Outsourcing Design Verifications Tasks to Subcontractors in the Dutch Civil Engineering Industry

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The change from Design-bid-build to D&C and DBFM-contracts in the Dutch civil engineering industry comes with numerous challenges for the main contractor. One of these challenges is how to outsource to subcontractors. A main contractor can chose between outsourcing only the construction phase or use a more integral approach and outsource design and design verification tasks as well as construction tasks. In this research, a framework is developed based on literature and expert sessions. This framework guides the main contractor in finding the appropriate division of verification tasks between the main contractor and the subcontractor. This framework is confronted with practice in a case study. Based on literature, four factors are determined that influence the appropriate division of verification tasks: the technical complexity of the design, the design verification knowledge and experience of the subcontractor, the size of the outsourcing and the uncertainty of the interfaces of the part that is outsourced has with other parts. The results on the case study match with what was expected based on the literature. The in the literature identified factors seem therefore to be applicable in determining the right division of design verification tasks between the main contractor and the subcontractor in the Dutch civil engineering industry.

Keywords: Design, Outsourcing, Systems Engineering, Subcontracting, Verification Tasks

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1 INTRODUCTION

In the last fifteen years, a trend is emerging towards more integrated contracts in the civil engineering industry. This started with the change from design-bid-build towards design and construct (D&C) (Ling, Chan, Chong, & Ee, 2004). Nowadays even DBFM (Design, Build, Finance and Maintain) or BOT (Build, Operate, Transfer) contracts are used which next to the design and construction also include finance and maintenance (Lenferink, Tillema, & Arts, 2012).

These D&C and DBFM-contracts are used in large civil engineering projects in the Netherlands for several reasons. These contracts are supposed to close the gap between the design and construction phase, reassure that the specific knowledge of the contractor is used and make room for optimization and innovation (Priemus, 2009; Lenferink, Tillema, & Arts, 2012).

In these integrated contracts, clients want to outsource a large part of their project life cycle to the contractor without losing control over its construction projects. Systems engineering (SE) is seen as a way to outsource a larger part of the project life cycle, e.g. design, engineering and construction, while still keeping control of the project (Makkinga, De Graaf, & Voordijk, 2018).

In the Systems Engineering handbook that is published by INCOSE, the following definition of Systems Engineer is given: 'Systems Engineering is an interdisciplinary approach and means to enable the realisation of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. Systems Engineering

integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.' (INCOSE, 2015, p. 20).

A consequence of the use of Systems Engineering is that de contractor becomes responsible for verifying and validating the work to make sure the requirements set by the client are satisfied (Makkinga, De Graaf, & Voordijk, 2018).

But as in the construction industry, 75-90% of the work is outsourced to subcontractors (Hinze & Tracey, 1994; Vrijhoef & Koskela, 2000), this raises the question how much the contractor should outsource to suppliers. For example, the contractor could decide to use design-bid-build and outsource only the construction and construction related verification tasks to the subcontractor. A main contractor can also chose to use a D&C approach where next to the construction tasks, also design and design verification tasks are outsourced to the subcontractor.

In other sectors, such as the Japanese automotive industry, it is (more) common to involve suppliers in the design process as it increases the manufacturability of the design. This due to the fact that suppliers' engineers are able to understand the manufacturing process at a far deeper level (Liker, Kamath, & Wasti, 1998). Furthermore, the engineers of the supplier are more motivated to put a lot of effort in the design. This extra design effort will lead to a more efficient production process. Since design and construction are outsourced to the same supplier, the production division of the suppliers gains the benefits from this extra design effort (Liker et al., 1998).

Contractors struggle in finding the appropriate division of verification tasks between the main contractor and subcontractor. Therefore, the aim of this research is to get insight in how to determine the appropriate division of verification tasks in the design phase between main and subcontractor. This will be done by the development of a theoretical framework a main contractor can use to determine the appropriate division of verification tasks.

There is literature available about involving subcontractors/specialty contractors/supplier in the design phase. Literature about involving the subcontractor in the Systems Engineering process during the design is however scarce. Therefore, the aim of this research is to get insight in how to determine the appropriate division of verification tasks in the design phase between main and subcontractor.

The paper is structured as follows: in section two is the methodology of this paper described. Section three contains the literature study and in section four is the framework presented. The case study is described in section five. In section six, the results are presented. The paper ends with the discussion, conclusions and limitations (section seven, eight and nine).

2 METHODOLOGY

The aim of this research is to study how to determine the appropriate division of verification tasks in the design phase between main and subcontractor. This is done with a case study according to the method of Yin (2003). In this method, theory development prior to the collection of any case study data is an essential step. The research is therefore divided in four steps, a literature study, the development of a framework, executing a case study and a comparison of the results from the literature with the results from the case study. These four steps are the next four sections in this paper. The four steps and their dependence is visualised in Figure 1.

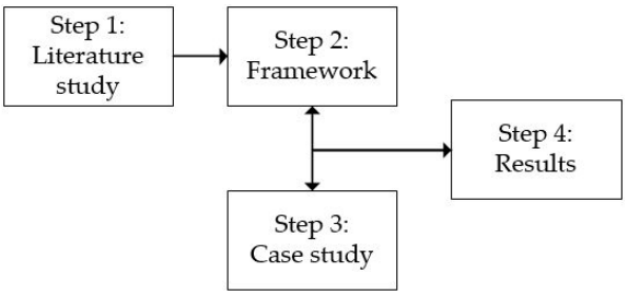

Figure 1: the four research steps visualised

2.1 Step 1: literature study

The first step of the research was the literature study. The aim of the literature study was to identify factors that influence the decision to outsource design and design verification tasks. Literature on outsourcing design verification tasks to subcontractors in civil engineering is scarce. Therefore, literature about outsourcing design tasks to subcontractors has been used. This is done by reviewing academic journals on the construction industry focusing specifically on research about design involvement of subcontractors. Next to literature from the construction industry, literature from other industries has been used as some industries are further developed with regard to integrating suppliers into their design and development process. Studying the journals resulted in the identification of four factors that influence the

decision to outsource design and design verification tasks. These four factors are described in section three.

2.2 Step 2: framework

The second step in this research is the development of the framework. This framework will give insight in the appropriate division of design and design verification tasks between the main contractor and the subcontractor. As shown in Figure 1, the literature study is used as input for developing the framework.

Firstly, a distinction is made between three forms of outsourcing design and verification tasks, varying from outsourcing all design and verification tasks to outsourcing no design and design verification tasks to the subcontractor, leaving only verification tasks in the execution phase to the subcontractor.

