Towards accurate labour hour estimates for capital projects in the construction industry

An exploratory study on labour productivity and project complexity

MSc thesis Ewout Vossen
August, 2015
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An exploratory study on labour productivity and project complexity

Information

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PREFACE
Preface

The thesis in front of you is the final product of my Master Thesis research project, which is part of the master program Systems Engineering, Policy Analysis and Management of Delft University of Technology in the Netherlands. The research was sponsored by Accenture Netherlands, an international consultancy company providing management consulting, technology and outsourcing services.

Like many former SEPAM students before me, I have been looking forward to the moment I get to write this final chapter of my thesis, as this means that I will hand in my master thesis soon. Without any doubt, I can say that the Master Thesis research project has been the most challenging project for me so far, from both an academic point of view as well as a personal point of view. I had never worked on a project before for such a long time. This was also my first experience as an intern at a professional consultancy company. I am convinced that I have learned a lot from this experience and consequently I have grown personally and professionally.

At certain points during the research it felt like managing a complex project myself, although the people I worked with were all very supportive and this definitely helped me to finish this project. Therefore I would like to take this opportunity to thank everyone who has in some way contributed to my research.

First of all I would like to thank my graduation committee for guiding me through this project. Thank you Wijnand Veeneman, for being my first supervisor and helping me throughout the research trajectory, especially in the start-up phase of my research and when things got difficult after having gathered the data for my research. The professor of the committee, Hans Bakker, thank you for introducing me to people from the NAP network, many of them were available and willing to participate in my research. In addition, your input during our meetings was very valuable and especially after the kick off meeting I could accelerate the research process as we could set clear boundaries and improved the scope for the research based on your comments. Furthermore, I want to thank Robert Verburg for being part of my graduation committee and supporting my research with detailed feedback, which has provided me with usable insights.

Moreover, I would like to thank Merijn van Mourik for giving me the opportunity to do my graduation internship at Accenture Netherlands. During my internship, I could always turn to you for questions and advice related to the research content and process. Your professionalism, time and help are greatly appreciated. Also, I would like to thank Hans Hertzberger and Wouter Knaack, as my day to day supervisors, for always being available to provide feedback on my thesis and coaching me throughout the project. Apart from the feedback with respect to thesis content, I think both of you taught me a lot about how to communicate effectively in specific situations, how to manage expectations as well as to keep me focused on the objective of this research rather than losing focus.

This research would not have been possible without the input of the respondents involved in this research. Therefore, I would like to thank the interviewees for making time available and sharing their thoughts on project complexity and labour productivity. I definitely enjoyed discussing the “ins and outs” regarding the capital projects during the interviews, as well as the opportunity to explore the construction industry and to learn how capital projects are managed.

A special thanks goes out to my parents and brothers. Mom, dad, thank you for your unconditional support, encouragement and the amazing chances you have given me over the years. I honestly appreciate your effort in always supporting and stimulating me, I am grateful to have such wonderful parents.

Lastly, I would like to thank my colleagues at Accenture for their warmth and making the internship a fun experience!

With regards,
Ewout Vossen - July 30, 2015
SUMMARY
Executive summary

Capital projects in the construction industry routinely overrun their pre-tender cost estimates. The inability to make accurate cost estimates is an urgent complication since the estimates establish the base line of the project cost at different stages of development of the project and therefore provide substantial information for decision making, cost scheduling and resource management (Carr, 1989; Venkataraman & Pinto, 2011). The scope of this research is limited to labour cost estimates, with a focus on labour hour estimates, because capital projects are typically labour intensive projects and labour cost usually comprise 20% to 50% of the total project cost (Hickson & Ellis, 2014; Soham & Rajiv, 2013). In practice a difference has been observed in ‘burned’ (actual) and ‘earned’ (estimated) labour hours for construction activities, which possibly affects the accuracy of the labour cost estimate.

Project complexity is frequently mentioned as being an important factor with respect to the accuracy of cost estimates. Despite the unambiguity around project complexity, it is assumed to be everywhere in today’s large projects and above all it is continuously growing, with an increasing pace (Vidal & Marle, 2008a). However, it is unclear how and to what extent the existence of project complexity can affect the accuracy of labour hour estimates of construction workers. As estimating labour productivity is vital for determining labour hours, the following research question is formulated:

Q1: How do project complexities influence labour productivity during the execution phase of capital projects in the construction industry and what are the implications for the accuracy of labour hour estimates?

The research is exploratory oriented and has the objective (1) to deepen understanding and to provide qualitative insights on the relationship between project complexity and labour productivity during the construction phase of capital projects in the construction industry; and (2) to translate these insights into recommendations for cost estimators on how to improve the accuracy of the labour hour estimate. In order to visualize the relevant relationships between the main topics in this research, the following causal model was developed (Figure 1.0):

![Figure 1.0: Causal relationship project complexity, labour productivity and project performance](image)

It can be seen that labour productivity is related to the accuracy of the labour hours estimate and project performance is related to the accuracy of the labour cost estimate. In this research project complexity is seen as a project characteristic and the complexity of a project can be determined by its complexity footprint, which consist of complexity factors (complexities). With this approach, it becomes possible to “measure” the impact of project complexity on labour productivity. Hence a complexity framework was developed based on a thorough literature review. The framework contains 51 complexities that are further categorized in eight categories. The categories are Experience (6), Contracts (5), Financial (4), International (3), Team/organization (9), Technology (9), External (7) and Materials/Transportation (6).¹

¹ The numbers in parentheses refer to the number of complexities in the respective category.
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Conducting surveys and interviews with people in relevant roles (project directors, project managers, construction managers and cost estimators) across different sectors within the construction industry were part of the research approach in order to meet the objective of this research. The survey was primarily aimed at gathering project characteristics and to validate the causal relationships (A1 and A2) that were made regarding project complexity, labour productivity and project performance. The interview was primarily aimed at obtaining the ‘why’ behind the survey responses.

Regarding the first causal relationship (A1), it became clear that project complexity cannot be disregarded when it comes to the accuracy of the labour hours estimate. In fact, sixteen respondents (80%) indicated that the accuracy of the labour hours estimate was much or very much influenced by the complexity of the project. The more complex the project, the lower the accuracy of the labour hours estimate. With regard to the second causal relationship (A2), fourteen respondents (70%) indicated that the accuracy of the labour cost estimate was much or very much influenced by DLH.

Despite that many respondents recognized the importance of project complexity, many respondents found it difficult to relate specific elements of project complexity to Delta Labour Hours as well as to score its impact, because:

1. The complexities in the framework were too specific or too high level (i.e. the abstraction level);
2. The complexities were interrelated so assessing the direct impact of the complexities is a rather difficult task for the respondent;
3. The respondent could not rely on labour productivity data regarding the execution phase.

Mainly due to the interrelatedness of the complexities, it proved to be difficult to gather sufficient insights on the one-on-one relationship between project complexities and DLH to make recommendations for cost estimators. On the basis of feedback provided by experts in the construction industry, an attempt was made to decrease the interrelatedness and ambiguity of the complexities in the framework. This provides a general preliminary basis for any more detailed studies into the relationship between project complexity and the accuracy of labour hours estimates for capital projects in the construction industry. Though it is not expected that translating the direct impact of each single complexity into labour hours will be possible.

Further development of the complexity framework and the approach on applying the framework, thereby taking into account the interrelatedness as a characteristic of project complexity, could assist in better identifying areas of project complexity which affect the accuracy of labour hour estimates.
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<td>CAPEX</td>
<td>Capital expenditures</td>
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<td>CE</td>
<td>Cost Estimator</td>
</tr>
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<td>CEV</td>
<td>Cost Estimate Variance: difference between actual and estimated total project cost</td>
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<tr>
<td>CP</td>
<td>Capital Project</td>
</tr>
<tr>
<td>DLH</td>
<td>Delta Labour hours: difference between actual and estimated labour hours</td>
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<td>FID</td>
<td>Final Investment Decision</td>
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<tr>
<td>HSSE</td>
<td>Health, Safety, Security, Environment</td>
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<tr>
<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>JV</td>
<td>Joint Venture</td>
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<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
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<td>LP</td>
<td>Labour Productivity</td>
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<tr>
<td>LPN</td>
<td>Labour Productivity Norm</td>
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<tr>
<td>NACE</td>
<td>Statistical Classification of Economic Activities European Community</td>
</tr>
<tr>
<td>OECD</td>
<td>Economic Co-Operation and Development</td>
</tr>
<tr>
<td>SEPAM</td>
<td>Systems Engineering, Policy Analysis and Management</td>
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<tr>
<td>TOE</td>
<td>Technical, Organizational, External</td>
</tr>
<tr>
<td>USD</td>
<td>United States Dollar</td>
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<td>WBS</td>
<td>Work Breakdown Structure</td>
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INTRODUCTION
1. Introduction

Cost performance remains one of the main measures of the success of a project. Most large construction projects, often referred to as mega projects, (capital) construction projects or large engineering projects, routinely overrun their cost estimates (Ahiaga-dagbui, 2014). In other words, there is a difference between the actual construction costs determined at time of project completion and the estimated costs, defined as budgeted or forecasted construction costs determined at the time of the decision to build (Cantarelli et al., 2010). Cost overruns and schedule overruns often go hand in hand (Ramanathan, Narayanan, Idrus, & Teknologi, 2002).

The inability to make accurate cost estimates is an urgent complication that needs to be addressed, since the estimates establish the base line of the project cost at different stages of development of the project and therefore provide substantial information for decision making, cost scheduling and resource management (Carr, 1989; Venkataraman & Pinto, 2011). Consequently, poor cost estimates make it particularly difficult to manage large projects (Cantarelli et al., 2010) and this often results in cost overruns (Doloi, 2011). In turn, cost overruns are problematic because they lead to a Pareto-inefficient allocation of resources, they destabilize policy, planning, implementation, and operations of projects and they lead to delays and further cost overruns (Flyvbjerg, 2007).

This thesis discusses how labour cost estimates of capital projects in the construction industry could be improved by focusing on project complexity and labour productivity and the interaction between these two during the construction phase of a capital project.

In this introduction chapter the research problem is presented in order to position the research. The research problem is based on a brief literature review and provides background information with regard to project performance, labour productivity and project complexity. The topics are prominent topics in project management literature and form an interesting research field as all of these topics can be related to cost estimating. After the topics are introduced, knowledge gaps are identified which subsequently will lead to the problem statement and research questions for this thesis. This Chapter concludes with the research approach, which both includes the methods that are used to answer the research questions as well as the outline of this thesis.

1.1 Research problem

This Sub section describes three major trends that can be observed in the construction industry. The first observed trend is in line with the introduction of this Chapter, which describes a declining trend of project performance in terms of costs, meaning that a lot of projects overrun their cost estimates. Secondly, labour productivity in the construction industry is showing a declining trend and this trend is likely to continue. Thirdly, project complexity is often accused as being one of the causes for project failure and is getting more attention under project managers and construction professionals. The trend regarding project complexity is that it is continuously growing and with an increasing pace.

1.1.1 Research background

Cost overruns in large construction projects are not limited to a specific industry or geography and is being investigated for years now. For example, cost overruns can be observed in transport infrastructure projects as a leading study into cost overruns by Flyvbjerg, Bruzelius, & Rothengatter (2003) shows. Their international research included 258 transport infrastructure projects and in 86% of the projects cost estimation was overwhelmed. Actual costs were on average 28% higher than the
estimates. Famous examples of transport infrastructure projects that overran their cost estimate are the “Betuweroute” and “HSL-South” in the Netherlands, the “Big Dig” in Boston and the Montreal-Mirabel airport in Quebec.

Delivering capital projects on budget is also proving more difficult than ever in sectors like oil and gas, chemicals, utilities and metals and mining. A multi-industry capital investment research initiative that involved 101 executives in those sectors across 25 countries shows that a majority (70%) of their projects are facing cost overruns with an average of more than 25% (Accenture, 2013). Other studies come up with similar results: (Merrow, 2012); (Shenhar & Dvir, 2007); (Doloi, 2011).

Despite the enormous amount of knowledge on project management as well as the availability of various (cost) estimating techniques and project control software, many construction projects still do not achieve their cost objectives (Olawale & Sun, 2010). Possible causes for project overruns and ways to deal with this during different project phases are prominent themes within project management literature. For example, many authors describe critical success factors that can enable better project performance. However, a solution for keeping large construction projects within budget seems hard to find. According to (Cantarelli et al., 2010), this is because the causes and explanations for cost overruns vary widely and are ambiguous. In turn, this may explain why cost estimates have not improved and overruns not decreased over the last 70 years (Flyvbjerg, 2003).

As the capital expenditures (CAPEX) of today’s mega projects in the construction industry easily can reach levels of more than one billion US Dollar, it goes without saying that cost overruns – even though the total cost of a project is only one or two percent higher than the estimate – are immense when expressed in absolute terms. Not to mention projects with capital expenditures reaching multi-billion levels. Cost overruns could cost companies millions of Dollars in lost investment so there is definitely a need to improve project performance of large construction projects.

The second trend observed is about labour productivity. Labour productivity is often considered one of the best indicators of production efficiency of construction projects (Rojas & Aramvareekul, 2003); (Chan, 2002). Also Ulubeyli, Kazaz, & Er (2014) underline the importance of productive workforce in construction projects: “labour productivity is a key intermediate concept that has the potential to affect all the elements of the Iron Triangle: time, cost and quality”. This might not come as a surprise, as large construction projects can be considered very labour intensive2 and labour cost comprises 20 to 50% of the overall project cost (Hickson & Ellis, 2014; Soham & Rajiv, 2013). Improving labour productivity could influence the total cost of a project to a great extent and therefore there is a need to maximize the productivity of labour resources (Ng et al., 2004). However, the results of a research by Teicholz (2013) do not support this need. Teicholz researched labour productivity within the construction industry in the United States. He included labour productivity statistics from the Census Bureau and Bureau of Labor Standards and concluded that labour productivity for the total construction industry slightly declined over the time period 1964 till 2012. Similar trends are observed outside the United States, for example in New-Zealand (Tran & Tookey, 2011) and the United Kingdom (IPA, 2009). Labour productivity can be defined and measured in many ways and this should be taken into account when interpreting labour productivity numbers or trends. Furthermore, it should be mentioned that within the construction industry, productivity numbers vary among different sectors.

Project complexity is a phenomenon which is often accused of being one of the underlying causes for project failure in construction projects (Williams, 2005); (Thomas & Mengel, 2008). However, there is no consensus on what is meant by project complexity: “the concept of project complexity is not

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2 Labour intensive refers to “the economically efficient employment of as great a proportion of labour as is technically feasible to produce as high a standard of construction demanded by the specification and allowed by the funding available” (McCutcheon, 1995).
unambiguously” (Cantarelli et al., 2010); “there are several concepts that deal with the same complexity of projects from different aspects” (Dunović, Radujković, & Škreb, 2014). Despite the unambiguity around project complexity, it is assumed to be everywhere in today’s large projects and above all it is continuously growing, with an increasing pace (Vidal & Marle, 2008a). Several studies by consulting companies support this view: “Today’s capital projects are highly complex and that the complexity of capital projects will continue to grow in the next years leading to great challenges for the management of these projects” (Accenture, 2013). A study performed by Ernst and Young on the same topic also stresses this point (EY, 2014).

The three trends described are prominent topics in project management literature and acknowledged by researchers and practitioners. Given the need to improve project performance, the increasing complexity in construction projects and declining labour productivity, more research into those trends is highly relevant. Sub section 1.1.2 will describe the knowledge gaps that exist around these trends, so a problem statement and relevant related research questions can be formulated.

