity of the questionnaire.

3.5 Ethics

All the respondents were guaranteed to be fully anonymous. At the beginning of the survey, all respondents received a question if their answers were allowed to be used for research purpose; if they answered no, they could not finalize the questionnaire.

4 Discussion

The main purpose of the work performed in this thesis was to contribute with knowledge from the three major actors about their view on the potential of increasing productivity in the Swedish bridge construction industry.

In order to increase productivity, it is important to put effort at the right time. It is widely known that the possibilities to affect the outcome are earlier in a project. One question from the questionnaire addressed the possibility to give the right conditions for high productivity at different stages in a project, during the development of land acquisition plan, and a tendering for DB and DBB delivery models. In contrast to what is concluded in [4, 61], the respondents do not see that there is a greater possibility to create the right conditions for high productivity earlier in the project, i.e., in the land acquisition plan. For technical parameters that could increase productivity, simplified geometries, the reinforcement design, and production-based member sizing were considered the three most important. Looking more into the reinforcement, reducing the shear reinforcement was considered important, this was also concluded in [36, 53]. Regarding standardisation, the majority of the respondents believe that standardisation has potential to increase productivity. The design engineers and the client believe that standardisation by hole bridge would be most efficient, while the contractors believe that standardisation by bridge parts would be more efficient to increase productivity. All the respondents also believe that the repetition that comes from standardisation will increase productivity after 5-10 parts. Paper A contributes with knowledge in the field of structural engineering.

Paper B focuses on organisational aspects, and primarily on how these could be obstacles for improved productivity. An interesting finding here is the distance between the client and the contractor regarding the importance of profit in a single project. This was considered the second most important aspect from the contractor's point of view, while it was the least important for the client. It is also interesting that the respondents from the contractor, value the profit in a single project higher compared to the company profit over time. For different project delivery models, both the contractors and the client thought that DB model had the best potential for high productivity. This was a bit surprising, especially since ECI is believed to create better conditions for better buildability, and thereby also productivity; this is also in contrast to what has been found in earlier research [10, 18, 45, 46, 62]. Paper B contributes with knowledge to the field of construction management.

When looking at the results from the two studies, it seems most of the respondents believe that productivity could be increased by standardisation. However, due to the organisational structure of the contractors and especially their incentive programs depending on the profit in a single project, they are not interested in developing standards if they do not receive any financial gains in that single project. Financial incentives have been shown to be important for construction workers [22, 23]. This is even though most of the respondents believe that productivity would be increased by standardisation. Since incentive programs have shown to increase productivity [5], it would be necessary to create incentive programs that also take long-term productivity into account. By doing this, the total productivity in the industry could increase. Since the Transport Administrations in different countries are the largest client for bridges and infrastructure, it would be important for them to procure projects with incentives that encourage standardisation so that the contractors try this on a large scale. The important role that the administrations have is to influence and facilitate this kind of development, which is also concluded by [8].

Even though all the respondents from the questionnaire for both studies in this thesis are working in Sweden, I believe that the results from this thesis could be applicable in an international context. The focus of this thesis is on bridges, but I believe that many of the principles could become applicable to other kinds of construction projects.

5 Conclusions

To increase productivity there are several parameters that are important to address. However, the most important parameters found in this thesis are:

- Reinforcement design: there are several ways to design the reinforcement in a structure. To minimise the amount of shear reinforcement was considered important.
- Simplified geometries: when designing bridges, simplifying the geometries has potential to increase the productivity.
- Production-based member sizing: for the different parts in a bridge, it is important that they are designed in a way that the different measures are chosen from the perspective of production. It could be better to make parts a little bit larger than necessary if that is more suitable from a production point of view.

For standardisation to increase productivity, standardisation of commonly used bridges was considered to be efficient by all the respondents. However, the contractor thought that standardisation of parts would be more efficient in order to increase productivity.

The finding that the contractors are more interested in the profit of one single project compared to the long-term profitability of the company is an important conclusion. This could be an obstacle for increased productivity over time since standardisation is related with a cost. However, the initial cost for the standardisation will probably be earned in future projects and will then lead to increased profit for the company and increased productivity in the industry.

6 Future work

For the future, it would be interesting to implement the results from the work performed in this thesis to a case study. This could be done by comparing a built project with a "fictive project". For the fictive project, the bridges could be designed in a way that takes the results regarding standardisation and repetition into account. The fictive project should then be compared (theoretically) to the built project to see if the productivity would increase, and then also be beneficial for the society.

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Appended papers