Secondly, the factors are operationalised. This means that the factors determined in the literature study are made measurable with the use of indicators. Specific literature about operationalizing these factors for use within the civil engineering industry was not applicable. Therefore, expert sessions were held to determine the indicators and to determine the values of these indicators for the three categories.

Thirdly, the framework itself is developed. The framework determines the appropriate division of design and verification tasks based on characteristics of the outsourcing. Therefore, the outsourcing needs to be categorized so that the outcome of these categorizations can be linked to the appropriate division of design and verification tasks with the framework. The framework is further explained in section four.

2.3 Step 3: case study

The third step of this research is the case study. The aim of the case study is to confront the theoretical framework with practice. Two cases were analysed and in both cases the outsourcing of the prefabricated beams, reinforcement and handrails were studied. These are three important subcontractors in the civil engineering industry, which are regularly involved in the design process. This makes these subcontractors relevant for this research.

The focus during the case study was on gaining three types of information. Firstly, getting information on the characteristics of the case study so the appropriate division of verification tasks could be determined. Secondly, getting to know the division of verification tasks on the outsourcings. Hereby the focus was on the contractual division but also on the perception of the division of the different stakeholders involved in the outsourcing. The third part of information necessary for the case study is to get insight in the verification problems that occurred within the outsourcings.

In the case study, a document study and interviews were conducted. The used sources within the case study are shown in Table 1. In the document study, the contracts were analysed as well as calculations, drawings and the Systems Engineering environment. Access to both the Systems Engineering environment as well as the document management software was granted and therefore all the needed documents were available. The document study gave insight in the agreed division of verification tasks in the design stage. Furthermore it became clear whether the tasks were executed as agreed in the contract. In the interviews, employees of both the main contractor and the subcontractor were interviewed. Questions were asked about their opinion on how the outsourcing went, the verification problems that occurred and the possible solutions to prevent this problems from happening in a next project. The employees that were interviewed were a design leader, Systems Engineer, purchaser, work preparator and site manager from the main contractor. From the subcontractors, a project leader was interviewed and when the subcontractor was involved in the design process, also a design manager. A description of the different outsourcings and their design involvement can be found in section five.

Table 1: sources used within the case study

Method	Source	Specified sources
Document study	Document management system	Calculations, contracts, drawings
	Systems Engineering environment	Verification documents, verifier
Interviews	Main contractor	Design manager, purchaser, site manager, Systems Engineer, work preparator
	Subcontractor	(Design manager), project leader

2.4 Step 4: Results

In the fourth step, the outcomes of the case study were compared with the framework. This gave

insight into the similarities and differences between the framework and the cases. This is done by comparing the applied division of design verification tasks of the outsourcings within the case study with the division of design verification tasks according to the framework. A match between the applied division and the division according to the framework should lead to no verification problems. This will give insight in the similarities and differences between the framework and the cases. The comparison of results is shown in section six.

2.5 Discussion, conclusion and limitations

In section seven, the conclusions of this research are presented. The conclusions are further discussed in section eight in which the discussion is presented. Section nine contains limitations and suggestions for further research, section ten contains the references.

3 LITERATURE STUDY

Literature about outsourcing design verification tasks to subcontractors is scarce. Therefore, literature on involving subcontractors/suppliers in the design phase is used, both from the Civil Engineering industry as well as other industries. In the literature study, four factors were identified that influence the decision to involve subcontractors in the design phase.

3.1 Technical complexity

The first factor identified is the technical complexity of the design of the part of the system that is outsourced. The technical complexity can be determined by the amount of design freedom and the complexity of the calculation.

Gil, Tommelein, Kirkendall, & Ballard (2001) state that subcontractors should be involved in the design of technical complex projects. Gil et al. (2001) study construction projects of semiconductor plants, these are high-tech facilities and are technically complex. Subcontractor involvement is necessary in such complex projects as the subcontractor can come up with creative design solutions (Gil et al., 2001).

Similarily, Shafaat, Maffous, Jackson, & Kandil (2014) state that subcontractor involvement is only necessary in complex projects, otherwise the project can be executed on organisational routine. The research of Shafaat et al. (2014) focuses on involving subcontractors in decision making in the design phase. Shafaat et al. (2014) conclude that different parties involved (engineering firm, main contractor and specialty contractor) have different knowledge and should therefore cooperate to reach an optimum design process. (Shafaat et al., 2014).

Likewise, also Franz, Leicht, & Riley (2013) state that only for complex tasks, subcontractors should be involved in the design process. The research of Franz et al. (2013) focuses on involving subcontractors in the design phase of building health care facilities and other high-performance facilities. For example, only the mechanical contractor is involved in the design process since the design of the HVAC system is a complex process. According to the research, the involvement of the subcontractor provides opportunities for reducing costs growth, reducing schedule growth, reducing safety incidents and improving the HVAC system performance (Franz et al., 2013).

The automotive industry is even further in involving suppliers in the design process. Liker et al. (1998) also state that suppliers of complex subsystems are the suppliers that should be involved in the design process in the automotive industry.

All four studies described above, involve subcontractors or suppliers in the design phase if the work that is being outsourced is complex. The technical complexity of the design is therefore the first factor of influence. A higher complexity relates to outsourcing more verification tasks in comparison with an outsourcing with a lower complexity.

3.2 Design verification knowledge and experience

The second factor identified from literature is the design verification knowledge and experience of the subcontractor. This is highly diverse and can vary from having none in-house designers and barely none design experience to having a whole design department with experience in the design process.

Shafaat et al. (2014) state that if a subcontractor has design knowledge and experience, design tasks should be outsourced. According to Shafaat et al. (2014) subcontractors have a wealth of knowledge about the design process and the product design itself, mainly gained though past experience. This is implicit knowledge, which de main contractor may not have. The experience of the subcontractor simplifies complex decisions to routine. This ensures that the subcontractor can make the appropriate decisions in the design phase without spending much time on that decision (Shafaat et al., 2014).

In the public sector, Griffis & Choi (2013) claim that consultancy firms have more specific knowledge than government agencies, as consultancy firms can specialize on a certain type of projects. Government agencies should therefore outsource design tasks to these consultancy firms. This is comparable with outsourcing design tasks from main contractor to the subcontractor. Subcontractors are specialized on a

certain type of project and have therefore more specific knowledge.

Liker et al. (1998) conducted research about supplier involvement in the automotive industry and state that design responsibility can only be given to suppliers that have technical capabilities matching with the responsibility. One of the reasons given for outsourcing design tasks is that the engineers of the supplier are likely to understand the manufacturing processes at a far deeper level than engineers from the car manufacturer (Liker et al., 1998).