1.1.2 Knowledge gaps and problem statement

It can be derived from the mentioned articles in Sub section 1.1.1 that construction projects routinely overrun their cost estimates, project complexity is seen as a contributor to project failure in terms of cost and labour productivity in the construction industry in decline. It provided you rather with some overall trends in the construction industry. By zooming in at those trends it becomes clear where knowledge gaps exist. This is done from a cost estimator-perspective, so it can be motivated why the particular trends as discussed in Sub section 1.1.1 are chosen.

Cost estimators are responsible for setting up the initial estimate for a project. The estimates they make incorporate the total cost of a construction project, which can roughly be divided into cost for labour, cost for materials and cost for equipment (PMI, 2011). Given that the complexity of construction projects is increasing, cost estimating is becoming much more challenging as it requires many more assumptions as to future conditions than are found in less complex projects (Galloway, Nielsen, & Dignum, 2012). Project complexity is often considered to be a key factor when it comes to the accuracy of cost estimates; numerous studies show that project complexity is negatively correlated with the accuracy of cost estimates (Anderson, Molenaar, & Schexnayder, 2007; Enshassi, Mohamed, & Abdel-Hadi, 2013). The following knowledge gaps around project complexity and cost estimating regarding large construction projects are identified:

* Literature does not provide clear answers on how and to what extent the existence of project complexity may influence the accuracy of cost estimates;
* It is unclear how to measure the impact of project complexity on the accuracy of cost estimates;
* It is unclear why cost estimates are often inaccurate even if cost estimators take project complexity into account.

There seems to exist a theory-practice gap. Most approaches to project complexity are theory-oriented (Baccarini, 1996; Whitty & Maylor, 2009; Williams, 2002), which makes it difficult to relate project complexity with practice. Although a trend can be observed of researchers who operationalize project complexity and create complexity frameworks in order to make it usable in practice (Bosch-Rekveldt, 2011; Maylor, Vidgen, & Carver, 2008; Vidal & Marle, 2008a), the findings of a literature review performed on the topics as discussed in Paragraph 1.1.1 point out that research with regard to practical applications (such as cost estimating) to cope with project complexity in large construction projects is rather limited.

Given the mentioned knowledge gaps, it is expected that much can be added to the understanding of the relation between (the accuracy of) cost estimates and project complexity. The focus of this
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research is on labour cost estimates. Labour cost estimating is an interesting research topic as the construction industry is a very labour intensive industry and labour cost contribute significantly to the total cost of large construction projects, usually 20-50% depending on the project type and location (PMI, 2008; Soham & Rajiv, 2013). Hence an overrun on labour cost could therefore have a significant impact on the total cost of a large construction project.

The following problem statement has been specified in order to make the problem more specific.

1.1.3 Problem statement
Large construction projects often do not meet their cost and time schedules. One of the most common contributors to project failure in terms of cost is project underestimation of resources and costs, driven by the increasing complexity in large construction projects. Accurate labour cost estimates are essential, however, in practice a difference has been observed in ‘burned’ (actual) and ‘earned’ (estimated) labour hours for construction activities, which may be due to lower labour productivity. Subsequently, this may cause inaccurate labour cost estimates. It is unclear how and to what extent the existence of project complexity could affect the accuracy of labour hours estimate and/or the accuracy of labour cost estimates. Therefore, the relationship between project complexity in the construction phase of construction projects and labour productivity should be studied.

The problem statement contains two assumptions, which need to be validated in this research.

A1: Project complexity impacts the accuracy of the labour hours estimate negatively as a result of its impact on the labour productivity of construction workers;
A2: The accuracy of the labour hours estimate contributes significantly to the accuracy of the labour cost estimate

The following causal model is built in order to visualize the relationships. A1 relates to the left arrow and A2 relates to the right arrow.

Based on the problem statement the following research objective has been formulated:

1.1.4 Research objective
The objective is to deepen understanding and to provide qualitative insights on the relationship between project complexity and labour productivity during the construction phase of capital projects in the construction industry. Subsequently, the gained insights and results will be translated into recommendations for cost estimators.

1.2 Research relevance and scope
The relevance of the proposed research is twofold; it has both practical and scientific relevance and this is described below.
1.2.1 Practical relevance
As can be seen from the research objective, the primary goal of this research is to provide qualitative insights for cost estimators regarding labour productivity and project complexity. Increased understanding of project complexity and labour productivity, in the context of this master thesis research, is expected to have a positive effect on the accuracy of labour cost estimates. Hence, knowing the elements of project complexity that impact labour productivity and the qualitative insights on this from different levels within a capital project organization, is expected to contain valuable information for cost estimators. Cost estimators could use this information for adjusting the labour productivity norms they use for setting up labour cost estimates.

1.2.2 Scientific relevance
Clark & Lorenzoni (1996) describe that “field labour productivity is the single greatest variable in any estimate and is extremely difficult to estimate.” It appears from the mentioned articles in Sub section 1.1.1 and Sub section 1.1.2 that labour cost estimating in the construction industry is becoming even more difficult due to the increasing complexity in today’s capital projects. Research on project complexity is a prominent topic in project management literature, it is gaining increasing attention by researchers and practitioners.

Research on improving the process of cost estimating and factors affecting labour productivity are available (Chan, 2002; Gundecha, 2012; Hickson & Ellis, 2014; Jarkas & Bitar, 2012), but an integration of these perspectives is often lacking. The factors identified by those authors are often not linked to project complexity. In terms of scientific relevance, this research contributes to the field of project complexity as it is focused on improving labour cost estimates by focusing on project complexity during the execution/construction phase of large engineering projects in the construction industry. Research on the relationship between project complexity and labour productivity in this specific phase is rather limited. More specifically, this research tries to understand the relation between inaccurate cost estimates, project complexity and labour productivity. This thesis will conclude with recommendations for further research on these topics.

1.2.3 Scope aspects of the research
Several scope aspects already have been mentioned throughout this Chapter and in this paragraph a clear enumeration of these aspects is given. Hence, it becomes clear where the research will focus on and what is left out of the scope. An elaboration of the following scope aspects can be found in Chapter 2 of this thesis.

- Large engineering projects, large construction projects, mega projects and capital projects are used interchangeably in project management literature. In this research, the term capital projects in the construction industry will be used. As projects of less than 50 million USD are not considered a capital project, these projects are left out of scope (Paragraph 2.1.2).
- Project performance can be defined and measured in many ways. In project management literature, project success is often defined as a project being on time, within budget, and achieving the required quality or functionality (Atkinson, 1999). This thesis only focuses on the cost aspect, leaving the relation between with the other success criteria out of the scope of this research. Within the cost aspect, the focus will be on labour cost rather than cost for materials and equipment, which is assumed to be one of the largest contributors to the total cost of a project (PMI, 2008);
- Labour costs in construction are determined by two factors: a monetary factor and a labour productivity factor. The monetary factor is related to hourly wage rates, wage premiums, insurance and taxes (PMI, 2008; Ulubeyli et al., 2014). Although numbers of the monetary factor components are available, for the proposed research, this factor will be considered a constant. This helps reducing the complexity of the problem;
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* “Cost estimates become more accurate during the project process. However, what is relevant is the estimate known by the decision maker, i.e. the estimate based upon which the decision maker decides whether or not to implement the project” (Cantarelli et al., 2010, p. 4). Thus, the focus is on cost estimating rather than cost controlling;
* The research will not be limited to projects that are executed in the Netherlands; capital projects performed outside the Netherlands will be included as well;
* The research will be done in the form of a graduation internship within a consultancy company in the Netherlands.

### 1.3 Research questions and deliverables

In today’s complex capital projects in the construction industry, for cost estimators it is hard to accurately estimate labour cost. The research question to be answered in this research is:

**Q1**: How do project complexities influence labour productivity during the execution phase of capital projects in the construction industry and what are the implications for labour hour estimates?

In order to answer the main research question, the following sub questions have been formulated:

**S1**: How are project performance, labour productivity and project complexity positioned in this research?

**S2**: How can project complexity be operationalized and which complexities are assumed to have an impact on labour productivity?

**S3**: How can the impact of complexities on labour productivity be measured?

**S4**: To what extent does a difference in labour hours contribute to a variance in labour cost?

#### 1.3.1 Research deliverables

The planned deliverables of this research are as follows:

* The first deliverable is a description of the relationship between project performance, project complexity and labour productivity.
* The second deliverable is the identification of complexity- and labour productivity factors that together will form a complexity framework. This framework is key for designing the survey and interviews.
* The last deliverable comprises the results of the online survey, i.e. an overview of relevant complexities regarding the accuracy of labour cost estimates, and the results of the interviews. The interview results will provide the ‘why’ behind the online survey results.

### 1.4 Approach thesis

The approach of the research can be summarized as an exploratory research, incorporating a quantitative and qualitative component. The qualitative component is leading as the results are mainly based on expert experiences with different roles, including cost estimators, construction managers, project managers and project directors. Both the quantitative component and the qualitative component can be related to the research methods that are discussed in this Paragraph (1.4.2).

In Figure 2 (next page) the research framework is shown, which also includes the research design. The research framework visualizes how the research questions are positioned in this research.
1.4.1 Thesis outline
This thesis starts with a literature review on project performance, labour productivity, project complexity and cost estimating in Chapter 2. The review will provide background knowledge of these topics, based on project management literature. All together, the presented literature sets this thesis’ theoretical background. Chapter 3 discusses the survey design, interview design. In Chapter 4 presents the projects that are in the dataset and discusses the outcomes of the online survey and interviews. This thesis concludes with Chapter 5 in which the conclusions of the research are presented and recommendation for further research are made. Furthermore, it includes a reflection on the research outcomes and research process.

Figure 2: Research framework (adapted from Hevner, March, Park, & Ram, (2004))

1.4.2 Research methods
Two research methods were used to gather data in order to answer the sub questions and subsequently the main research question: survey and interview. All research questions are related to one or more research methods and this is visualized in in Figure 2.

Before data through these research methods is gathered, a literature study will be carried out on project performance, project complexity and labour productivity within (project management) literature. Additionally, cost estimating is introduced and related to those topics. Although a literature review cannot be considered a research method, it generates the necessary information to perform the research. More specifically, one of the objectives of the literature review is to gain more background knowledge of the research topics. It is important to understand what research has been done on these topics and what the key issues are. Moreover, exploring literature helps further reducing
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the scope of this research, making it possible to produce an overview of how the topics are related to each other. The first findings on project performance, projects complexity and labour productivity are discussed in the introduction of this Chapter and form the basis of a more thorough literature review of which the results are presented in Chapter 2 of this thesis. Scientific articles are gathered by means of several search engines, including Science Direct, Scopus and Google Scholar. In addition, Google and Mendeley’s catalog of academic literature is used to search for books, news articles and websites. Also the consultancy’s’ internal database and supervisors’ network are consulted to gather information.

**Interview and survey**
Most essential for the research is the availability of sufficient people in relevant roles (project directors, project managers, construction managers and cost estimators) across different sectors within the construction industry, who are willing to be interviewed about their most recently completed project. Their qualitative thoughts on labour productivity and project complexity mainly concern the qualitative component of this research.

Project characteristics were gathered by means of an online survey, which had to be filled in by the respondent before the interview. During the interview there was time for the respondent to elaborate on their personal experience in the construction industry, the project characteristics and the project context. The survey includes some quantitative aspects such as ranking and scoring.

In order to determine ‘how many interviews are enough’ for collecting the qualitative data for this research, literature by (Guest, 2006) was consulted, which describes that a sample size of twelve interviews is sufficient for this research. In total an amount of twenty people have been interviewed in a time slot of slightly over three weeks. Eighteen of them filled in the online survey before the interview. The interview could then be prepared on the basis of their individual responses and this helped reducing the time needed for introducing the topics to be discussed during the interview. Hence more time was available for answering the questions relevant for the research. The survey design and interview design are discussed in more detail in Chapter 3 of this thesis.

**1.4.3 Exploratory research**
The purpose of this research is exploratory oriented since there is limited understanding on the interaction between project complexity and labour productivity. Exploratory research has the following characteristics (Kooiker, Broekhoff, & Stumpel, 2011):

* Exploratory research is broad in focus and rarely provide definite answers to specific research issues;
* Exploratory research is often not generalizable to the population;
* Exploratory research determine the best methods to be used in a subsequent study;
* The objective of exploratory research is to identify key issues and key variables, i.e. the researcher would like to understand an issue more thoroughly.
THEORY
2. Theoretical framework

In this Chapter, the results of a more thorough literature review on the research topics will be presented in order to better understand the framework in which this research takes place from a theoretical point of view. It appeared from the mentioned articles in Chapter 1 that capital projects in the construction industry routinely overrun their budgets, complexity in projects is increasing and labour productivity in the construction industry is declining. The identified trends were then related to cost estimating. Relating cost estimating to those trends really helped to narrow the scope of this research. Using a top-down approach, this Chapter will elaborate on these and other relevant topics. The specific content as well as the outline of this Chapter is summarized below and visualized in Figure 3. The numbers refer to the Sub sections in this Chapter.

**Figure 3: Overview theoretical framework**

- The definition of a capital project in the construction industry (Sub section 2.1). The objective of this Sub section is to gain background knowledge on capital project in the construction industry. At the end of this Sub Section a clear definition of a capital project, i.e. what is meant by a capital project in this thesis, is given;
- The definition of project performance (Sub section 2.2). First a general review of the overall state of project management is presented and how project management relates to project performance. Subsequently, the essence of cost estimating is discussed order to keep close to the research objective;
- The objective of Sub section 2.3 is to create better understanding on labour cost estimating, thereby further narrowing the scope. The literature review is aimed at positioning labour
productivity within labour cost estimating. In other words, how is labour productivity defined, measured and used as an input for making labour cost estimates.

- Sub section 2.4 presents the key concepts of project complexity as well as the definition of project complexity that is derived from project management literature. This Sub section concludes with an operationalization of project complexity and the created framework provides, together with the findings of Sub section 2.3 and Sub section 2.4, a starting point for Chapter 3: Research design.

- The final Sub section of this Chapter answers the first and second sub question of this research (S1 and S2), based on the findings of the literature review.

### 2.1 Capital projects in the construction industry

Throughout this thesis, we focus on capital projects in the construction industry. It is necessary to clearly describe what is meant by a “capital project in the construction industry” because capital projects, large engineering projects and mega projects are used interchangeably and defined in various ways in project management literature. There should be no ambiguity about this definition and in order to achieve this, we will first look into several definitions of “project” and “capital project” in project management literature. Next, these definitions will be related to the construction industry.

A project:

- “[..] is an organization of people dedicated to a specific purpose or objective. Projects generally involve large, expensive, unique, or high risk undertakings which have to be completed by a certain date, for a certain amount of money, with some expected level of performance. At a minimum, all projects need to have well defined objectives and sufficient resources to carry out all the required tasks.” Tuman (1983)

- “[..] is an endeavour in which human, financial and material resources are organised in a novel way to undertake a unique scope of work, of given specification, within constraints of cost and time, so as to achieve beneficial change defined by quantitative and qualitative objectives.” Turner (1999)

- “[..] is a temporary endeavor undertaken to create a unique product or service. Temporary means that every project has a definite beginning and a definite end. Unique means that the product or service is different in some distinguishing way from all other projects or services.” Project Management Body of Knowledge (Project Management Institute, 2008)

Although there is no general consensus on the definition of a project – even the project management institutes and organization maintain various definitions (Bakker, 2008) – it is learnt from the above definitions that a project has a temporary character; a unique scope of work is undertaken; within specified constraints.

A project has a temporary character meaning that it has a start and end. During the life cycle of a project, different phases can be identified. According to Westland (2006), a project’s life cycle can be divided into four distinct stages: project initiation, project planning, project execution and project closure (Figure 4). The first phase of a project is the initiation phase. At this stage a project business problem or opportunity is identified. Preliminary goals and alternatives are specified during this phase, as well the possible means to accomplish those goals (Pinto & Slevin, 1987).

After the initiation phase the planning phase commences and this involves, among other activities, creating a project plan outlining the activities, tasks, dependencies and time frames; listing the labour, materials and equipment required; setting up a quality plan providing quality targets, assurance and control measures (Westland, 2006).
Phase 3, the execution phase, is typically the longest phase of the project in terms of duration and is often referred to as the construction phase. It involves implementing the plans created during the project planning phase as well as monitoring the actual work against the plans created. The person who is responsible for this is the project manager. The project manager implements cost management, quality management, risk management and other types of management in order to monitor and control the project. After the construction phase is completed, the “product” is handed over to the client depending on the contract document.

Figure 4: Project life cycle

2.1.1 Capital project in the construction industry

This research focuses on a specific type of projects within a specific industry: capital projects in the construction industry. At least these projects share the general nature of a “normal” project as discussed above, however, to what extent are capital projects different from the definitions by Tuman, Turner and Project Management Book of Knowledge?

As mentioned earlier, capital projects, large engineering projects and mega projects are used interchangeably. Hence, several definitions from different sources are studied in order to formulate a clear definition of a capital project in the construction industry.

* “Mega-project can be defined as simply as projects whose capital for the complete construction exceeds a certain number of million US dollar” (Merrow et al., 1988)
* “Large engineering projects are high-stakes games characterized by substantial irreversible commitments, skewed reward structures in case of success, and high probabilities of failure.” (Lessard & Miller, 2001)
* Fiori and Kovaca (2006): “a construction project, or aggregate of such projects, is characterized by: magnified cost, extreme complexity, increased risk, lofty ideals, and high visibility, in a combination that represents a significant challenge to the stakeholders, a significant impact to the community, and pushes the limits of construction experience.”
* Jergeas (2008) defined mega projects as being huge in magnitude and over $1 billion Canadian Dollar in total installed cost, excluding development costs expended prior to the project being formally approved. Mega projects are characterized by a significant number of interfaces, interdependencies, complexity, and risks, some of which are strategic and must be managed at a level above the project team.
* “A capital project is a long-term investment made in order to build upon, add or improve on a capital-intensive project. A capital project is any undertaking which requires the use of notable amounts of capital, both financial and labor, to undertake and complete. Capital projects are often defined by their large scale and large cost relative to other investments requiring less planning and resources.” (Investopedia, 2014)

Based on the definitions presented above and additional project management literature (Marrewijk, 2014) on mega projects, the following characteristics are identified (next page):
Characteristics of mega projects

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>High degree of complexity * (Discussed in Sub section 2.4)</td>
<td>The period of inception until realization often covers decades;</td>
</tr>
<tr>
<td>Budget and schedule overruns * (Discussed in Sub section 2.2)</td>
<td>Embedded in a national political context which can change over time;</td>
</tr>
<tr>
<td>Large-scale, and geographical dispersed;</td>
<td>New and unproven technologies and legislation;</td>
</tr>
<tr>
<td>Requirements of huge investment costs (over millions/billions of Euros);</td>
<td>Involvement of many stakeholders;</td>
</tr>
<tr>
<td>Uncertainty associated with project implementation over an extended period of time;</td>
<td>Often unique at national level;</td>
</tr>
<tr>
<td>Have a major impact on the environment and society;</td>
<td>High quality aesthetics;</td>
</tr>
<tr>
<td>Labour-intensive: tens of thousands workforces from multi countries;</td>
<td>Incorporate many uncertainties;</td>
</tr>
<tr>
<td>Logistic challenges, especially on mega projects at remote sites;</td>
<td>Mixture of joint organization and sub-contracting to legally separate partners;</td>
</tr>
<tr>
<td>Can be subject of citizen resistance;</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Characteristics of mega projects (adapted from Marrewijk, 2014)

Many of the characteristics in Table 1 are also applicable to construction projects (Sub section 1.1). Construction projects can be divided into six categories, which refer to the activities performed during the life cycle of a construction project. Every category contains more detailed descriptions of activities and those activities are specified in the Statistical Classification of Economic Activities in the European Community (NACE), a European industry standard classification system. According to this classification system, the construction industry can be divided into six activity categories: (1) Architectural and engineering activities and related technical consultancy; (2) Site preparation; (3) Building of complete constructions or parts thereof; (4) Building installation; (5) Building completion; (6) Renting of construction or demolition equipment with operator.

The activities that are mentioned above are not limited to a specific sector, they may apply to different sectors within the construction industry. The construction industry can roughly be divided into four sectors (Construction Sector Council, 2014):

* New home building and renovation: building, remodeling or renovating houses and apartment buildings;
* Heavy industrial construction: building and maintaining industrial facilities such as cement, automotive, chemical or power plants, refineries and factories;
* Institutional and commercial construction: building commercial and institutional buildings and structures such as stadiums, schools, hospitals;
* Civil engineering construction: engineering projects such as highways, dams, water and sewer lines, power and communication lines and bridges.

2.1.2 Definition of a capital project in the construction industry

In this research, when referred to a capital project, the project at least matches two or more characteristics that are mentioned in Table 1. In an attempt to synthesize the relevant characteristics of capital projects within the construction industry and in order to limit the scope for this research, the following definition will be used in this research: A capital project is a project with a lifecycle of at least two years and CAPEX of at least 50 million US Dollar. The minimum level with regard to capital expenditures was not based on findings in the literature, as literature did not provide a minimum cost level for a capital project.
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2.1.3 Stakeholders for construction projects

Construction projects potentially can have different sets of stakeholders. Stakeholders hold the key to the environment in which the project operates and the subsequent financial and operating performance of the project (Itanyi & Ukpere, 2014). Figure 5 provides a simplified representation of stakeholders for a construction project. As mentioned in the introduction of this thesis, essential for the research is the availability of sufficient people in relevant roles (project directors, project managers, construction managers and cost estimators), either belonging to the project owner or contractor. The stakeholders involved in this research are highlighted in blue.

Figure 5: Stakeholders in a construction project (adapted from Department for Business Information & Skills, 2013)

Winch (2010) provides a more comprehensive overview of potential stakeholder in a construction project and these stakeholders can be categorized into two main categories: internal stakeholders and external stakeholders (Table 2). Internal stakeholders can be defined as those who are formally connected with the project, whereas external stakeholders are those affected by the project in some way (Gibson 2000).

<table>
<thead>
<tr>
<th>Internal stakeholders</th>
<th>External stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand side</td>
<td>Supply side</td>
</tr>
<tr>
<td>Client</td>
<td>Architects</td>
</tr>
<tr>
<td>Financiers</td>
<td>Engineers, cost estimator</td>
</tr>
<tr>
<td>Client’s employees: cost estimator, project manager</td>
<td>Principal contractors</td>
</tr>
<tr>
<td>Client’s customers</td>
<td>Trade contractors</td>
</tr>
<tr>
<td>Client’s tenants</td>
<td>Materials suppliers</td>
</tr>
<tr>
<td>Client’s suppliers</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Stakeholders in a construction project (adapted from Winch, 2010)

Basic understanding of stakeholders involved in a capital project is necessary since people with different roles will be interviewed for this research. An overview of the interviewees who participated in this research, their roles and brief role description is presented in Appendix 3 of this thesis.

Stakeholders in a project environment have a certain impact on the project and their impact could be expressed in, for example, power (high, medium low), support (positive, neutral, negative), influence (high or low), interest (high or low) or attitude (supportive or obstructive). Mapping stakeholders that are involved in a project helps understanding the behavior or perception of stakeholders, however, for
this research it is assumed that understanding of the role descriptions of the interviewees is sufficient to reach the objective of this research. Hence no stakeholder analysis will be performed.

2.2 Project performance

In the introduction of this thesis it is mentioned that a majority of capital projects are underperforming. In that specific context, project performance is measured by calculating the difference between actual construction costs determined at time of project completion and the estimated costs, defined as budgeted or forecasted construction costs determined at the time of the decision to build. One could speak of negative project performance when the actuals overrun the estimates.

However, there is not just one way to measure project performance. For example, one also could assess project performance based on only return on investment, schedule performance, quality performance, labour hour performance, customer satisfaction or a combination of those (CBP, 2005). Hence, project performance depends on the key performance indicators (or: criteria) that are set and agreed upon before a project is started. The criteria that are set, however, may vary between different stakeholders that are involved in the project. Hence, there could be a bias on what is meant by project performance and thus project success. Even project teams, involved at different phases in the life cycle of a capital project, may have different perceptions on project success. Project success can be seen as a multi-dimensional category (Fortune & White, 2006) and is prone to subjectivity (Bryde, 2008). Also within project management literature, different perceptions on how to measure project performance are found. The only agreement seems to be the disagreement on what constitutes ‘project success’ (Prabhakar, 2008).

2.2.1 The role of project management in measuring project success

Project management is the application of knowledge, skills and techniques to execute projects effectively and efficiently (Pmi, 2008). It is aimed at achieving project success and its criteria, however, there are multiple perspectives on the definition of project success. De Wit (1988) argues that most project management literature advocates that project management has three major objectives in order to achieve project success: a project must be managed on time, within budget and to quality/performance specifications. This view is rather limited and too much focused on the “classic” perspective of project management. After reviewing literature on this topic, other perspectives on project success are identified and they will be discussed below so it will become clear how project success is embedded in this research.

According to Olsen (1971), project management is “the application of a collection of tools and techniques to direct the use of diverse resources toward the accomplishment of a unique, complex, one-time task within time, cost and quality constraints. Each task requires a particular mix of these tools and techniques structured to fit the task environment and life cycle of the task”. Olsen highlights three criteria for project management success: time, cost and quality. These criteria are often referred to as the Iron Triangle. Although the criteria of the Iron Triangle apply to project management, the criteria are often used to measure project success. However, projects continue to be described as failing using time, cost and quality as main criteria. This is remarkable, as these criteria are used for years now.

According to De Wit (1988), a distinction should therefore be made between project management success and project success. Does this mean that the Iron Triangle can only be attributed to project management success rather than project success? This question was also raised by (Atkinson, 1999b). Based on theory by Bernstein and Handy he argues that the criteria researcher and practitioners have been focusing on for years now for measuring project success may have been in error. Two types of errors were identified, Type 1 errors and Type 2 errors. Type 1 errors occur when something is not done in a right way. The examples he gives are poor planning, inaccurate estimates and lack of control.
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Beyond these examples, this error seems relevant in this research as earlier explained in the introduction of this thesis. In the introduction it was stated that inability to make accurate cost alarming, since the estimates establish the base line of the project cost at different stages of development of the project and therefore provide substantial information for decision making, cost scheduling and resource management (Carr, 1989). Consequently, poor cost estimates make it particularly difficult to manage large projects (Cantarelli et al., 2010) and often lead to cost overruns (Doloi, 2011). In the next paragraph the focus will be on the Type 1 error, thereby introducing factors that enable project success in terms of time, cost and quality.

The type 2 error basically comes down to the extent in which we succeeded to create a set of complete criteria for project success. Atkinson argues that this type of error is relevant and with this he implies that the wrong criteria for measuring project success have been used. “They are not as good as they could be, or something is missing” (Atkinson, 1999a, p. 341). In line with this, several authors acknowledge the importance of the Iron Triangle for measuring project success, thereby making a distinction between criteria for project management success and criteria for project success. Their focus is on the latter and they mention other criteria in addition to the Iron Triangle (de Wit, 1988; Lewis, Welsh, & Dehler, 2002; Menches & Hanna, 2006; Pinto & Slevin, 1987). For example, Menches & Hanna (2006) developed a performance measurement index, including the following success criteria: “Actual percent profit”, “Percent schedule overrun”, “Amount of time given to complete work”, “Rating of communication between team members”, “Budget overrun” and “Percent change in work hours”. The latter can be seen as a performance measure of labour productivity. This is discussed in more detail in Sub section 2.3.

Several perspectives on project management have now been discussed in order to position how project success can be measured. As it is not in line with the objective of this research to add, adapt or improve existing success criteria for measuring project success, no further literature is reviewed on the operationalization of project success. Based on the literature discussed in this paragraph, it can be concluded that there is a general agreement on the importance of schedule (time), quality and budget (cost) as criteria for measuring project success. Given this, and the fact that these criteria are relatively easy to quantify (Locke, 1984), the criteria are commonly used in practice.

In this paragraph it is explained how project management relates to project performance. However, some studies suggest that for some projects, especially those with a high dynamic character and dynamic environment, it is better to use a process management rather than a project management approach in order to achieve project success (Bruijn & Heuvelhof, 2007).

2.2.2 Definition of cost performance
With regard to project performance, the focus is on cost performance rather than time or quality performance. Therefore, the definition of project cost performance should be clear. The cost estimate known by the decision maker at the Final Investment Decision (FID) is used as a reference point for determining the cost performance of a project. Hence the following term is introduced: Cost Estimate Variance (CEV). CEV describes the difference between the Actual cost of work performed and Budgeted cost of work scheduled:

\[
\text{EQ1: Cost Estimate Variance} = \text{Budgeted cost of work scheduled} - \text{Actual cost of work performed}
\]

If the Actual cost exceed the Budgeted cost one could speak of a cost overrun and if the Budgeted cost exceed the Actual cost one could speak of a cost underrun. Evidently, cost overruns are undesired but also cost underruns could affect the total performance of a project negatively.
Figure 6 emphasizes that this definition applies to the execution phase of a capital project.

2.2.3 Critical success factors
A clear distinction has been made between project success and project management success (Atkinson, 1999a; de Wit, 1988) and two types of error are discussed regarding project success criteria are discussed in the previous paragraph. Since the Type 1 error seems to be relevant to this research, the next step is to zoom in on this error type. Type 1 errors occur when something is not done in a right way to achieve projects success. To make this error more specific, the concept of critical success factors is introduced. Critical Success factors (CSFs) are “characteristics, conditions, or variables that can have a significant impact on the success of the project when properly sustained, maintained, or managed” (Milosevic & Patanakul, 2005). Hence one should focus on CSFs in order to achieve project success. Figure 7 visualizes how CSFs, project performance and project success are related.

If CSFs can have a significant impact on project success, what is it that has to be done right to achieve project success? In other words, what are the critical success factors according to literature which have a positive impact on the Iron Triangle? The answer to this question is not straightforward as CSFs may differ from sector to sector and from project to project. Given the diversity of capital projects it is not possible to come up with all CSFs that affect project success. Nonetheless, Table 3 (next page) covers CSFs which are frequently mentioned in project management literature. Not that many CSFs in Table 3 can be related to cost estimating, although accurate cost estimating is getting more attention in more recent literature as being a critical success factor. It is often stated that inaccurate estimates of resources and costs is one of the most common contributors to project failure (Caltrans Project Development Procedures Manual, 2014; Enshassi et al., 2013). Therefore it is important to find ways to improve the accuracy of cost estimates.
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2.2.4 Why are cost estimates important and why are cost estimates often inaccurate?