The three papers describe research about outsourcing design tasks, but all between different parties (contractor-subcontractor, government agency-consultancy firm and car manufacturer-supplier). The studies are similar with regard to the conclusion, though. The specific knowledge and experience is the reason for outsourcing design tasks to subcontractor/consultancy firm/supplier. Liker et al. (1998) and Shafaat et al. (2014) note that it must be assured that the supplier/subcontractor has the appropriate technical capabilities matching with the responsibility that is transferred. Therefore, the amount of design knowledge and experience of the subcontractor is the second factor that influences the degree of outsourcing design verification tasks to the subcontractors. Subcontractors with more knowledge should get more verification tasks than subcontractors with less knowledge.

3.3 Size of the outsourcing

The third factor that has been identified in the literature is the size of the outsourcing. Outsourcing design and design verification tasks is more appropriate when the size of the outsourcing is large. According to Transaction Cost Economics (TCE) of Williamson (1985) the transaction costs of an outsourcing should be in proportion to the total costs of the outsourcing. This means that high transaction costs are more appropriate by outsourcings that have a large size.

Outsourcing the design and design verification tasks leads to higher transaction costs. It requires additional coordination in the precontractual phase to define the exact division of design and design verification tasks. Also, coordination is necessary during the design phase to make sure the design made by the subcontractor fits with the overall design. Last issue driving up the transaction costs is the fact that the main contractor has to check the work of the subcontractor to make sure the subcontractor satisfies the terms of the contract. This all contributes to higher transaction costs then when only the construction is being outsourced. Therefore, outsourcing design and verification tasks is most effective when the size of the outsourcing is large.

Wasti & Liker (1997) conclude their research stating that car manufacturers should involve suppliers in their design process to profit from the product and process integration. However, they should be selective in order to offset the transaction costs. They come to this conclusion by comparing the Japanese automotive industry with the American automotive industry. The success of the Japanese auto industry is partly because of the cooperation with suppliers whereas American literature suggest that it is risky to outsource design responsibilities and refer hereby to TCE and the higher transaction costs of outsourcing instead of in-house development. Wasti & Liker (1997) state that both are true and that the cooperation as applied in the Japanese automotive industry should only been used when the size of the outsourcing is large enough.

Bucklin & Sengupta (1993) state that it is very difficult to cooperate successfully if the transaction costs are high. This conclusion is based on a research over strategic alliances between companies that complement each other. For example, the cooperation of Apple and IBM in 1991. These two companies complemented each other since IBM was focused mainly on corporate computing and Apple on personal computing. The researchers focus on factors that makes these alliances successful. An important conclusion is that the transaction costs of the alliance play an important role in the successfulness of the alliance. Alliances with relatively high transaction costs are harder to get successful in comparison with alliances with less transaction costs (Bucklin & Sengupta, 1993). Therefore, it can be said that it is more likely for companies to form an alliance if the transaction costs are relatively low in comparison to the total size of the cooperation.

The transaction costs play an important role in the cooperation between companies and by involving suppliers in the design process. Working close together and shifting more tasks to a subcontractor leads to higher transaction costs but can also lead to product and process integration. As argued, outsourcing design and design verification tasks leads to higher transaction costs. Therefore, the size of the outsourcing should be sufficient to offset the transaction costs. It is more likely to outsource design verification tasks by a large outsourcing than by a small outsourcing.

3.4 Uncertainty of interfaces

De last factor identified in the literature is the uncertainty of the interfaces the outsourcing includes.

Shokri, Haas, Haas, & Lee (2015) combine several definitions of interfaces given in literature and summarize this as follows: "Interfaces are considered as the boundaries between independent, yet interacting organizations, systems, project phases, scope packages, construction elements and stakeholders" (Shokri et al., 2015, p. 2). For this study, the focus will be on interfaces between construction elements and the uncertainty of these interfaces. Hereby are the amount of interfaces the element that is being outsourced has relevant as well as the uncertainty of the element and the importance of the interface for other elements of the structure.

Shafaat et al. (2014) state that the uncertainty of the design of an element is an important factor in determining if a subcontractor should be involved in the design process. If there is no standard solution that is going to be used, it is more relevant to involve this subcontractor in decision-making and designing to tackle this uncertainty early in the design process. This is especially relevant as the element designed by the subcontractor has important interfaces with other elements.

The paper of Wasti & Liker (1997), about supplier involvement in the Japanese automotive industry, has similar conclusions as Shafaat et al. (2014). The level of supplier involvement in design work is positively associated with the technological uncertainty of the design of the component. (Wasti & Liker, 1997). This uncertainty is particularity relevant when other elements are dependent on the uncertain element.

Both papers argue that suppliers who design and produce parts with high uncertainty, should be involved early in the design process. By early involving the subcontractor, the uncertainty can be taken away in the beginning of the design stage. This links to the importance of interfaces. If the part that is being outsourced has important interfaces with no standard solutions, the uncertainty of this interface is high. Therefore, it is important to involve the subcontractor as early as possible in order to reach an agreement about this interface in the beginning of the design stage. This is necessary so other disciplines can adapt their design to the interface. If an important interface would have been managed at the end of the design stage, it might be necessary to change the whole design. This makes it important to have the knowledge and experience of the subcontractor available in the beginning of the design process. This can be done by outsourcing the responsibilities in design and design verification if there are important interfaces with high uncertainty.

4 FRAMEWORK

In this section the framework is developed. The first subsection describes the different forms of outsourcing verification tasks. The second subsection is the operationalization of the factors. In the last subsection, the framework itself is presented and explained.

4.1 Different forms of outsourcing verification tasks

There are different forms of outsourcing verification tasks in the design stage. Before describing the three variants that are used in this research, the V-model is explained shortly. The V-model is used within the field of Systems Engineering. The V-model is applied in the Dutch Systems Engineering approach for civil construction projects as well. The V-model describes how to get from requirements to working systems. The left side of the V-model represents the design phase. With every design step the requirements are derived, functions are established, the design is elaborated in further detail and verifications are done to make sure the design meets the requirements. This process is repeated until the desired level of detail is reached.

The right side of the V-model is the construction phase. This is the upside part of the V-model and works from a high level of detail upwards until a fully functioning system is created and verified (i.e. a road infrastructure system) (Rijkswaterstaat, ProRail, Bouwend-Nederland, & ONRI, 2008). For Civil structures in the Netherlands a typical distinction is made between three design phases. The preliminary design phase, the final design phase and the execution design phase. This three will be discussed briefly.