Cost estimates at different stages of the project provide substantial information for allocating resources, time planning and decision making in general (Doloi, 2011). The main purpose of a cost estimate is to provide as accurate predictions and the actual development costs of a construction project adequately to the various stages of its implementation (Antohie, 2009). This implies that not every cost estimate is the same. In fact, cost estimates can be categorized into different classes of estimation depending on the precision of the estimate and stage of project development. The methods used for cost estimating become more definitive and produce estimates with increasingly narrow probabilistic cost distributions when approaching the end of the project (European Commission, 2006). The following major classes/categories can be distinguished (Antohie, 2009; Greenhalgh, 2013, p. 84):

<table>
<thead>
<tr>
<th>Estimate class</th>
<th>Purpose</th>
<th>Accuracy compared to actual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Feasibility estimate</td>
<td>To establish a “ball-park” figure; Check technical and economic feasibility</td>
<td>40%</td>
</tr>
<tr>
<td>B Design estimate</td>
<td>To serve as a “reality check” on the development of the design; Define development alternatives, recommend solutions</td>
<td>30%</td>
</tr>
<tr>
<td>C Bid estimate</td>
<td>To benchmark the tender bids when they are received from contractors</td>
<td>20%</td>
</tr>
<tr>
<td>D Tender estimate</td>
<td>To build up the real costs of the works by the proposed contractor for conversion to a tender figure and contract price; Select optimal development concept</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 3: Critical success factors
Control estimate

To control the construction stage expenditure, especially variations. This estimate is the basis for project execution control.

<table>
<thead>
<tr>
<th>€</th>
<th>10%</th>
</tr>
</thead>
</table>

Table 4: Estimate classes (adapted from Antohie, 2009 and Greenhalgh, 2013)

Table 4 provides a clear overview of the different classes where estimates can be categorized into, however, the estimate that is relevant in this research is the tender estimate, i.e. the estimate known by the decision maker in charge who will decide whether or not to implement the project at the time of the decision to build. Moreover, this estimate is also used to measure project success. It is observed that many capital project routinely overrun their estimates by more than 15%, so the accuracy numbers presented in the table seems to apply to “typical” projects rather than capital projects. “Typical projects” refer to projects which do not share the characteristics of a capital project that are mentioned in Sub section 2.1. For example, typical projects are less complex in terms of organizational complexity and technical complexity. Although it is observed in literature that cost overruns are more common than cost underruns, it can be concluded that both could be problematic regarding the performance of projects Cantarelli (2011). Literature provides several insights on factors causing inaccurate cost estimates. According to (Greves & Joumier, 2003), the achievable level of accuracy for a cost-estimating will be dependent on the following factors:

- Level of understanding of the problem;
- Completeness and the correctness of the information relating to the cost-driving parameters;
- Quality of the cost model.

The above list is rather general and can be operationalized. This is done by Odusami and Onukwube (2008, p.34), they identified and studied the influences that affect the accuracy of cost estimation on a more detailed level. The factors in Table 5 have been complemented with factors identified by the Association for the Advancement of Cost Engineering International (AACE International, 2011).

<table>
<thead>
<tr>
<th>List of factors causing inaccurate estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expertise of the estimator</td>
</tr>
<tr>
<td>Quality of information</td>
</tr>
<tr>
<td>Quality of assumptions used in preparing the estimate</td>
</tr>
<tr>
<td>Quality of reference cost estimating data</td>
</tr>
<tr>
<td>Project teams experience</td>
</tr>
<tr>
<td>Tender period/ Time and level of effort budgeted to prepare the estimate</td>
</tr>
<tr>
<td>Availability of labour and materials</td>
</tr>
</tbody>
</table>

| Market conditions                        |
| Design detail;                           |
| Complexity of the design                 |
| Estimating techniques employed           |
| Level of non-familiar technology in the project |
| Complexity of the project                |

Table 5: List of factors causing inaccurate estimates

The accuracy of early cost estimates for capital projects are affected by several factors and these factors include, but are not limited to, the ones that are mentioned above (Odusami and Onukwube, 2008, p.34; AACE International, 2011). However, it gives an indication of the segments that have room for improvement. Several of the factors that are presented in Table 5 support the importance of project complexity with regard to the accuracy of cost estimates, as was already mentioned in the introduction of this thesis. For example, the factor “quality of assumptions used in preparing the estimate” is influenced by the increasing complexity in capital projects due to the fact that many more assumptions as to future conditions are found than in a less complex project (PMBoK, 2010). Also other factors like the “quality of reference cost estimating data”, “project team’s experience” and “expertise of the cost estimator” relate to project complexity. Reviewing the concept of project complexity is therefore highly relevant. As it is not possible to list all factors that might cause inaccurate cost estimates, only
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the factors that relate to the research context are listed. The relationship between project complexity and labour cost estimating is further explained in Sub section 2.3.

Other factors or causes that seem relevant are listed below (Flyvbjerg (2009):

* Delusions or honest mistakes; managers make decisions based on delusional optimism rather than on a rational weighting of gains, losses, and probabilities. They overestimate benefits and underestimate costs and time;
* Deceptions or strategic manipulation of information or processes: different preferences and incentives of the actors in the system. Politicians, planners or project champions deliberately and strategically overestimate benefits and underestimate costs in order to increase the likelihood that their projects, and not their competition's, gain approval and funding.

Also other studies claim that strategic behavior is an important factor with regard to inaccurate estimates (Brunes & Lind, 2014; Cantarelli, Chorus, & Cunningham, 2011). Although their research is limited to strategic behavior in large-scale transport infrastructure projects, it is argued that strategic behavior is not limited to this specific sector only (Coskun & Katirci, 2012; PMI, 2008).

2.2.5 Sub conclusion on project performance

Several important topics have been discussed in Sub section 2.1 & 2.2 in order to better understand the framework in which this research takes place from a theoretical point of view. A top-down approach is used in order to present relevant literature and to keep focus on the objective of this research during the literature review.

It is concluded that it is accepted to use the Iron Triangle criteria for measuring project success and presented an overview of critical success factors that enable project success. Given the objective of this research, it is wise to further limit the scope and hence the focus in this thesis will be on cost performance rather than time or quality performance to measure project success. Project performance in terms of cost is measured by comparing the “Actual cost of work performed” with the “Budgeted cost of work scheduled”: Cost Estimate Variance. Regarding Budgeted cost of work scheduled, there is referred to the tender estimate. Project complexity is often related to the inability to accurately estimate the cost of a project. The concept of project complexity is discussed in more detail in Sub section 2.4

2.3 Cost estimating and labour productivity

In the introduction of this thesis it was stated that labour productivity in the construction industry slightly declined over the time period 1964 till 2012. This is a rather general trend which was observed after performing a brief literature study. What is relevant here, thereby referring to the previous Sub section, is labour productivity in the context of labour cost estimating. In order to build understanding on the concept of labour productivity, this Sub Section will first review some definitions of labour productivity that are used in the construction industry. Subsequently, literature is reviewed on how labour cost estimates are established. With this, the use of labour productivity numbers by cost estimators is discussed.

2.3.1 How labour productivity is measured within capital projects in the construction industry

In construction, productivity is usually taken to mean labour productivity. However, even within the construction industry labour productivity is measured differently depending on measurement
objectives and the availability of data. According to Thomas & Mattehews (1985) and Shehata & El-Gohary (2011), a distinction can be made between labour productivity unit rates and labour productivity performance rates. Labour productivity unit rates generally involve the following equations:

**Equation 2 & 3: Labour productivity unit rate equations**

**EQ2:** \[ \text{Labour productivity} = \frac{\text{Output}}{\text{Labour cost}} \]

**EQ3:** \[ \text{Labour productivity} = \frac{\text{Output}}{\text{Work hour}} \]

Both equations are unit rates and are related to a specific activity, for example, steel reinforcement, concrete placement and so on. Units that are often used are square meter, tons and cubic meter. The labour productivity of a construction worker could for example be 100 m³ concrete/hour or 30 m² bricks/hour. “Growth in labour productivity may come from applying more capital (machinery and equipment, structures) to the production process or from technological change. And to the extent that the sources of growth from these two sources can be decoupled, the effect of policies that affect these two differentially can be evaluated.” (Government of Canada, 2014)

The units that are mentioned (square meter, tons, etcetera) are typical for measuring labour productivity during a project rather than for an entire economy or industry. For measuring labour productivity on a macro level (for example a country), the Gross Domestic Product (GDP) is often used together with the Number of paid hours of work. This results in the following equation:

**Equation 4: Labour productivity unit rate equation (macro level)**

**EQ4:** \[ \text{Labour productivity} = \frac{\text{GDP (Country, industry or sector)}}{\text{Number of paid hours of work}} \]

Labour productivity levels of several countries are measured by the Organisation for Economic Co-operation and Development (OECD), based on GDP and employment data from the OECD Annual National Accounts and on hours worked from the OECD Annual National Accounts, the OECD Employment Outlook and national sources.

Labour productivity can also be measured by using labour productivity performance rates. In fact, labour productivity performance rates combine labour productivity unit rates. Labour productivity performance rates are often referred to as efficiency and measures the ratio between estimated unit rate and actual unit rate.

**Equation 5: Labour productivity performance rate**

**EQ5:** \[ \text{Labour productivity} = \frac{\text{Estimated unit rate}}{\text{Actual unit rate}} \]

A unit that is often used in this equation is labour hour. If the above equation is equal to 1, this means that labour productivity is accurately predicted. In practice, however, estimating labour productivity during construction appears to be extremely difficult since many (known or unknown) variables have the potential to affect labour productivity. The relationship between labour productivity and labour cost estimating is explained in the next paragraph.

### 2.3.2 How is labour productivity related to cost estimating in this research?

Cost estimating is a factual process designed to predict the cost price of undertaking construction work. Regarding labour cost estimating, the following aspects are relevant: direct labour cost, indirect labour cost, labour hours and a monetary factor. These aspects are visualized in Figure 8. The labor
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Cost component of a construction project often ranges from 30% to 50%, and can be as high as 60% of the overall project cost. Therefore, it is clear that construction labour is a vital component of a construction project (PMI, 2008).

![Diagram](image)

**Figure 8: Relevant aspects regarding labour cost estimating**

2.3.2.1 Direct labour cost and indirect labour cost
Most labour cost estimates are divided into two categories; direct labour cost and indirect labour cost. While indirect labour cost are cost occurring during the execution of work that cannot be assigned directly to specific activities, they are necessary cost of doing business. Indirect cost accounts fall into two broad categories, overhead and general and administrative expenses. Overhead cost are indirect cost in the indirect sphere that are relevant to the implementation of the work (Vliet, 2011), such as material overhead, manufacturing overhead, engineering overhead and site overhead. Some of the costs that would typically be included in manufacturing overhead include costs for staff who perform maintenance on the equipment and depreciation on the manufacturing equipment and facilities (Averkamp, 2015; PMI, 2008).

General and administrative expenses must be incurred by or allocated to the general business unit. Some examples of general and administrative expenses include, but are not limited to, executive salaries, staff services such as legal, public relations and accounting. As the objective of this research is to provide qualitative insights on the relationship between project complexity and labour productivity during construction, indirect labour cost are left outside the scope of this research.

Direct labour cost are directly attributable to production labour that is assigned to a specific product and is generally considered to be the cost of regular hours, shift differentials, and overtime hours worked by employees. In this thesis labour hours refer to hours worked by construction workers during the construction phase of capital projects in the construction industry. In addition, direct labour cost relate to a monetary factor, which include the related amounts of hourly wage rates, wage premiums, insurance and taxes. Direct labour cost could then be estimated by multiplying the estimated labour hours for all construction activities and the monetary factor.

\[ \text{Direct labour cost} = \text{Estimated labour hours} \times \text{Wage rate (monetary factor)} \]

2.3.2.2 Estimated labour hours and Wage rate
There are several techniques a cost estimator could use in order to produce an estimate of the number of labour hours required for the construction activities in a capital project. A technique that is commonly used involves the use of a work breakdown structure (WBS). A WBS is produced in the very
early stages of a project and is a hierarchical structure of work elements – i.e. a deliverable-oriented decomposition of a project into smaller elements – that defines the full family tree of a work activity or work output’s contents (Stewart, Wyskida, & Johannes, 1995). A rather simplified WBS is visualized in Figure 9.

Figure 9: Example of a Work Breakdown Structure

“Each work package in a WBS is costed and arranged in such a way that the total cost of the packages on any branch must add up to the cost of the package of the parent package on the branch above” (Lester, 2014, p. 53). Once the WBS is has been drawn and the works elements are scheduled, a bottom-up labour cost estimate can be produced starting at the lowest branch of the family tree. First, the direct labour hours are estimated for the construction activities that are specified on the lowest branch and secondly the estimated labour hours for all activities are multiplied with the wage rate. For estimating the direct labour hours, cost estimators use labour productivity norms. A labour productivity norm refers to a number of hours per unit of measurement (read: construction activity). A more detailed definitions is described by the Dutch Association of Cost Engineers (DACE):

“[..] the number of labour hours required to complete a defined construction activity, given the specific qualifications associated with each individual labour productivity norm. By definition, each labour productivity norm is a typical or average number of labour hours required by the collection of all individuals (i.e., crew) associated with the construction activity” (Vliet, 2011, p. 4)

The labour productivity norms are only applicable for all work that is executed under normal conditions, with experienced laborers, having a normal performance, using the correct tools and applying the best working method. However, a capital project environment does not always provide those ideal circumstances. In fact, labour productivity of construction workers can be affected by the physical conditions of a specific project location if these conditions are abnormal (Clark & Lorenzoni, 1996). Hence factors can be applied to adjust the labour productivity norms for other locations or specific local characteristics of the project environment, often referred to as local content. The adjustment factors are calculated by the cost estimator and may be based on historical information on similar projects or the cost estimator’s experience (PMI, 2008). In other words, establishing the labour hours can be accomplished only after establishing or predicting the labour productivity of the construction workers.

It is a difficult task to accurately estimate the labour hours needed for the construction activities to be performed as there are many factors which influence labour productivity (Akintoye & Fitzgerald, 2000). Hence there is often a delta (read: difference) in the scheduled labour hours at the FID and the total number of labour hours as determined at the end of the construction phase. It is observed in literature that cost estimators often underestimate the amount of hours needed for construction activities.
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(Chan, 2002; Durdyev & Mbachu, 2011) and this indicates that the productivity of the construction workforce must have been lower than expected.

In an attempt to synthesize what is mentioned above, the definition Delta Labour Hours (DLH) is introduced:

\[ \text{Delta Labour Hours (DLH)} = \text{Scheduled labour hours} - \text{Real labour hours} \]

In project management literature, Scheduled labour hours are often referred to as “earned hours” or “estimated labour hours” and Real labour hours are often referred to as “burned hours”. A negative DLH means that there were more labour hours needed than estimated and a positive DLH means that there were less labour hours needed than scheduled. Hence one could speak of a more accurate labour hours estimate when Delta Labour Hours is small. The following Figure emphasizes that these definitions are linked to the construction phase of capital projects.

The second variable with regard to the direct labour cost is the wage rate (monetary factor in EQ6). In this research the monetary factor is considered a constant, as hourly wage rates, wage premiums, insurance and taxes often do not change during the life cycle of a project. Even when numbers with regard to the monetary factor change, the numbers are assumed to be readily available and therefore this will not influence the accuracy of the labour cost estimate. This assumption is based on the literature provided by (Clark & Lorenzoni, 1996; Greves & Joumier, 2003).

Given that the monetary factor is considered a constant and up to date data is available regarding this constant, the accuracy of the direct labour cost estimate depends on the accuracy of the labour hours estimate only. In turn, the accuracy of the estimate is assumed to be influenced by project complexity. The next Sub section elaborates on the concept of project complexity.

A clear overview of how direct labour cost, indirect labour cost, labour hours and the monetary factor are related can be find in Appendix 5 of this thesis.

2.4 Project complexity

As was mentioned in the introduction Chapter of this thesis, capital projects are becoming more complex. A recent research performed by Accenture highlights this trend. The research was focused on challenges in effective delivery of capital projects and for the research, over 100 executives of energy and utility companies were interviewed. Over two-third of respondents indicated that today’s capital projects are highly complex. Moreover, they expect that the size and complexity of capital projects in the energy industry will continue to grow in the next five years leading to great challenges
for the management of these projects (Accenture, 2013). A study performed by Ernst and Young on the same topic also stresses this point (EY, 2014).

Project complexity is not limited to a specific industry or sector; “the construction process may be considered the most complex undertaking in any industry” (Baccarini, 1996, p. 1). Furthermore, Baccarini (1996) states that the construction industry has displayed great difficulty in coping with the increasing complexity of major construction projects (read: capital projects). He argues that project success is dependent on the complexity of a project and is having a direct effect on the overall project performance. In line with this, Williams (2005) argues that project complexity is a phenomenon which is often accused of being one of the causes for project failure in capital projects. Therefore an understanding of project complexity is of significant importance.

The concept of project complexity is not unambiguously, there are several concepts that deal with the same complexity of projects from different aspects (Dunović et al., 2014). Also Sinha et al (2001) and Rodney (2009) underline this:

* “There is no single concept of complexity that can adequately capture our intuitive notion of what the word ought to mean.”

* “At any point in time, even if one person were able to recognize complexity in a system, other players might have a very different understanding of what that complexity looks like, or might not perceive that complexity is present at all. Perceptions of both the dimensions of complexity and its severity vary between individual observers and over time.” (Remington & Turner, 2009)

Not surprisingly, there is a lack of consensus among researchers in relation to the definition of project complexity (Azim et al., 2010). Hence numerous definitions of project complexity can be found in literature. Therefore, when research is performed in the field of project complexity, one should indicate precisely what is meant by project complexity.

In order to understand how project complexity is imbedded in this research, first a basic understanding of the concept of complexity needs to be developed. A selection of the key concepts is discussed below. On a high aggregation level, two approaches on complexity can be recognized (Senge, 1994):

* Detail complexity: many components with a high degree of interrelatedness;
* Dynamic complexity. Dynamic complexity has the following characteristics: the potential to evolve over time (self-organization and co-evolution) and limited understanding and predictability.

Detail complexity is the most dominant element mentioned in literature on complexity (Hertogh & Westerveld, 2010). Dynamic complexity occurs when an action has one set of consequences locally and a different set of consequences in another part of the system; the same action has dramatically different effects in the short and the long run; or when obvious interventions produce non-obvious consequences. Following these two approaches, complex projects can be summarized as projects consisting of many components which interrelate with each other and change over time.

Baccarini (1996) argues that project complexity can be operationalized in terms of differentiation (the number of different elements) and interdependence (the degree of interrelatedness between these elements), thereby stating the same as Senge (1994). According to Baccarini, this definition “can be applied to any project dimension relevant to the project management process, such as organization, technology, environment, information, decision making and systems”. Therefore, when talking about project complexity it is important to state clearly the type of complexity being dealt with.
Williams (2002) argues that project complexity can be characterized by two dimensions; he defines uncertainty next to structural uncertainty. Structural uncertainty has two sub-dimensions, which were already described by Baccarini and Senge: the number of elements and interdependence of elements. This is visualized in Figure 11. Uncertainty refers to unexpected behavior, for which probabilities of the outcomes of that behavior cannot be easily quantified. Uncertainty should not be confused with risk; risk refers to uncertain events, however, the distribution of the outcomes is known.


* The structural complexity they describe is similar to Williams’ structural complexity;
* Technical complexity refers to design characteristics or technical aspects that are untried or unknown;
* Directional complex projects have unclear of undefined goals, where “progress is hindered by unknown political agendas, or where stakeholders disagree or misunderstand project goals. Ambiguity exists with regard to the issues of problem definition, understanding stakeholders’ needs and negotiating an agreed direction for the project.” (Zolin & Kropp, 2010);
* Temporal complexity exists when projects experience significant environmental change outside the direct influence or control of the project.

It can be concluded that complexity is a prominent theme in literature. Although there are several concepts of project complexity, all concepts ultimately come to two aspects: structural complexity and uncertainty. Table 6 presents an overview of distinctions made in literature describing these different types of complexity.

<table>
<thead>
<tr>
<th>Author</th>
<th>Description of types of complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senge (1994)</td>
<td>Complicated projects, Dynamic projects</td>
</tr>
<tr>
<td>Baccarini (1996)</td>
<td>Structural technical complexity, Structural organizational complexity</td>
</tr>
<tr>
<td>Williams (2002)</td>
<td>Structural complexity, Uncertainty</td>
</tr>
<tr>
<td>Teisman (2005)</td>
<td>Complicated, Composed</td>
</tr>
<tr>
<td>Whitty &amp; Maylor (2007)</td>
<td>Structural complexity, Independent dynamic, Interacting dynamic</td>
</tr>
<tr>
<td>Kurtz, Snowden</td>
<td>Complicated, Complex</td>
</tr>
</tbody>
</table>
It is observed that most literature regarding project complexity is rather theory-oriented, however, a trend can be observed of authors who further operationalize project complexity in order to make it usable in practice. Leading examples of project complexity frameworks are described below.

Vidal & Marle (2008) built a complexity framework, based on a broad literature review. The framework aims at being a reference for any project manager to identify and characterize some aspects of its project complexity in order to better understand its project complexity management. Vidal & Marle used Baccarini’s (1996) work, considering that project complexity is composed of technological and organizational complexity. Interestingly, the factors they identified within these two categories were unevenly distributed. In fact, 70% of the identified complexity factors (70 in total) are related to organizational complexity, while approximately 30% of the factors is related to technical complexity.

Maylor, Vidgen, & Carver (2008) developed a grounded model of managerial complexity. Their model is called MODeST, referring to the complexity categories Mission, Organization, Delivery, Stakeholders and Team. As the framework is focusing on managerial complexity, a technical component is lacking and therefore this framework is only partially useful in nowadays capital projects, which face increasing technical complexities (Hertogh & Westerveld, 2010).

Bosch-Rekveldt (2011) also developed a framework that support the characterizing and understanding of project complexity, based on theory and practice. In contrast to Vidal & Marle, this framework categorized project complexity into three categories: Technical, Organizational and External (TOE). The TOE framework consist of 50 elements and each of those elements is placed into one of the three categories (TOE). All elements together form the complexity footprint of the project so that the complexity of projects can be assessed. In Bosch-Rekveldt’s research, it is assumed that project complexity has a dynamic character, meaning that complexity will change over the life-cycle of the project. The projects in the scope of her research are projects in the process industry.

**2.4.1 The definition of project complexity**

Project management literature gives many definitions and concepts of project complexity and this Subsection provided you with a brief overview of the key concepts and definitions. However, it is important that the definition of project complexity in this thesis should be usable within the context this research takes place. More specifically, the definition of project complexity should allow the author of this thesis to (partially) quantify or assess it, as scoring of project complexity will be part of the survey (Chapter 4).

In this research project complexity is defined as the extent to which complexity factors are applicable to a capital project. The complexity of a project can be established by scoring pre-defined complexity factors (read: complexities). The more complexities considered to be relevant in a capital project, the more complex a capital project.

This definition builds on the research by Bosch-Rekveldt (2011), in which she argues that a project could be characterized by its complexity footprint. The complexity framework she has developed can assist in establishing such a footprint. However, it is not the objective of this research to assess the complexity of a project based on a list of complexities. In fact, we are interested in how project complexity in capital projects affect labour productivity of construction workers during the execution phase of capital projects in the construction industry. Therefore, we would like to create a framework
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of complexities that are relevant in this phase of a capital project. The complexity frameworks that are discussed in this Sub section provide a starting point for the building of such a framework.

2.4.2 Relationship between project complexity and labour cost estimating

The relevance of project complexity and labour cost estimating has already been mentioned in this thesis (Introduction Chapter and Paragraph 2.2.2). Based on the results of the literature reviews performed, it is hypothesized that the increasing complexity in capital projects affect labour productivity of construction workers during execution of capital projects in the construction industry, resulting in a difference between earned and burned hours (Sub section 1.1). Subsequently, this has a negative impact on the accuracy of labour cost estimates. The question is raised: what are the complexities that may have an impact on the accuracy of labour cost estimates? A list with complexities that are identified can be found in Appendix 2 of this thesis. The list is the result of a literature review on complexity factors and labour productivity factors. The steps taken in order to come to this list/framework are described in Appendix 1.

2.5 Sub-conclusion: answer to sub question 1 (S1) and sub question 2 (S2)

A literature review on project performance, labour productivity and project complexity in the context of this research have resulted in more understanding about these topics. A top down approach is used to relate these topics to labour cost estimating for capital projects in the construction industry. In this Sub section the first and second sub question of this research will be answered:

**S1**: How are project performance, labour productivity and project complexity positioned in this research?

**S2**: How can project complexity be operationalized and which complexities are assumed to have an impact on labour productivity?

Figure 12 shows how project complexity, labour productivity and project performance are positioned in this research. It can be seen that labour productivity is related to the accuracy of the labour hours estimate and project performance is related to the accuracy of the labour cost estimate. The negative sign on the left arrow indicates that it is assumed that there is a negative causal relationship between project complexity and labour productivity (A1). In other words, if the complexity the project is high(er), the accuracy of the labour hours estimate will be low(er). Furthermore, the positive sign on the right arrow indicates a positive causal relationship between labour productivity and project performance (A2). In other words, if the accuracy of the labour hours estimate is high(er), the accuracy of the labour cost estimate will be high(er).

How project complexity is related to project complexity factors, labour productivity to the accuracy of labour hour estimates and project performance to the accuracy of labour cost estimates is described below. First project performance will be discussed, then labour productivity and finally project complexity.
**Project performance**

Project performance tells us something about the results of project activity. Project performance becomes meaningful when the performance of a project is compared with project success criteria that are set and agreed upon before the start of a project. Simply put: if the project success criteria are met, one could speak of project success. The project success criteria, however, may vary between different stakeholders that are involved in the project. Hence there is often a bias with regard to what is meant by success. In project management literature, however, project success is often defined as a project being on time, within budget, and achieving the required quality or functionality (Level 1 of the pyramid). It is concluded that these success criteria are still accepted in practice.

Given the scope and objective of this research, the focus is on cost performance rather than quality and time performance. This is visualized in Figure 13, Level 2 (L2) of the pyramid. Project cost performance on L2 is measured by comparing actual construction costs determined at time of project completion and the estimated costs, defined as budgeted or forecasted construction costs determined at the time of the decision to build. This is called Cost Estimate Variance (CEV). Subsequently the scope is further narrowed to labour cost performance. At Level 3, labour cost performance is measured by comparing actual labour costs and estimated labour cost. In this thesis, when talking about project performance, there is specific attention for labour cost performance. To a certain extent you could argue that the accuracy of the labour cost estimate can be related to labour cost performance. In other words, if the labour cost estimate is met you could speak of good labour cost performance. This is only true under the assumption that labour cost are not deliberately overestimated in order to make sure there will be no overrun on labour cost.

![Figure 13: Project performance](image)

**Labour productivity**

In this thesis, labour productivity refers to the productivity of construction workers during the execution phase of capital projects in the construction industry. Labour productivity is a key intermediate concept that has the potential to influence project schedule, cost and quality. As the focus of this research is on the cost aspect, labour productivity will be discussed in the context of labour cost estimating. Cost estimators use labour productivity norms, together with the quantity of work required, to estimate the labour hours needed for performing the work. In practice a difference has been observed in estimated (earned) labour hours and actual labour hours (burned) and in this thesis this is called Delta Labour Hours (DLH). Figure 14 shows where DLH is positioned in this research (L5) and how this relates the labour cost of a project. The actual labour hours often exceed the estimated labour hours for capital projects in the construction industry. This implies that the productivity of the construction workers during the execution phase was lower than expected, the quantity of work...
required was underestimated or a combination of those. It is hypothesized that inaccurate labour hour estimates lead to inaccurate labour cost estimates.

Project complexity
Capital projects are becoming more complex according to researchers and practitioners. Project complexity is not limited to a specific industry or sector but capital projects in the construction industry are certainly an applicable field for project complexity. Project complexity is an ambiguous concept and therefore, when performing research in the field of project complexity, one should clearly state how project complexity is interpreted and defined.

In this research it is assumed that project complexity is a project characteristic and that the complexity of a project can be determined by its complexity footprint. This complexity footprint consist of complexity factors (complexities) and if a complexity is applicable to a certain project then this increases the complexity of the project. It is not the aim of this research to assess the complexity of capital projects in the construction industry, the focus is on how project complexities influence labour productivity instead. Therefore, based on a literature review, a complexity framework was developed which contains 51 complexities that are categorized in eight categories. The categories are Experience (6), Contracts (5), Financial (4), International (3), Team/organization (9), Technology (9), External (7) and Materials/Transportation (6). The numbers in parentheses refer to the number of complexities in the respective category. The complexity framework is presented on the next page and is the result of an iterative approach, consisting of the following three broadly defined steps:

- Identify project complexity factors and labour productivity factors related to project complexity;
- Reduce the number of complexities;
- Validate and categorize the complexities.

The steps taken (detailed) to achieve such a framework, as well as the literature that is related to the complexity framework, are described in Appendix 1 of this thesis. The framework forms the basis of the online survey- and interview design and will be used to investigate the relationship between project complexity and labour productivity.
<table>
<thead>
<tr>
<th>Complexity category</th>
<th>Complexities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat.1: Experience</td>
<td>C1 Experience construction workers</td>
</tr>
<tr>
<td></td>
<td>C2 Experience project manager</td>
</tr>
<tr>
<td></td>
<td>C3 Experience cost estimators</td>
</tr>
<tr>
<td></td>
<td>C4 Experience contractor</td>
</tr>
<tr>
<td></td>
<td>C5 Experience construction manager</td>
</tr>
<tr>
<td></td>
<td>C6 Shortage of experienced construction workers</td>
</tr>
<tr>
<td>Cat.2: Contracts</td>
<td>C7 Completeness of contract documents</td>
</tr>
<tr>
<td></td>
<td>C8 Contractual conflicts between contractor and consultant</td>
</tr>
<tr>
<td></td>
<td>C9 Number of main contract types</td>
</tr>
<tr>
<td></td>
<td>C10 Changes to the terms of ownership or terms of the ownership/JV/Production Sharing agreement</td>
</tr>
<tr>
<td></td>
<td>C11 Environment related regulation or lobbying activities by interest groups</td>
</tr>
<tr>
<td>Cat.3: Financial</td>
<td>C12 High amount of capital expenditures (CAPEX)</td>
</tr>
<tr>
<td></td>
<td>C13 Contractor financial difficulties</td>
</tr>
<tr>
<td></td>
<td>C14 Project owner financial difficulties</td>
</tr>
<tr>
<td></td>
<td>C15 Shortage of budget for labour as a result of strategic behavior within project organization</td>
</tr>
<tr>
<td>Cat.4: International</td>
<td>C16 Number of different nationalities</td>
</tr>
<tr>
<td></td>
<td>C17 Different time zones</td>
</tr>
<tr>
<td></td>
<td>C18 Communication problems due to cultural differences</td>
</tr>
<tr>
<td>Cat.5: Team/organization</td>
<td>C19 Level of construction worker participation in decision-making (low responsibility)</td>
</tr>
<tr>
<td></td>
<td>C20 Appropriate delegation of owner responsibilities to contractors</td>
</tr>
<tr>
<td></td>
<td>C21 Match between matrix structure of project and department structure of organization</td>
</tr>
<tr>
<td></td>
<td>C22 Frequent changes in laborers</td>
</tr>
<tr>
<td></td>
<td>C23 Presence of joint venture partner(s)</td>
</tr>
<tr>
<td></td>
<td>C24 Trust in project team</td>
</tr>
<tr>
<td></td>
<td>C25 Clear schedule drive</td>
</tr>
<tr>
<td></td>
<td>C26 Social activity opportunities construction workers</td>
</tr>
<tr>
<td></td>
<td>C27 (HSSE) awareness under construction workers</td>
</tr>
<tr>
<td></td>
<td>C28 Corruption</td>
</tr>
<tr>
<td>Cat.6: Technology</td>
<td>C29 Open to new technologies for construction activities by project stakeholders</td>
</tr>
<tr>
<td></td>
<td>C30 Adequate IT infrastructure and application in project</td>
</tr>
<tr>
<td></td>
<td>C31 Design errors made by designers (unclear and inadequate details in drawing)</td>
</tr>
<tr>
<td></td>
<td>C32 Technical dependencies between construction tasks</td>
</tr>
<tr>
<td></td>
<td>C33 Contradicting norms and standards</td>
</tr>
<tr>
<td></td>
<td>C34 Frequency of design changes due to technical reasons</td>
</tr>
<tr>
<td></td>
<td>C35 Adequacy of method of construction</td>
</tr>
<tr>
<td></td>
<td>C36 Strict technical quality requirement(s)</td>
</tr>
<tr>
<td></td>
<td>C37 Level of experience by project team with (new) technology</td>
</tr>
<tr>
<td>Cat.7: External</td>
<td>C38 Inclement weather (rain, wind, low temperature)</td>
</tr>
<tr>
<td></td>
<td>C39 Legal disputes between project participants</td>
</tr>
<tr>
<td></td>
<td>C40 Breach of an asset or site through physical interference</td>
</tr>
<tr>
<td></td>
<td>C41 Natural disasters</td>
</tr>
<tr>
<td></td>
<td>C42 Stability of project environment</td>
</tr>
<tr>
<td></td>
<td>C43 Dependencies of external stakeholders</td>
</tr>
<tr>
<td></td>
<td>C44 Poor ground conditions</td>
</tr>
<tr>
<td></td>
<td>C45 Government policy</td>
</tr>
<tr>
<td>Cat.8: Materials/Transportation</td>
<td>C46 Operational or ancillary infrastructure limitation in region</td>
</tr>
<tr>
<td></td>
<td>C47 Availability of tools and machinery</td>
</tr>
<tr>
<td></td>
<td>C48 Availability of power and/or water supply on site</td>
</tr>
<tr>
<td></td>
<td>C49 Adequate transportation materials on site</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>CS0</th>
<th>Access to materials within construction site</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS1</td>
<td>Availability of materials</td>
</tr>
</tbody>
</table>