The preliminary design is the first design of the structure. Aim of the preliminary design is to develop a global representation of the structure so the different elements and disciplines can be adjusted to each other. The final design is the second design stage. The definitive design is an iteration of the preliminary design whereby the dimensions of the structure are made definitive. The last design stage is the execution design. This is the last design stage, in this stage are the different components of the structure worked out in detail. This can be done parallel for the different components since the dimensions are already agreed upon in the definitive design.

In the construction phase a distinction is made between work preparation and the execution phase, together being the construction phase. An overview of the V-model and the different stages can be found in Figure 2. The V-model is shown three times

whereby the orange line varies. This orange line represent the phases in which verification tasks are outsourced to the subcontractor. The three different variants are discussed in the next three paragraphs respectively with the order of the Figure.

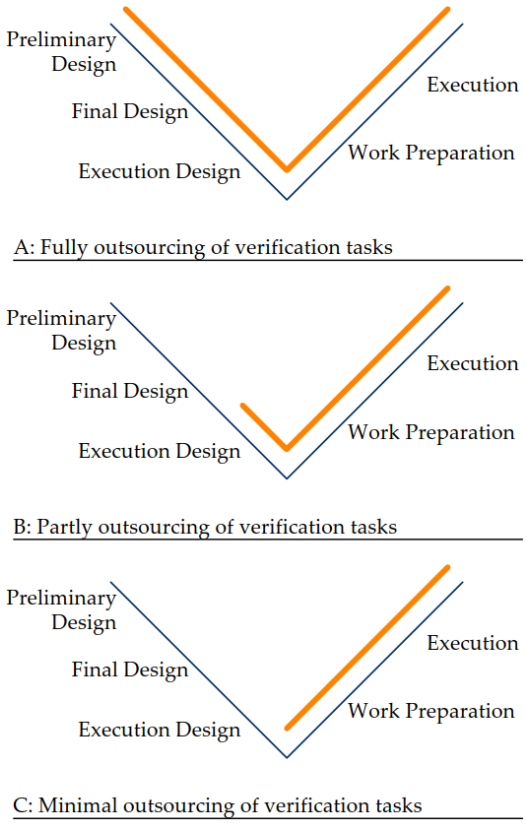

Figure 2: Different ways of outsourcing verification tasks

Variant A is outsourcing all verifications tasks in design and execution. This makes the subcontractor responsible for a subsystem; it is the most extensive form of outsourcing.

Variant B is outsourcing the verification tasks in execution design and construction. This means the subcontractor gets the freedom to work out his own part but is not contracted to carry out design and verification tasks in the integral design stages preliminary design and definitive design. This means that the dimensions of this part are already decided and the subcontractor can work out the details of his own part mostly on his own. This significantly reduces the transaction costs. Outsourcing verification tasks starting from definitive design would be illogical since the phases preliminary and definitive design are highly interconnected.

Variant C is outsourcing of verification tasks only in the construction phase. This means that the subcontractor gets no verification responsibility in the design stage and is only responsible for verification tasks in the work preparation and execution phase. This is the more traditional division of tasks.

4.2 Operationalisation of the factors

In order to create a useable framework, it is necessary to operationalise the factors described in the previous section. Specific literature about operationalizing these factors for use within the civil engineering industry was not applicable, therefore the operationalisation is done with the use of expert meetings. In this expert meetings two senior strategic purchasers (both over 20 years of experience), one process manager (over 10 years of experience) and one design manager (over 20 years of experience) have given their input on the operationalization of these factors. The operationalization of the factors is shown in Table 2. The technical complexity of the design of the part that is outsourced can be categorised by the degree of standardization, the design freedom, the number of parameters required for the calculation and the number of load combinations that are necessary in the calculation. The division of knowledge can be categorized by the design capacity, design experience and amount of in-house staff for these design tasks of the subcontractor. The size of the outsourcing can be categorized by the value of the outsourcing or a percentage of the total construction costs of the structure. The interfaces can be categorized by the number of physical interfaces, the consequences a change in the interface has on other design parts and the degree of standardization of these interfaces.

4.3 The framework

The framework links the different ways of outsourcing to the factors identified in the literature. An outsourcing can get a score based on the operationalisation of the factors as presented in Table 2. An outsourcing can get a score varying from minus one to plus one for each of the four factors. If the four outcomes are summed, a value varying from minus four to plus four is obtained. When the score is plus four, it is recommend to outsource design and verification tasks than by a value of minus four. To link this value to a form of outsourcing design and verification tasks, a linear relation is suggested. Since there are four factors with each three possibilities, there are 81 different combinations. In order to divide these 81 possibilities over the three types of divisions of verification tasks all values of one and higher are linked to outsourcing all verification tasks in design and execution. Outsourcings with a total value of zero are linked with outsourcing verification tasks in execution design and construction and values lower

than zero are linked with outsourcing only verification tasks in construction. This is shown in the framework by the green area from the left bottom to the right top of the framework. The framework is shown in Figure 3. When more verification tasks are outsourced then should be according to the framework, verification problems could occur. Outsourcing less design verification tasks then should be according to the framework, no verification problems should occur, but the knowledge and expertise of the subcontractor is not used, leading to an inefficient design.

Table 2: operationalisation of factors

	-1	0	1
Complexity	Not technical complex - standardized product - very limited to none design freedom - limited number of parameters required (<10) - limited number of load combinations (<5)	Semi-technical complex - standard product with custom changes or standard product from product series - Some degree of design freedom - average number of parameters required (≥10 and <20) - average number of load combinations (≥5 and <10)	Technical complex - Non-standardized product - A lot of design freedom - A high number of parameters required for calculations (≥20) - A high number of load combinations (≥10)
Design verification knowledge and experience	Limited design verification knowledge and experience by subcontractor - subcontractor has limited capacity for executing design works - subcontractor cannot execute design with own designers - staff of subcontractor has limited experience on comparable design tasks	Execution design verification knowledge and experience by subcontractor - subcontractor has available capacity for executing execution design - subcontractor can execute design with own designers - staff of subcontractor has a lot of experience on comparable execution design tasks	Full design verification knowledge and experience by subcontractor - subcontractor has available capacity for executing total design - subcontractor can execute design with own designers and engineers - staff of subcontractor has a lot of experience on comparable design tasks
Size	Small outsourcing (<10% of the construction costs of structure and <€50.000)	Average outsourcing (≥10% and <25% of the construction costs of structure and ≥€50.000 and >€100.000	Large outsourcing (≥25% of the construction costs of the structure or ≥€100.000 of the construction costs)
Interfaces	- limited amount of physical and functional interfaces with other parts of the structure (<3) - changing the interfaces has limited consequences for the design of other parts of the structure - interfaces are highly standardized	- Average number of physical and function interfaces with other parts of the structure (≥3 and <5) - changing the interfaces has average consequences for the design of other parts of the structure - interface can be managed by using one of the several standardized solutions	- lot of physical and functional interfaces with other parts of the structure (≥5) - changing the interfaces has big consequences for design of other parts of the structure - no standard solution exist for managing of the interfaces