*Table 7: Complexity framework*
3. Research design

This chapter describes how the research is conducted in order to answer the research questions and to meet the objective of this research, which is to deepen understanding and to provide qualitative insights for cost estimators on the relationship between project complexity and labour productivity of construction workers during the construction phase of capital projects in the construction industry.

3.1 Research methods and research design

This research uses two research methods in order to answer the research questions, which include a survey and interview. Before this, a literature review was performed in order to better understand the theoretical framework in which this research takes place. The knowledge gained on project complexity has resulted in a complexity framework, which is central to this research as it will be used to investigate the relationship between project complexity and labour productivity. The complexity framework is the basis of the online survey and interview design. Figure 15 illustrates how the interview methods relate to each other as well as the activities/outcomes of the research methods.

![Figure 15: Research methods in chronological order: online survey and interview](image)

3.1.1 Online survey

The target group for the online survey and interviews are experts in the construction industry, including project directors, project managers, construction managers and cost estimators. This way, multiple viewpoints are accounted for. In total 35 experts were invited to participate in this research. An email with a web link to the online survey was sent out to each interviewee typically two weeks before the interview date. Furthermore, this email functioned as a reminder to the appointment and provided the interviewee with an outline of the interview. The online survey can be found in Appendix 4 of this thesis.

At the start of the online survey, the respondent was asked to answer the survey questions based on their most recent completed project he/she was involved in. In this way it was avoided that the respondents would base their responses on successful projects only, which might have resulted in a biased dataset.

The online survey serves four main purposes:

1. To gather characteristics of the capital project the respondent was involved in;
2. To validate the assumptions that are made regarding the accuracy of labour cost estimates;
3. To gather impact scores of complexities on Cost Estimate Variance;
4. To obtain a top 3 ranking of the complexities that have an impact on Delta Labour Hours.

Regarding the first purpose, project characteristics were gathered in order to gaining an understanding of the project context. The survey questions included the following project characteristics: Country project (q5), Sector within construction industry (q6), Upstream/midstream/downstream\(^3\) (q7), Greenfield/brownfield\(^4\) (q8,q9), Planned duration (q10), Construction activities (q11-q14), Number of construction workers on peak (q15), CAPEX (q16), Total cost performance (q17), Labour cost performance (q18) and Labour cost/total cost ratio (q53).

The second purpose of the online survey is to validate the hypothesized relationship between project complexity, labour productivity and project performance (this is described in Sub section 2.5). Hence q54 and q27 were included in the survey. Both survey questions are closed questions and are measured with a five point Likert scale.

- q54: To what extent is Delta Labour Hours a result of decreasing labour productivity caused by project complexity?
- q27: To what extent do you think the Cost Estimate Variance with regard to labour\(^5\) was caused by Delta Labour Hours?

Regarding the third purpose, questions about the relationship between project complexity and cost performance of the capital project the respondent was involved in are included in the survey. In this way, it is possible to compare complexity scores on two different levels: CEV and DLH. For measuring the impact of complexities on Cost Estimate Variance, the definition CEV is discussed in Paragraph 2.2.1, a five point Likert scale which provides an ordinal measurement of the opinion of the interviewee is used. The scale used ranges from -2 to 2 and the values on this scale should be interpreted as follows, using complexity 'X' as an example (complexity X may refer to any complexity that is in the complexity framework).

- Score -2: Complexity X caused a **significant** difference in budgeted and actual cost, i.e. **more** cost overrun;
- Score -1: Complexity X caused a **small** difference in earned and burned hours, i.e. **slightly more** cost overrun;
- Score 0: Complexity X did not cause a difference in budgeted and actual cost;
- Score 1: Complexity X caused a **small** difference in budgeted and actual cost, i.e. **slightly less** cost overrun;
- Score 2: Complexity X caused a **significant** in budgeted and actual cost, i.e. **less** cost overrun.

As experts with different backgrounds will be interviewed, an extra answer option is added to the Likert scale. The interviewee will have the possibility to choose “do not know” if the question does not apply to his/her expertise or job responsibilities. This is done in order to prevent the interviewee to become frustrated if (s)he cannot answer the question and for this reason abandon the survey.

The response options for the CEV questions are presented in Table 8.

---

\(^3\) Upstream/midstream/downstream refer to three levels in the oil and gas industry and encompass the main segments in the supply chain.

\(^4\) The term greenfield is used where a project will occur on a site not previously used for that project. This term originally was used in construction to reference land that has never been used (e.g. green or new), where there was no need to demolish or rebuild any existing structures.” (Still, 2014)

\(^5\) “Cost Estimate Variance with regard to labour” refers to the accuracy of the labour cost estimate.
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**Likert scale**

<table>
<thead>
<tr>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greatly negative DLH</td>
<td>Slightly negative DLH</td>
<td>Neutral</td>
<td>Slightly positive DLH</td>
<td>Greatly positive DLH</td>
</tr>
</tbody>
</table>

为主题的探索。例如，项目特征CAPEX被分为资本支出低于500百万美元的项目和资本支出超过500百万美元的项目（表9）。将复杂性得分在不同细分之间进行比较是探索性研究方法的一部分，并可能提供更深入的洞察，了解项目复杂性和劳动力生产力之间的关系。

在理想情况下，每个细分包含足够的项目，以便进行比较。然而，最终项目集的组成将取决于受访者的可用性和他们最近完成的项目。

### Table 8: Five point Likert scale for scoring DLH

为了调查项目复杂性是否可以归因于特定的项目特征，细分被为每个项目特征制备。

### Project characteristics and subdivisions

在第四部分中，受访者被要求对每个复杂性类别进行排名。具体来说，对于每个复杂性类别，受访者将需要创建一个前3。

* Rank 1: Highest impact on Delta Labour Hours
* Rank 2: Second highest impact on Delta Labour Hours
* Rank 3: Third highest impact on Delta Labour Hours

随后，可以根据受访者的调查结果准备访谈。例如，如果受访者表示“频率的变更”是技术类别中对Delta Labour Hours影响最大的复杂性，访谈者可以更多时间讨论这个特定的复杂性。同样的，对于其他复杂性也适用。

在总结中，调查问题可以分为以下类别：

### Survey question category

<table>
<thead>
<tr>
<th>Survey question category</th>
<th>Survey question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background respondent</td>
<td>q1 – q4</td>
</tr>
<tr>
<td>Project characteristics</td>
<td>q5 – q18, q52, q53</td>
</tr>
<tr>
<td>Scoring impact complexities on CEV</td>
<td>q19 – q26</td>
</tr>
<tr>
<td>Ranking complexities on DLH</td>
<td>q28 - 51</td>
</tr>
</tbody>
</table>

Table 8: Five point Likert scale for scoring DLH

在理想情况下，每个细分包含足够的项目，以便进行比较。然而，最终项目集的组成将取决于受访者的可用性和他们最近完成的项目。

### Table 9: Project characteristics and subdivisions

在第四部分中，受访者被要求对每个复杂性类别进行排名。具体来说，对于每个复杂性类别，受访者将需要创建一个前3。

* Rank 1: Highest impact on Delta Labour Hours
* Rank 2: Second highest impact on Delta Labour Hours
* Rank 3: Third highest impact on Delta Labour Hours

随后，可以根据受访者的调查结果准备访谈。例如，如果受访者表示“频率的变更”是技术类别中对Delta Labour Hours影响最大的复杂性，访谈者可以更多时间讨论这个特定的复杂性。同样的，对于其他复杂性也适用。

在总结中，调查问题可以分为以下类别：
Validate the hypothesized relationship: q27, q54
Miscellaneous: q55, q56

Table 10: Survey question categories

3.1.2 Semi structured interviews

Semi structured interviews are well suited for the exploration of the perceptions and opinions of respondents and enable probing for more information and clarification of answers (Barriball & While, 1994). Qualitative insights, i.e. perceptions and opinions of the respondents about the relationship between project complexity and Delta Labour Hours, are the main source of information. Hence “semi structured interviews” is an appropriate research method for this research. The interview was designed in such a way that the respondents of the survey could elaborate on their survey responses during the interview. Thus, the interviews were primarily aimed at obtaining the ‘why’ behind the survey-responses.

Most interviews took place in face-to-face meetings lasting approximately 30 minutes to 90 minutes, but some interviews were conducted by telephone in case the interviewee was not in the Netherlands within the interview period that was scheduled for this research. Typically three days before the interview an email was sent to the interviewee with a slide deck containing the content of the interview. In the slide deck the complexity framework was included in which the top 3 ranking for every category was highlighted. The following questions were asked with regard to the complexities that were in the top 3 ranking of the respondent.

- Can you explain why the highlighted complexities contributed to Delta Labour Hours in your most recent, completed project you were involved in?
- Can you provide examples of how this complexity caused a delta in labour hours?

Next to these questions, the interviewees were asked to score the impact of the complexities on Delta Labour Hours. For this purpose, the five point Likert scale used for measuring the impact of the complexities on CEV was slightly adapted. The values on this new scale should be interpreted as follows, using complexity ‘X’ as an example.

- Score -2: Complexity X caused a significant difference in earned and burned hours, i.e. more hours were needed to complete construction activities than estimated by the cost estimator;
- Score -1: Complexity X caused a small difference in earned and burned hours, i.e. more hours were needed to complete construction activities than estimated by the cost estimator;
- Score 0: Complexity X did not cause a significant difference in earned and burned hours
- Score 1: Complexity X caused a small difference in earned and burned hours, i.e. less hours were needed to complete construction activities than estimated by the cost estimator;
- Score 2: Complexity X caused a significant difference in earned and burned hours, i.e. less hours were needed to complete construction activities than estimated by the cost estimator.

It is expected that the ‘survey-interview approach’ will generate valuable insights on the relationship between project complexity and Delta Labour Hours. Subsequently, the gathered insights could be translated into recommendations for cost estimators with the ultimate goal to improve the accuracy of labour hour estimates. This survey-interview approach is deliberately chosen over a ‘survey approach’ only. With a survey approach, one could spend more time on distributing the online survey and thus increase reach, allowing the author to collect a broader range of data which makes it easier to find statistically significant results than other data gathering methods. However, given the objective of this research, which is to provide qualitative insights on the relationship between project complexity and labour productivity, a survey-interview approach is preferred because this will produce richer data (Krosnick, 2010). Furthermore, there are numerous advantages of semi-structured interviews as defined by Browne (2011), the most important ones are mentioned below:
Respondents can answer questions in as much detail as they want;
* Flexibility – the interviewer can adjust questions and change direction as the interview is taking place.

Semi-structured interviews are usually conducted face-to-face. A disadvantage of doing face-to-face interviews is that it is very time consuming as the interviewer needs to be present at the location the interview is going to be held. However, conducting face-to-face interviews has advantages over conducting interviews by telephone, for example:

* An informal atmosphere can encourage the interviewee to be open and honest;
* More valid information about respondents’ attitudes, values and opinions can be obtained, particularly how people explain and contextualize these issues.

3.1.3 Processing the surveys and interviews

The online survey was created with Google Forms and this allowed the author of this thesis to easily share the survey with a web link. Furthermore, the responses were automatically saved in an online Excel sheet so only a few steps were needed to be taken in order to process the survey responses:

* Prepare the data for quantitative analysis, which include coding of the data and deleting incomplete or incorrect survey responses;
* Highlight the complexities in the complexity framework for each complexity category, based on the top 3 ranking of the respondent. Include this prepared framework in the slide deck that will be sent to the respondent prior to the interview.

After having conducted the interviews, the following steps were taken with the purpose to process the interview results in a consistent way.

* Make summary of the interview, using the interview audio recording and/or notes made during the interview;
* Send interview transcript to interviewee so the interviewee could make corrections if necessary or desired. Only perform this action if the interviewee requested for this or in case the interview has not been recorded;
* Process the impact-scores of the complexities on DLH in Excel. If applicable, make adjustments to the survey responses based on the interview;
* Identify key statements with regard to project complexity, labour productivity and project performance;
* Determine whether the interview results contribute to the main purpose of conducting the interviews, which is to gather qualitative insights on the relationship between project complexity and labour productivity as defined in this research. If not, consider to contact the interviewee.
RESULTS
4 Results

Now that the theoretical framework is set and the research design is discussed, this Chapter will discuss the survey results and interview results. In order to present the results in a structured way, this Chapter is divided into 4 Sub sections.

- Sub section 4.1 introduces the respondents according to their role and experience and subsequently the survey results will be presented, which includes the characteristics of the projects that are in the dataset.
- Sub section 4.2 presents the results with regard to the hypothesized causal relationship between project complexity, labour productivity and project performance.
- Sub section 4.3 presents the scores of the complexities on Delta Labour Hours as well as the qualitative insights of the respondents on the relationship between labour productivity and project complexity.
- Sub section 4.4 discusses the impact scores for projects that share the same project characteristics and the impact scores on Cost Estimate Variance;
- The last Sub section reflects on the results of the online survey and interviews, thereby focusing on how the results should be interpreted by cost estimators to improve their tender labour cost estimates.

A total of twenty experts filled in the online survey and all of them have been interviewed. The results are thus based on twenty projects, unless states otherwise. Given the sample size of 20 project (N=20), the results cannot be generalized to population, i.e. all capital projects in the construction industry. For ease of reference, the projects in the dataset are labeled alphabetically, ranging from Project A to Project T. As the respondents (or: interviewees) are linked to these projects, the respondents are also labeled alphabetically from A to T.