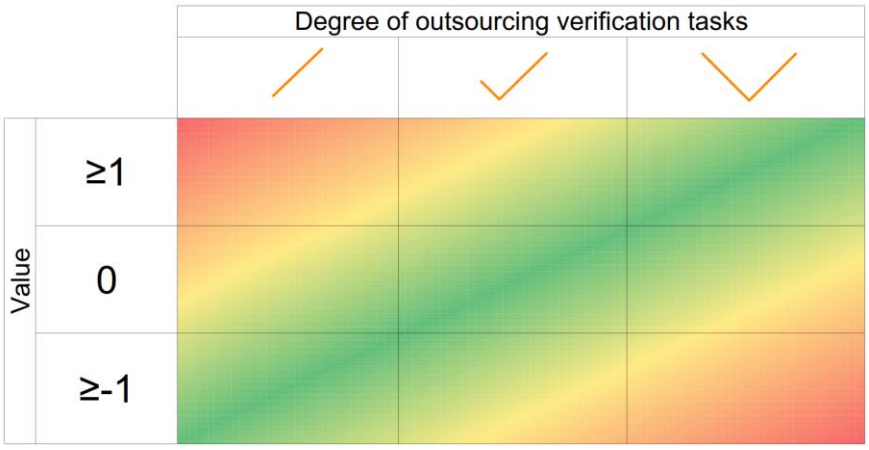

Figure 3: framework

5 CASE STUDY

In the case study six outsourcings were researched on two different projects. On both projects, the outsourcing of the prefab beams, reinforcement and handrails were researched. The first project, in this paper referred to as project A, was the construction of a bridge with 15 spans. The second project, in this researched referred to as project B, was the construction of 19 viaducts. The results of the different outsourcings are described briefly in this section.

5.1 Outsourcing A-1 precast beams

Project A faced a change of scope when the contractor almost finished their final design and the subcontractor for the precast beams was already selected. Due to this scope change, the design had to be redone after the subcontractor was selected. The main contractor and subcontractor agreed to give the subcontractor the responsibility to design the bridge deck and do all the necessary verifications in both the design and construction phase. Both contractor and subcontractor were satisfied with this division of tasks. Together both parties were able to find an optimum between the number of spans and the length of the beams. Furthermore, a higher level of detail was reached in the preliminary design because of the knowledge of the subcontractor. The only flaw was the discussion between the parties about the deviation in deflection of the beams. This did meet the criteria from the prevailing guideline but did not match with the design criteria. The subcontractor argued that the average deflection did meet the design criteria but the main contractor did not accept this. This was the only discussion point of a further smooth design process; the problem was eventually solved by extra calculations made by the subcontractor to verify that the beams still met the requirements.

5.2 Outsourcing A-2 reinforcement

Project A was a pilot project where contractor and subcontractor chose to outsource the execution design of the reinforcement to the subcontractor. This was the first time for both the main contractor and subcontractor that design tasks and corresponding verification tasks for reinforcement were transferred to the subcontractor. The subcontractor made the 3D models of the reinforcement and the corresponding drawings. The designers of the subcontractor had knowledge of buildability, leading to a design that was easy to build and very little design flaws were discovered during construction. While constructability of the design was better than when the main contractor would have made it, the models and drawings did not meet all the standards and regulations. The subcontractor was too unexperienced in designing reinforcement and those mistakes where discovered by the main contractor who checked the models. This led to verification problems, sometimes more than five revisions were needed before the models, and drawings met all requirements. The quality of the models and drawings improved over time within the project. Employees of the main contractor stated that it were likely to go better on a next project.

5.3 Outsourcing A-3 handrails

On this project, no custom design was made for the handrails but an existing design from a previous project has been used. Therefore, not much verifications were needed in the design phase. The subcontractor was selected during the final design phase and was not involved at all in the design of the handrails. When the execution design was finished and handed over to the subcontractor, the subcontractor started making his own production drawings. During this process, some design flaws were discovered as well as some optimizations. The

execution drawings from the main contractor had to be adapted to the findings of the subcontractor. Both main contractor and subcontractor agreed that it would have been better as the subcontractor would have made the execution drawings.

5.4 Outsourcing B-1 precast beams

The subcontractor for the design, production and placing of the precast beams is selected short after the project was awarded to the main contractor. The subcontractor was a well-known partner for the main contractor. The subcontractor was given the responsibility for all the design- and verification work of the bridge deck. This was a common division of tasks between the two parties. The subcontractor was able to implement several optimizations relative to the tender design. Furthermore, the main contractor and subcontractor worked well together by making agreements on the allowed tolerances on the deflection of the beams and finding solutions to facilitate the water drainage of the viaduct through the beams. Barely no problems occurred in both design and construction, making this a very successful outsourcing.

5.5 Outsourcing B-2 reinforcement

For the outsourcing of the reinforcement, one of the parties that is often used by the main contractor had no capacity, this forced the main contractor to work with a different subcontractor. The subcontractor had no design and verification tasks in the primary and final design phase. In the execution phase, the reinforcement models and drawings had to be made. Neither of the two parties had the capacity to do so, especially with the high time pressure the project was under. For a long time it was unclear who was going to make the models and drawings. Finally, there was chosen to let the main contractor make the models, mostly with hired staff, and outsource the making of the drawings to a third party. Due to all the delay early in the process there was no time to implement the changes as proposed by the subcontractor to improve the buildability. The construction phase of the reinforcement faced many problems. Design errors led to a lot of reinforcement that was produced and delivered but not used due to late discovered design errors. The poor quality of the models and drawings also led to an inefficient process for the reinforcement fixers.

5.6 Outsourcing B-3 handrails

The subcontractor for the handrails was involved in the tender process to make a cost estimate. This subcontractor is a partner of the main contractor and they have worked together for many years. In comparison with the handrails for project A, this outsourcing was different. The subcontractor was responsible for all design and verification tasks, where normally only the execution design was handed over to this subcontractor. In this project is chosen to hand over all design and verification tasks because the handrails had to be integrated with the edge elements, the handrail had to be certified and tested to make sure it could withstand the impact of a car and there were high architectural demands. The knowledge and expertise of the subcontractor was necessary to deal with those challenges. The subcontractor was able to manage all this challenges and created a design that satisfied all parties involved. The calculation and verification documents were however not from the required level. Eventually the subcontracted solved this by making a verification document to verify al the specified requirements and by hiring an engineering firm to make the calculations.