4.1 Projects in the dataset

4.1.1 Respondents related to the projects

The respondents related to the projects in the dataset are active in various sectors within the construction industry and fulfill different roles (nine project directors, six project managers, one construction manager and four cost estimators). In Figure 16 and Figure 17 the respondents are categorized according to their years of job experience in the construction industry and sector within the construction industry. It can be derived from Figure 16 that 70% of the interviewees has over eleven years’ of project experience. Furthermore, the majority of the people who participated in this research were active in the oil and gas sector on their most recent completed project. Regarding the oil and gas projects that are in the dataset, six projects can be categorized as upstream projects, two as downstream projects and four as midstream projects. The response rate of people working in other sectors was significantly lower.
4.1.2 CAPEX and project duration

In this Sub section the distribution of the project characteristics will be visualized, starting with CAPEX and project duration. Some projects in the dataset do not meet the criteria that are set. More specifically, the CAPEX of project K, N and O is below the threshold of 50 million USD and the lifecycle for these projects are all below the threshold of two years. Furthermore, project A meets the CAPEX criterion but the duration of this project is just under two years. Hence, when strictly applying the criteria that are set, project K, N, O and A should be excluded from the dataset. However, literature did not provide a minimum cost level for a capital project and also the differences in CAPEX for the projects in the dataset are very large; there are projects with CAPEX exceeding one billion US Dollar or two billion US Dollar and projects with a CAPEX of 40 million US Dollar or 200 million US Dollar. Therefore it would make no sense to exclude the projects that just not meet the threshold by 30 million USD or less. Figure 18 visualizes the distribution of the projects’ CAPEX and project duration.

4.1.3 Overall cost performance and labour cost performance

Other project characteristics gathered by means of the online survey are total cost performance and labour cost performance, visualized in Figure 19 and Figure 20 respectively. It can be derived from the survey results that eleven projects (55%) experienced an overrun on the total cost estimate and this is in line with the trend as discussed in the introduction Chapter of this thesis. Six of these projects overran their estimate with more than 20 percent, while in five projects the overrun was less than 20 percent. The projects with a cost overrun of more than twenty percent occur in the projects with CAPEX exceeding one billion US Dollar. Successful projects

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6 Both characteristics are included in the definition of a capital project as discussed in Chapter 2: a capital project is defined as a project with a lifecycle of at least two years and CAPEX of at least 50 million USD.
in terms of meeting cost estimates are included in the dataset; six of the projects were delivered on budget.

![Cost estimate (labour)](image1)

**Figure 20:** Distribution dataset with regard to labour cost estimate (left)

**Figure 21:** Distribution dataset with regard to the labour cost estimate (right)

With regard to the labour cost performance of the projects in the dataset, eight out of twenty projects (35%) experienced an overrun on labour cost. However, this percentage might be higher than 35% since seven respondents could not indicate if there was a labour cost overrun or did not want to share information about this. From the five projects that were delivered without exceeding the labour cost estimate, there are three projects where the labour cost and realization were about the same. For the other two projects the realized labour cost were up to 20% less than the estimated cost.

### 4.1.4 Labour intensity and geography

Capital projects in the construction industry are frequently mentioned as being labour intensive and according to project management literature labour cost may comprise 20 to 50% of the overall project cost (Hickson & Ellis, 2014; Soham & Rajiv, 2013). The projects in the dataset show a quite different picture. As can be seen in Figure 21, the narrow majority of the projects has a labour cost/total cost ratio of less than 20%. For these projects, labour cost are still a significant part of the total cost but despite this, variations in labour cost probably do not have that much effect on the total cost of the project. The impact of labour cost variations on the total cost for projects that are in the 20-40% range is probably higher. The ratio does not define anything about the labour intensity as the ratio may be influenced by the cost for labour. In other words, the ratio would be higher in high labour cost countries compared to low labour cost countries. Also indirect labour cost play a role in this. Therefore, the labour intensity of the project is established by looking at the amount of labour hours and the amount of construction workers working on peak activity of the project. As can be seen from the Figures below, the differences between the projects are large. However, this is not unexpected given the wide distribution regarding the capital expenditures of the projects that are in the dataset.

![Construction workers on peak activity](image2)

**Figure 22:** Construction workers on peak activity (left)

**Figure 23:** Labour hours (right)
Different geographical areas are covered such as Europe, Asia and Africa and South America, although the greater part of the projects was performed in Europe and Asia. Within Europe, Dutch projects are overrepresented as seven projects were performed in the Netherlands. The detailed overview on the next page sums up all projects and the related project characteristics. All projects together form a mixed group of projects, however, the projects also share some characteristics such as their size in terms of CAPEX, sector and other characteristics that are mentioned in this Sub section. Analysis of the complexity scores is necessary to determine whether the complexities in the framework are related to certain project characteristics.

Figure 24: Projects by geography
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<table>
<thead>
<tr>
<th>Person/Project</th>
<th>Country</th>
<th>CAPEX</th>
<th>Total cost overrun (CE= Cost Estimate and RC= Realized Cost)</th>
<th>Labour cost overrun</th>
<th>% Labour cost</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Netherlands</td>
<td>60-80 million USD</td>
<td>CE and RE about similar</td>
<td>Labour CE and realization were about similar</td>
<td>10-20%</td>
<td>Chemicals</td>
</tr>
<tr>
<td>B</td>
<td>Qatar</td>
<td>&gt; 1 billion USD</td>
<td>CE was exceeded by up to 10%</td>
<td>Labour cost estimate was exceeded by up to 10%</td>
<td>30-40%</td>
<td>Oil and Gas upstream EPC</td>
</tr>
<tr>
<td>C</td>
<td>Netherlands</td>
<td>100-500 million USD</td>
<td>CE and RE about similar</td>
<td>Realized labour costs were between 11 to 20% less than the estimated costs</td>
<td>10-20%</td>
<td>Wind Energy EPC</td>
</tr>
<tr>
<td>D</td>
<td>Netherlands</td>
<td>100-500 million USD</td>
<td>Do not know</td>
<td>Do not know</td>
<td>30-40%</td>
<td>Oil and Gas downstream EPC</td>
</tr>
<tr>
<td>E</td>
<td>Azerbeidjan</td>
<td>&gt; 1 billion USD</td>
<td>CE was exceeded by up to 10%</td>
<td>Do not know</td>
<td>Don’t know</td>
<td>Home building / EPC</td>
</tr>
<tr>
<td>F</td>
<td>South Africa</td>
<td>100-500 million USD</td>
<td>RC were between 11 to 20% less than CE</td>
<td>Do not know</td>
<td>Don’t know</td>
<td>Food Engineering</td>
</tr>
<tr>
<td>G</td>
<td>Ireland</td>
<td>&gt; 1 billion USD</td>
<td>CE was exceeded by more than 20%</td>
<td>Labour cost estimate was exceeded by more than 20%</td>
<td>30-40%</td>
<td>Infrastructure EPC</td>
</tr>
<tr>
<td>H</td>
<td>Peru</td>
<td>100-500 million USD</td>
<td>CE was exceeded by more than 20%</td>
<td>Labour cost estimate and realization were about similar</td>
<td>10-20%</td>
<td>Oil and Gas midstream EPC</td>
</tr>
<tr>
<td>I</td>
<td>Netherlands</td>
<td>100-500 million USD</td>
<td>RC were up to 10% less than the CE</td>
<td>Labour cost estimate was exceeded by more than 20%</td>
<td>20-30%</td>
<td>Oil and Gas midstream EPC</td>
</tr>
<tr>
<td>J</td>
<td>Germany</td>
<td>&gt; 1 billion USD</td>
<td>CE was exceeded by more than 20%</td>
<td>Labour cost estimate was exceeded by more than 20%</td>
<td>10-20%</td>
<td>Chemicals</td>
</tr>
<tr>
<td>K</td>
<td>Netherlands</td>
<td>Less than 20 million USD</td>
<td>CE was exceeded by up to 10%</td>
<td>Labour cost estimate was exceeded by more than 20%</td>
<td>10-20%</td>
<td>Oil and Gas midstream EPC</td>
</tr>
<tr>
<td>L</td>
<td>Singapore</td>
<td>&gt; 1 billion USD</td>
<td>RC were up to 10% less than the estimated costs</td>
<td>Labour cost estimate was exceeded by up to 10%</td>
<td>30-40%</td>
<td>Oil and Gas midstream EPC</td>
</tr>
<tr>
<td>M</td>
<td>France/ Korea / Australia</td>
<td>&gt; 1 billion USD</td>
<td>CE was exceeded by more than 20%</td>
<td>Labour cost estimate was exceeded by more than 20%</td>
<td>30-40%</td>
<td>Oil and Gas midstream EPC</td>
</tr>
<tr>
<td>N</td>
<td>Netherlands</td>
<td>Less than 20 million USD</td>
<td>CE was exceeded by up to 10%</td>
<td>Labour cost estimate was exceeded by up to 10%</td>
<td>10-20%</td>
<td>Oil and Gas upstream EPC</td>
</tr>
<tr>
<td>O</td>
<td>Netherlands</td>
<td>Less than 20 million USD</td>
<td>RC were between 11 to 20% less than the CE</td>
<td>Realized labour costs were up to 10% less than the estimated costs</td>
<td>10-20%</td>
<td>Chemicals</td>
</tr>
<tr>
<td>P</td>
<td>Oman</td>
<td>&gt; 1 billion USD</td>
<td>Do not know</td>
<td>Do not know</td>
<td>10-20%</td>
<td>Oil and Gas upstream EPC</td>
</tr>
<tr>
<td>Q</td>
<td>United Arab Emirates</td>
<td>500 million - 1 billion USD</td>
<td>CE was exceeded by up to 10%</td>
<td>Labour cost estimate was exceeded by more than 20%</td>
<td>10-20%</td>
<td>Home building EPC</td>
</tr>
<tr>
<td>R</td>
<td>Global</td>
<td>&gt; 1 billion USD</td>
<td>Do not know or do not want to share</td>
<td>Do not know</td>
<td>30-40%</td>
<td>Oil and Gas upstream EPC</td>
</tr>
<tr>
<td>S</td>
<td>Brunei</td>
<td>&gt; 1 billion USD</td>
<td>CE was exceeded by more than 20%</td>
<td>Labour cost estimate and realization were about similar</td>
<td>10-20%</td>
<td>Oil and Gas upstream EPC</td>
</tr>
<tr>
<td>T</td>
<td>Asia</td>
<td>&gt; 1 billion USD</td>
<td>CE was exceeded by more than 20%</td>
<td>Do not know</td>
<td>20-30%</td>
<td>Oil and Gas upstream EPC</td>
</tr>
</tbody>
</table>

Table 11: Project characteristics
4.2 Causal model project complexity, labour productivity and project performance

This Subsection encompasses the discussion of the causal model regarding the relationship between project complexity, labour productivity and project performance (Figure 25). The causal model consists of two causal relationships of which the assumptions A1 and A2 (see introduction Chapter) are both validated by the experts who participated in this research, thereby taking in mind their most recently completed project (s)he was involved in. The individual outcomes of the validation provide valuable information on how the respondents’ scoring efforts, i.e. their impact scores of project complexities on DLH, should be interpreted. For example, if a respondent indicates that project complexity does not have any effect on Delta Labour Hours while at the same time consistently providing high scores on the complexities, then this should definitely be taken into account and discussed in more detail during the interview. In that case, clarification of the respondent would help the interviewer to place the scoring results of the respondent better into perspective.

The first causal relationship is related to the main research question of this thesis, while the second causal relationship is related to Sub question 4. Based on the survey results, Sub question 4 can be answered.

**S4:** To what extent does a difference in labour hours contribute to a variance in labour cost?

### 4.2.1 First causal relationship: project complexity and Delta Labour Hours

With regard to the first causal relationship, sixteen respondents (80%) indicated that the accuracy of the labour hours estimate was much or very much influenced by the complexity of the project. In other words, a majority of the 20 respondents confirm that project complexity played a role with regard to Delta Labour Hours on their last project (Figure 26). There seems to be consensus about the existence of this relationship as well as the sign of the correlation coefficient between project complexity and Delta Labour Hours. The more complex the project the lower the accuracy of the labour hours estimate. This means that there is a negative causal relationship between project complexity and Delta Labour Hours.

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**Figure 25:** Causal model project complexity, labour productivity and project performance

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**Figure 26:** Distribution of 20 survey responses regarding the relationship between project complexity and Delta Labour Hours (first causal relationship, N=20)
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Although the survey results indicate that this relationship is certainly not irrelevant for most projects that are in the dataset, it can be derived from Figure 26 that four respondents (20%) do not share this thought. They indicated that the impact of project complexity on Delta Labour Hours was very little (project F), little (project I) or not influenced (project A and S) by the complexity of the project. The respondents gave various reasons for this, for example, the respondent of Project A mentioned that the project was a small project in terms of CAPEX (<100 million USD) so the complexity of the project was “manageable”. Furthermore, the respondent argued that that the project owner and contractor have been working together for more than 30 years on many different projects and as a result of this, the project was planned properly as they knew very well what to expect from each other. More specifically, the scope of the project was well defined and contractually documented, and the right people were assigned for roles in the project team. According to the respondent, the impact of project complexity was therefore limited or accounted for so there was no relation between project complexity and DLH.

Respondent F argued that for 300 million USD CAPEX projects, together with the project characteristics of project F, it is relatively easy to estimate the labour cost within a 10% range, however, given that a lump sum contract was used, the respondent did not know whether there was an underrun or overrun on labour hours and if project complexity had an impact on this. Despite this, the respondent believes that the impact of project complexity on DLH was very little because the project was quite straightforward. The labour cost estimate was set up by using data from similar projects, which was available within the company, and by making adjustments to account for differences between the new project and completed project. An advantage of using this approach is that estimates can be developed quickly and at minimum cost. This in contrast to a bottom up approach, which is very time consuming and requires detailed information about construction activities and labour hours that are needed to perform the construction activities. This information is not always available for cost estimators, making the analogy method the preferred approach for estimating labour hours and labour cost. As most experience is within the company, the company is not fully dependent on the expertise of contractors when starting a new project. This means that organizational complexity is significantly lower than other sectors like oil and gas, where the dependence on contractors is usually higher. On the other hand, the respondent mentioned that for projects with capital expenditures exceeding 500 million USD it becomes more difficult to manage the complexity of the project due to the increasing number of interfaces.

Respondent I indicated that project complexity had little impact on Delta Labour Hours because overruns on labour hours were compensated by reducing the scope of the project. This subsequently resulted in less labour hours for construction activities so overall there was not a big delta on labour hours, while there was for individual construction activities. Therefore project complexity certainly seemed to play a role with regard to DLH.

In summary, A1 is validated as the majority of the respondents indicated that project complexity in some way caused a delta in labour hours. Hence the following questions are raised: which complexities did have an impact on the labour hours estimate and is it possible to relate the complexities to specific projects characteristics? Analysis of the impact scores for both the whole dataset as well as the “individual” projects will provide answers to these questions and are discussed in Sub section 4.3.
4.2.2 Second causal relationship: Delta Labour Hours and Accuracy labour cost estimate

![Causal model project complexity, labour productivity and project performance](image)

With regard to the survey results on the second causal relationship, fourteen respondents (70%) indicated that the accuracy of the labour cost estimate was much or very much influenced by Delta Labour Hours and this is visualized in Figure 28. In other words, it has been confirmed by a majority of the respondents that labour productivity of construction workers potentially had a significant impact on the labour cost performance of capital projects. However, the arguments by respondent H are in line with this statement as the respondent indicated that the massive disparity between the burned and earned man hours was predominantly driven by the fact that the cost estimator at the very beginning got it wrong as he worked out the estimate on the basis of Spanish rates. As a result more man hours were needed in the field than was estimated for and this had a significant impact on the accuracy of the labour cost estimate. The impact of complexities on labour productivity during the construction phase are negligible compared to the impact of using the wrong base-rates, at least for that particular project.