6 RESULTS

In this section the outcomes of the case study are compared with the framework. This is visually shown in Table 3. The six outsourcings are shown in the first column. Then the categorization of the cases is shown (with the use of Table 2). In this categorization, the division of verification tasks is determined with the use of the framework as presented in subsection 4.3. In the next column, the applied division of tasks is compared with the division of tasks that should be applied according to the framework. The symbols in the column show if the applied division of verification tasks is more than, less than or equal to the division of design verification tasks that should be applied according to the framework. The last column describes the degree of verification problems and the design and design verification problems that occurred within this outsourcing.

Outsourcing A-1 is technical complex, the precast beams require complex calculations and there is a lot of design freedom. The subcontractor has his own experienced designers and the outsourcing had a large size. Last factor are the interfaces, the beams have many interfaces with among others the joints, the substructure, the handrails and the road alignment. All factors are categorized with a one, making the total four. Therefore, outsourcing all verification tasks in design and execution should be outsourced according to the framework. This is also the division of verification tasks that has been done in practice. This led to almost no verification problems and an optimum design for both contractor and

Table 3: Comparison framework and case study

Outsourcing	Technical complexity	Division of knowledge	Size	Interfaces	Division of verifications tasks framework	Applied division of verification tasks	Comparison	Verification problems
A-1	1	1	1	1			=	No verification problems, only discussion between contractor and subcontractor about tolerances on deflection of precast beams.
A-2	0	-1	1	0			=	Serious verification problems, drawings did not met the requirements as specified in standards and regulation
A-3	-1	0	1	0			<	No verification problems, but bad design quality resulting in redesign by subcontractor
B-1	1	1	1	1			=	No verification problems
B-2	0	-1	1	0			<	No verification problems, but major design problems
B-3	1	0	1	0			=	Some verification problems

subcontractor. Only topic of discussion was the disagreement between both parties about the allowed tolerance. Apart from the disagreement about the deflection, which should have been made more explicit in the beginning, the outsourcing went very well. The appropriate type of outsourcing of verification tasks has been used, this supports the framework.

Outsourcing A-2 is not so technical complex, but the design of the reinforcement has still some design of freedom and is therefore categorized as zero. The division of knowledge is debatable. However, the subcontractor does not have enough experience in designing reinforcement on such large scale, the knowledge division will be categorized as minus one. The outsourcing was large and therefore categorized as one. The reinforcement has some interfaces, amongst other with the foundation and the precast beams but the importance of those interfaces is limited, it is therefore categorized as zero. The sum of the four factors is zero, referring to outsourcing of execution design and construction. This is also the applied division of verification tasks. This led to verification problems, as the subcontractor did not have enough knowledge and expertise about standards and regulations. This shows an important flaw of the framework, if all factors are categorized positive except knowledge division, the framework still suggest outsourcing design and verification tasks while the subcontractor had no experience in this.

Outsourcing A-3 was technically not complex, as a design of a previous project had been used, the complexity is therefore categorized as minus one. The subcontractor has own designers and experience in making the executing design, the design knowledge and experience is therefore categorized as zero. The size of the outsourcing was large and therefore categorized as one. The handrails do not have much interfaces but some non-standardized interfaces so it is categorised as zero. The sum of the four categorisations is zero, suggesting outsourcing of verification tasks in execution design and construction according to the framework. The outsourcing of the handrails led to no verification problems in the design stage. Although no verification problems occurred, the subcontractor did make his own production drawings, as the execution design of the main contractor was not efficient and had some constructability errors. This design problems could be expected as less design verification tasks were outsourced than should be according to the framework. This can lead to design problems.

Outsourcing B-1 can be categorized as outsourcing A-1. It is complex, has a high value and many important interfaces. Although a different subcontractor is used in comparison with outsourcing A-1, this subcontractor is also experienced in

designing precast beams and has their own in-house designers. The sum of the categorisations is four so according to the framework outsourcing of all verification tasks in both design and construction phases should be outsourced. This is also the division that has been applied by the main contractor. This resulted in very little problems and both main contractor and subcontractor were very satisfied with this outsourcing. The two companies work together on a lot of projects and for a long time and therefore now each other quite well. This division of tasks was for both companies standard procedure, so the companies were both known with the division of tasks. This prevented different interpretation as happened by outsourcing A-1. The outsourcing can be seen as successful. This confirms that the appropriate division of verification tasks is chosen and that the framework was correct for this outsourcing.

Outsourcing B-2 is also comparable to outsourcing A-2 on the aspect of complexity, size and interfaces. The design knowledge and experience is even less than by outsourcing A-2 as this company had very limited experience and capacity. Since the main contractor had also no capacity, the main contractor used hired staff and even outsourced a part of the design to a third party, this caused a lot of problems. It resulted in drawings that contained many errors. Since the contractor had no capacity for the execution design, it would have been best as the subcontractor did this. The selected subcontractor had no capacity to do so, making the whole outsourcing hard to get successful from the beginning. According to the framework, outsourcing from execution design and construction should have been used, this was however not possible with this subcontractor. The main contractor should have selected a different subcontractor who had the knowledge and experience to do so. This means the framework suggested an division of verification tasks that could not have been applied due to the lack of knowledge and experience of the subcontractor.

For outsourcing B-3 a custom design had to be made with high architectural demands, furthermore maintenance for over 25 years had to be done and the design had to be tested. This handrail can therefore be categorised as technical complex. The subcontractor did not have the knowledge and expertise to be responsible for the entire design and verification process but was very eager to learn this. Since they did not had the experience the design knowledge and experience is characterised as zero. The size of the outsourcing was large. The interfaces were limited, but some are not standardized, so it is categorised as zero. The sum of the four categorizations is two, so the division of verification tasks should be outsourcing all verification tasks in design and construction according to the framework. This is also the applied division of verification tasks. The reason the main contractor chose this division of tasks was that it wanted to give the subcontractor the chance to gain experience in making a preliminary and final design. This led to some verification problems because of the inexperience of the subcontractor. In this case, the framework suggest outsourcing of all verification tasks even though the subcontractor does not have the knowledge and experience about this.

7 CONCLUSION

This aim of this research was to study how the appropriate division of verification tasks in the design phase between main and subcontractor can be determined.

In the literature study, four factors that influence the decision to outsource design verification tasks to subcontractors are identified. These four factors are characteristics of the outsourcing and the selected subcontractor. The four factors are: the technical complexity of the outsourcing, the design verification knowledge and experience of the subcontractor, the size of the outsourcing and the uncertainty of the interfaces of the part that is outsourced.

The results of the case study match with the expectations based on the literature study. Therefore, it can be concluded that the four factors that were identified in the literature give a good indication of how to divide design verification tasks between the main contract and subcontractor. The factors are applicable to prevent verification problems when outsourcing to subcontractors in the Dutch Civil Engineering industry. No indication was found that there are other factors that influence the decision to outsource verification tasks to subcontractors.

Out of the results from the case study, design verification knowledge and experience turns out to be a requirement instead of just a factor. Outsourcings in the case study whereby design verification tasks were outsourced but the subcontractor did not have the knowledge and experience to do so, resulted in many verification problems. Therefore, design verification tasks should only be outsourced to the subcontractor if the subcontractor has design verification knowledge and experience, otherwise verification problems will occur. Lack of design verification knowledge turns out to be an important explanatory factor for design verification problems.

The main contractor researched in the case study does not outsource design verification tasks as often as one would expect based on literature. The case study showed that the main contractor is careful with outsourcing design verification tasks to the subcontractor. It is likely that it has to do with the risk-averse behaviour of contractors as recognized by Barlow & Köberle-Gaiser, (2009) and Barnes (1983). The fact that outsourcing design verification tasks to subcontractors is relatively new, is also a logical explanation for contractors being careful with outsourcing design verification tasks. Possibly, outsourcing design verification tasks will become more applied in the next decade as contractors are gaining more experience with outsourcing design verification tasks.

8 DISCUSSION

In the discussion the comparison between the literature and the case study is central. Firstly, the relation between the in the literature identified factors and the framework is compared with the case study. Secondly, the relation between the framework and the verification problems that occurred is compared with the case study. Lastly, some suggestions to improve the framework were done.

8.1 Relation between factors and outsourcing design verification tasks

In this subsection, the similarities and differences between the in literature found factors and the case study are discussed. This is done per factor.

The first identified factor in literature was the technical complexity. Gil et al. (2001), Shafaat et al. (2014) and Franz et al. (2013) all suggested that involvement of the subcontractor by the design process was necessary if the design was technically complex. In the case study, this was of high influence as well. By three of the six outsourcings, the technical complexity was categorised with the value one, meaning it was complex. These three outsourcings were also the three outsourcings where the main contractor chose to outsource all design verification tasks. These three outsourcings did not lead to much verification problems. The literature and the case study match very well on the aspect that the technical complexity of the design influences the degree of outsourcing design and design verification tasks to the subcontractor.

The second factor identified in literature was the design knowledge and experience of the subcontractor. Shafaat et al. (2014), Griffis & Choi (2013) and Liker et al. (1998) argue that a subcontractor/supplier/consultancy firm is specialized in a certain activity and therefore they have specific knowledge and expertise about that activity. Liker et al. (1998) and Shafaat et al. (2014) state that it must be assured that the supplier has the technical capabilities matching with the responsibility that is transferred. Therefore, it is assumed that it is more likely to outsource design and design verification tasks to subcontractors with design knowledge and experience than subcontractors without this knowledge and experience. The results of the case study go even further and show that the design and verification knowledge and experience is crucial for outsourcing design and design verifications without verification problems, outsourcing A-2 and B-3 show that. Verification tasks were outsourced to these subcontractors even though they did not have the experience. This resulted in some verification problems, especially in the beginning of the project. In the case of outsourcings A-2 and B-3 the subcontractors were very eager to develop this new skills but the framework suggested by outsourcing B-2 to outsource the execution design to the subcontractor even though the subcontractor did not have any experience or capacity with this. This shows that the design knowledge and experience does not only have influence on outsourcing design and design verification tasks to subcontractors but is a requirement to be able to outsource successful, according to the case study. This was also recognized by Liker et al. (1998) stating that the subcontractor needed to have the right capabilities for the transferred responsibility.

The third factor identified in literature was the size of the outsourcing. According to Williamson (1985) should the costs of the transaction match with the direct costs of the outsourcing. Wasti & Liker (1997) and Bucklin & Sengupta (1993) use this statement of Williamson (1985) to state that cooperation between companies and subcontractor involvement in the design stage is more likely to be successful when the transaction cost are low in comparison with the direct costs of the outsourcing. In the case study, only large outsourcings are studied so it is not possible to verify the statement with the different outsourcings within the case study. However, these outsourcings were chosen strategically because by small outsourcings, outsourcing design and design verification tasks to the subcontractor is almost never applied by the main contractor. This matches with the conclusion of Bucklin & Sengupta (1993) stating that it is hard to get a cooperation successful if the transaction costs are relatively high and the statement of Wasti & Liker

(1997) that car manufacturers should be selective to offset the transaction costs. The transaction costs argument appears to be valid for the construction industry.

Last factor identified in the literature was the uncertainty of the interfaces. Shafaat et al. (2014) and Wasti & Liker (1997) conclude that it is more likely to involve subcontractors or suppliers who produce products with high uncertainty than products with low uncertainty. This is especially relevant if this uncertainty is of influence on other parts of the structure. The interfaces and the uncertainty of the interfaces is therefore defined as factor in the literature study. In the case study are two outsourcings that have a value of one on the aspect of interfaces: A-1 and B-1. There outsourcing were both for precast beams. The precast beams have a high uncertainty and many interfaces and by both outsourcings all design and design verification tasks are outsourced to the subcontractor. Furthermore, the precast beam sector is the most developed in doing their own design and verification work. Although the complexity of these products also plays a role, the uncertainty and the interfaces make it important that the subcontractor is involved early in the process. That is the only way to take away the uncertainty early in the process and make sure no clashes are appear later on in the design phase. The uncertainty seems to play an important role in the decision to involve the subcontractor early in the design process instead of later on in the design process. This is recognised both in literature as in the case study.

8.2 Relation between framework and verification problems

This subsection discusses the relation between the framework, that is drafted based on literature and presentenced in chapter four and the verification problems that occurred.

In none of the six outsourcings is more outsourced than should be according to the framework. Therefore, no verification problems would be expected as verification problems are only expected as more design verification tasks our outsourced than should be according to the framework.

There were however, two outsourcings whereby verification problems occurred. This were outsourcings A-2 and B-3. The verification problems occurred even though the subcontractor was given design verification responsibilities as should be according to the framework. However, the subcontractors did not have the knowledge and experience to execute these design verifications, resulting in verification problems. The main contractor chose consciously to do so, to give the subcontractor the chance to gain knowledge and experience. Nevertheless, the verification problems did occur even though the division of verification tasks according to the framework was applied. This shows an important downside of the framework. By outsourcing A-2 is the knowledge division categorised with minus one, whereas the other three factors are categorized with zero or one. This does however lead to verification problems as the subcontractor is not capable of executing these tasks. The same goes for outsourcing B-3, the knowledge and experience of the subcontractor is categorized with zero whereas the other three factors are categorized with zero or one. This does however lead to verification problems as the subcontractor is not capable of executing these tasks.

Both outsourcings where verification problems occur show an important downside of the framework. If the knowledge and experience of the subcontractor is low, but the outsourcing is technical complex, large in size and has uncertain interfaces, the framework still suggest outsourcing design verification tasks. The case study showed that this leads to verification problems.

In the case study are two outsourcings whereby less design verification tasks are outsourced then should be outsourced according to the framework. This are outsourcings A-3 and B-2. Both outsourcings did not suffer from design verification problems, but the quality of the design by both outsourcings was a problem. By outsourcing A-3, the design of the main contractor was inefficient and contained some constructability errors. Therefore, the subcontractor did not use the execution design made by the main contractor but made his own execution design. By outsourcing B-2, the design was of poor quality resulting in a lot of problems in the construction phase.

Cases A-3 and B-2 show that if less design verification tasks are outsourced than should be according to the framework, this not leads to verification problems but does lead to poor design quality as the knowledge and experience of the subcontractor is not used.

8.3 Suggestion to improve the framework

Discussing the relation between the framework and the verification problems, a suggestion is done to improve the framework.

The suggestion is related to a problem that occurs when there is a mismatch between the knowledge and experience and the other factors. If a

subcontractor has limited design verification knowledge and experience but the outsourcing is very complex, has a large size and has many uncertain interfaces. The framework still suggests outsourcing all design and verification tasks. Comparing the case study with the framework can be concluded that it is better to make sure that the design knowledge and experience matches with the other three factors. This means that if an outsourcing is three times categorized with a one, it is highly recommended to choose a subcontractor whose design knowledge and experience is also one or is zero but is willing to gain experience. The same goes for an outsourcing that is three times categorized with ones and zeros, it is advised to have a subcontractor with design knowledge and experience categorized with a zero or with a minus one and willing to gain experience.

9 LIMITATIONS AND SUGGESTIONS

This research has three limitations.

Firstly the number of outsourcings that are studied. Due to the lack of time only six outsourcings are being studied, all by the same main contractor. To improve the reliability of this study more outsourcings could have been studies at varying main contractors.

Secondly, the study was carried out in the civil engineering industry in the Netherlands; it is therefore not directly applicable in other industries or countries. Additional research is necessary to determine if the framework is wider applicable.

Thirdly, the study focuses only on the division of design verification tasks whereas the division of design tasks also play a role in the choice to outsource design and design verification tasks.

10 REFERENCES

Bucklin, L., & Sengupta, S. (1993). Organizing Successful Co-Marketing Alliances. *Journal of Marketing*, 57(2), 32-46.

De Graaf, R., Voordijk, H., & Van den Heuvel, L. (2016). Implementing Systems Engineering in Civil Engineering Consulting Firm: An Evaluation. *Systems Engineering*, 19(1), 44-58.

Franz, B., Leicht, R., & Riley, D. (2013). Project Impacts of Specialty Mechanical Contractor Design Involvement in the Health Care Industry: Comparative Case Study. *Journal of Construction Engineering and Management*, 139(9), 1091-1097.

Gil, N., Tommelein, I., Kirkendall, R., & Ballard, G. (2001). Leveraging specialty-contractor knowledge in design-build organizations. *Engineering, Construction and Architectural Management*, 8(5-6), 355-367.

Griffis, F., & Choi, H. (2013). Design of Public Projects: Outsource or In-House? *Journal of Management in Engineering*, 29(1), 2-9.

Hinze , J., & Tracey, A. (1994). The Contractor-Subcontractor Relationship: The Subcontractor's View. *Journal of Construction Engineering and Management*, 120(2), 274-287.

Lenferink, S., Tillema, T., & Arts, J. (2012). Towards sustainable infrastructure development through integrated contracts: Experiences with inclusiveness in Dutch infrastructure projects. *International Journal of Project Management*, 31(4), 615-627.

Liker, J., Kamath, R., & Wasti, S. (1998). Supplier involvement in design: a comparative survey of automotive suppliers in the USA, UK and Japan. *International Journal of Quality Science*, 3(3), 214-238.

Ling, F., Chan, S., Chong, E., & Ee, L. (2004). Predicting Performance of Design-Build and Design-Bid-Build Projects. *Journal of Construction Engineering and Management, 130*(1), 75-83.

Makkinga, R., De Graaf, R., & Voordijk, H. (2018). Successful verification of subcontracted work in the construction industry. *Systems Engineering*, 21(2), 131-140.

Priemus, H. (2009). Do Design & Construct contracts for infrastructure projects stimulate innovation? The case of the Dutch high speed railway. *Transportation Planning and Technology*, 32(4), 335-353.

Rijkswaterstaat, ProRail, Bouwend-Nederland, & ONRI. (2008). *Guideline Systems Engineering for Public Works and Water Management.* The Netherlands: Rijkswaterstaat, ProRail, Bouwend-Nederland and ONRI.

Rook, P. (1986). Controlling software projects. *Software Engineering Journal*, 1(1), 7-16.

Shafaat, A., Maffous, T., Jackson, C., & Kandil, A. (2014). Decision Making Model by Specialty Subcontractors in Construction Project . *Construction Research Congress 2014* (pp. 867-876). Atlanta, Georgia, VS: American Society of Civil Engineers.

Shokri, S., Haas, C., Haas, R., & Lee, S. (2015). Interface-Management Process for Managing Risks in Complex Capital Projects. *Journal of Construction Engineering and Management*, 142(2), 1-12.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management*, 6(3-4), 169-178.

Wasti, S., & Liker, J. (1997). Risky Business or Competitive Power? Supplier Involvement in

Japanese Product Design. *Journal of Product Innovation Management*, 14(5), 337-355.

Williamson, O. (1985). The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting (Vol. 11). New York, USA: The Free Press.

Yin, R. (2003). *Case Study Research: Design and Methods* (3e ed.). Thousand Oaks: Sage Publications Ltd.