![Impact DLH on Accuracy labour cost estimate](image)

It can be derived from this figure that three respondents (15%) indicated that the impact of DLH on the accuracy of the labour cost estimate was very little (project F) or neutral (I, S). Respondent F stated that given the lump sum contract he did not have any information on labour hour and/or labour cost performance to base his response upon. However, the respondent indicated that the accuracy of the labour cost estimate was probably very little influenced by DLH because there was only a slight overrun on labour hours. In addition, construction workers from low-cost labour countries were used and so the impact on the labour cost could not have been high. The same applies to project S. Although the respondents of project M, N and O could indicate how the projects performed in relation to the labour cost estimate, they could not indicate how DLH played a role in this. However, respondent M pointed out that the indirect labour cost are at least as important as the direct labour cost when it comes to its contribution to the total labour cost. This is because every extra hour, day or week a construction worker needs to finish construction activities, there should be staff, machinery and housing available for the construction workers. The latter is often applicable, but not limited to, projects performed in remote areas. According to M, it is therefore difficult to relate the impact of DLH on labour cost...
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performance. Only when there is agreement on which cost can be related to DLH, one could say something about this relationship.

### 4.3 Complexity impact scores on Delta Labour Hours

A majority of the respondents indicated that the accuracy of the labour hours estimate was much or very much influenced by the complexity of the project. In this Sub section we relate this finding with the complexity framework that has been drawn up for this research. In other words, what are the relevant complexities for the projects in the dataset when it comes to DLH? In order to answer this question, this Sub section first visualizes how the responses on the five point Likert scale are distributed as this will give a first indication of whether the complexities are relevant for the projects in the dataset. Also, the average impact scores of the complexities are presented and substantiated with comments of the respondents;

#### 4.3.1 Distribution of survey responses

With regard to DLH, 59% of the total responses given by the respondents (53%+6%) are labeled as “not applicable” or “0” (Figure 29). In other words, in 59% of the cases the respondents indicated that the complexities did not have an impact on DLH. This percentage is fairly high and was not expected, since a majority of the respondents indicated earlier that project complexity played an important role with regard to DLH. On the other hand, in 41% of the cases the respondents indicated that the complexities did have an impact on DLH (score 1, -1, 2, 2).

Figure 29: Distribution of responses for all complexities on DLH (N=15)
Figure 30: Average impact scores per complexity category (N=15)

Figure 30 shows the average scores per complexity category. It can be derived from the figure that:

- All average scores are negative. This is in line with the first causal relationship of the causal model (A1), which illustrates that complexities are often perceived as something having a negative impact on DLH;
- Team/Organization and Materials/Transportation score fairly low compared to categories International, Contracts and Experience, although the differences between the complexity categories are relatively small.

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7 The average score should be interpreted on a scale from -2 to 2 as is explained in Paragraph 2.3.2. The author is aware of the fact that an average score of zero for a complexity does not necessarily mean that the complexity does not have an impact on DLH since scores of -2 and 2 would average out around zero. The complexities with a low average score and high variance are C5, C7 and C27, but the complexity category scores were not significantly influenced by this.
An overview of the complexities and corresponding average impact scores is presented in Table 12. Each of the subsequent paragraphs will provide examples on how the complexities that are listed in this Table are related to DLH.

<table>
<thead>
<tr>
<th>Complexity category</th>
<th>Complexities</th>
<th>Average score (DLH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat.1: Experience</td>
<td>C1 Experience construction workers</td>
<td>-0.9</td>
</tr>
<tr>
<td></td>
<td>C2 Experience project manager</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C3 Experience cost estimators</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C4 Experience contractor</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C5 Experience construction manager</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C6 Shortage of experienced construction workers</td>
<td>-0.8</td>
</tr>
<tr>
<td>Cat.2: Contracts</td>
<td>C7 Completeness of contract documents</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C8 Contractual conflicts between contractor and consultant</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>C9 Number of main contract types</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>C10 Changes to the terms of ownership or terms of the ownership/JV/ Production Sharing agreement</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C11 Environment related regulation or lobbying activities by interest groups</td>
<td>-0.4</td>
</tr>
<tr>
<td>Cat.3: Financial</td>
<td>C12 High amount of capital expenditures (CAPEX)</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C13 Contractor financial difficulties</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C14 Project owner financial difficulties</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C15 Shortage of budget for labour as a result of strategic behavior within project organization</td>
<td>-0.6</td>
</tr>
<tr>
<td>Cat.4: International</td>
<td>C16 Number of different nationalities</td>
<td>-1.1</td>
</tr>
<tr>
<td></td>
<td>C17 Different time zones</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C18 Communication problems due to cultural differences</td>
<td>-1.1</td>
</tr>
<tr>
<td>Cat.5: Team/organization</td>
<td>C19 Level of construction worker participation in decision-making (low responsibility)</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C20 Appropriate delegation of owner responsibilities to contractors</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C21 Match between matrix structure of project and department structure of organization</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C22 Frequent changes in laborers</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td>C23 Presence of joint venture partner(s)</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td>C24 Trust in project team</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td>C25 Clear schedule drive</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C26 Social activity opportunities construction workers</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C27 (HSSE) awareness under construction workers</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>C28 Corruption</td>
<td>0</td>
</tr>
<tr>
<td>Cat.6: Technology</td>
<td>C29 Open to new technologies for construction activities by project stakeholders</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C30 Adequate IT infrastructure and application in project</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>C31 Design errors made by designers (unclear and inadequate details in drawing)</td>
<td>-1.0</td>
</tr>
<tr>
<td></td>
<td>C32 Technical dependencies between construction tasks</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C33 Contradicting norms and standards</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>C34 Frequency of design changes due to technical reasons</td>
<td>-1.3</td>
</tr>
<tr>
<td></td>
<td>C35 Adequacy of method of construction</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>C36 Strict technical quality requirement(s)</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>C37 Level of experience by project team with (new) technology</td>
<td>-0.4</td>
</tr>
<tr>
<td>Cat.7: External</td>
<td>C38 Inclement weather (rain, wind, low temperature)</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>C39 Legal disputes between project participants</td>
<td>-0.9</td>
</tr>
<tr>
<td></td>
<td>C40 Breach of an asset or site through physical interference</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C41 Natural disasters</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C42 Stability of project environment</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>C43 Dependencies of external stakeholders</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td>C44 Poor ground conditions</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C45 Government policy</td>
<td>-0.8</td>
</tr>
<tr>
<td>Cat.8: Materials/Transport</td>
<td>C46 Operational or ancillary infrastructure limitation in region</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>C47 Availability of tools and machinery</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C48 Availability of power and/or water supply on site</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C49 Adequate transportation materials on site</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C50 Access to materials within construction site</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C51 Availability of materials</td>
<td>-0.8</td>
</tr>
</tbody>
</table>

Table 12: Complexity framework with impact scores
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The scores are also provided at the beginning of the subsequent paragraphs. If a complexity is not highlighted in blue, this means that the respondents could not provide specific examples of how that complexity related to DLH. Hence only the complexities that are highlighted in blue will be discussed in the corresponding paragraph.

4.3.1.1 Complexity category 1: Experience

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 Experience construction workers</td>
<td>-0.9</td>
</tr>
<tr>
<td>C2 Experience project manager</td>
<td>-0.5</td>
</tr>
<tr>
<td>C3 Experience cost estimators</td>
<td>-0.7</td>
</tr>
<tr>
<td>C4 Experience contractor</td>
<td>-0.7</td>
</tr>
<tr>
<td>C5 Experience construction manager</td>
<td>-0.4</td>
</tr>
<tr>
<td>C6 Shortage of experienced construction workers</td>
<td>-0.8</td>
</tr>
</tbody>
</table>

Rounded average of category: (-0.7)

Experience is ranked second based on the average score and within this category the complexity Shortage of experienced construction workers contributes most to DLH (-0.8). Also the complexity Experience of construction workers has proven to be important. This is probably because a lot of projects in the database were delivered just before the global economic recession. This is underpinned by:

* Project B: “The project was delivered during the 2007, 2008, 2009 period. At this time there was a real construction boom in the Middle East so the availability of experienced workers was a real challenge. As a result, the overall labour productivity during the construction phase of the project was lower than expected.”
* Project L: “There was a great shortage of skilled labour and because of this we made pre-commitments with contractors in order to make sure that sufficient skilled labour was available at the beginning of the construction phase. However, at that time the project site was only partially accessible for construction workers and as a result most construction workers could not perform their work. On paper this resulted in an overrun on the labour hours estimate.”
* Project J: The respondent argued that this complexity had by far the highest impact on DLH. There was a great shortage of skilled labour due to the tight labour market. The project was performed just before the global financial crisis and in this time there was a huge demand for construction workers. Because there was a great shortage of skilled labour, the contractor was forced to hire less experienced construction workers. The productivity of these semi-skilled construction workers was significantly lower than the productivity of the construction workers which they had actually wanted to hire. This resulted in a disparity between burned and earned hours because cost estimators worked out their estimates on labour productivity calculated for more experienced construction workers.

The complexities C1: Experience of construction workers and C6: Shortage of experienced construction workers seem to be correlated. However, these complexities were separately incorporated in the complexity framework because it was assumed that a shortage of experienced construction workers would not always affect the overall experience of the construction workers on site, for example when the project owner is willing to pay for an experienced workforce. Furthermore, a shortage of experienced construction workers on the labour market was expected to have a lower impact for smaller projects (<200 construction workers on peak) compared to larger projects (>1000 construction workers on peak). As the impact of C1 and C6 could be different they were included separately in the complexity framework, however, it appeared from the interviews that these complexities are more likely to be interrelated rather than not interrelated: they measure the same. Apart from this, the key message here is that for non-European projects the experience of construction workers is often overestimated by cost estimators, particularly when local contractors are involved.
The complexity Experience of the contractor scored high, but not many respondents elaborated on this during the interview. This is probably because most interviewees worked for a contractor. From a project owner perspective it was argued that:

- Respondent B: “the experience of the contractor is important but it doesn’t necessarily guarantee success. For example, you might think you’ve tendered or awarded a very experienced contractor, but the team on the ground, is the team on the ground representing the company and vice versa. It might be a very inexperienced contractor but they have a great team working for you and it can be fine.”
- Project E: “The experience of the contractor is of high importance, especially when the contractor knows the local content requirements regarding the availability and experience of construction workers and local law. Also the ability of the contractors to select the right subcontractors is part of the experience of the contractor.”

Important to note is that project owners, amongst other factors, select a contractor based on their experience and ability to do the job. So if it turns out at the end of the project that under the applied form of contract the main contractor did have an impact on DLH, as some respondents indicated, this confirms that it is difficult for cost estimators to assess the experience of the contractor in the early stages of the project and translate this into the labour hours estimate. In addition, the complexity Experience of the contractor involves a lot of aspects that could influence DLH, which makes it a rather broad term of which the impact on DLH is difficult to determine. Important aspects that may have an impact on the accuracy of the labour hours estimate which could be verified by a cost estimator in the early stages of a project, relate to the contractors’ experience on local content factors: local law and insight in the availability and experience of local construction workers.

According to the average scores, the Experience of the construction manager is not a decisive factor with respect to Delta Labour Hours. This was unexpected because the construction manager is responsible for managing the construction workers on site. Poor management and unclear communication (Paragraph 4.3.1.4), could therefore lead to poor productivity of the construction workers. Only respondent B shared this thought:

- Project B: “The most important complexity within the experience category is the experience of the construction manager. Although the project manager is the supervisor of the construction manager, the construction manager has more detailed knowledge of the activities that are performed on site thus making the construction manager more important when it comes to labour productivity of construction workers. Labour productivity of construction workers may be affected by construction managers providing instructions to the construction workers on site.”

A more general comment was made by Respondent R (from a project owner perspective), who argued that executives of both the project owner and contractor(s) must get leeway to fill key positions with the right people, competencies and skills. Project owners usually get this done, while contractors struggle to fill key positions with the right people due to seniority or hierarchy in the contractors’ organization. The project team of the project owner should anticipate on this by filling the project team with people who have the skills to manage this inefficiency. For Project R, however, this was a rather difficult task as the project is executed on the interface of the offshore, process and marine industry. Many industries and cultures were brought together and this made it difficult to align the experiences of the project team members.
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4.3.1.2 Complexity category 2: Contracts

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Rounded average of category: (-0.7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- C7 Completeness of contract documents (-0.7)</td>
<td></td>
</tr>
<tr>
<td>- C8 Contractual conflicts between contractor and consultant (-1)</td>
<td></td>
</tr>
<tr>
<td>- C9 Number of main contract types (-0.6)</td>
<td></td>
</tr>
<tr>
<td>- C10 Changes to the terms of ownership or terms of the ownership/JV/Production Sharing agreement (-0.5)</td>
<td></td>
</tr>
<tr>
<td>- C11 Environment related regulation or lobbying activities by interest groups (-0.4)</td>
<td></td>
</tr>
</tbody>
</table>

The average score of the complexity category Contracts is -0.7 and is placed among the three highest scoring complexity categories. Due to the high variance of the responses for complexity C7, the total impact of this category on DLH is actually higher. Only two respondents indicated that this complexity did not have an impact on DLH. However, the respondents argued that the direct impact of the Completeness of contract documents on DLH is rather difficult to measure. Though impact scores other than 0 were given to indicate that complete contract documents at the time of awarding are important because this will:

- limit the effect of added/changed scope on project (labour) budget and schedule (from a contractor point of view). Added or changed scope result in rework or additional hours;
- limit the effect of hidden site conditions on the project (labour) budget and schedule. Additional site preparations may be necessary so the construction start is delayed;
- limit claims from contractors for extension of time and additional compensation. This will not necessarily impact DLH although claims definitely increases the total cost for the project.

Hence, complete contract documents enable the cost estimator to estimate the labour hours on site more accurately. Respondents A and N mentioned during the interview that the contract documents at the time of awarding could be regarded as “complete” and argued that trust played an important role in this. In both projects, the project owner and contractor knew what to expect from each other as they already worked together on several projects before and this resulted in clear documentation of the scope, tasks and responsibilities. The majority of the respondents, however, indicated that contract documents were incomplete and this had several reasons:

- starting contract design efforts too late;
- short bidding period because due to eagerness of the project owner to start with the construction phase: not all drawings and specifications could be verified;
- lack of trust between project participants.

Another high scoring complexity is C8: Contractual conflicts between contractor and consultant. According to the respondents, this complexity appeared to be highly correlated with complexity C39: Legal disputes between project participants. Both complexities indicate that there are conflicts which are contractual in nature. Despite the high average impact scores for these complexities, it appeared that both complexities, if applicable to the project, are more likely to have an impact on the total cost of a project or the project completion date rather than DLH. For example, the project could be delayed as a result of conflicts but if no hours are burned then this does not impact DLH. The delays involve financial cost and also legal disputes add to the total cost of the project, while DLH may not be impacted. The impact scores for both complexities as presented in this Sub section therefore do not...

According to the respondents, the complexities C9 and C10 neither have an impact on the labour productivity of the construction workers on site nor on the ability of the cost estimator to estimate the amount of labour hours more accurately. This should be taken into account when interpreting the average scores of these complexities. Nonetheless, complexity C9 and C10 may add complexity to the projects.
4.3.1.3 Complexity category 3: Financial

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C12</td>
<td>-0.5</td>
<td>High amount of capital expenditures</td>
</tr>
<tr>
<td>C13</td>
<td>-0.7</td>
<td>Contractor financial difficulties</td>
</tr>
<tr>
<td>C14</td>
<td>-0.4</td>
<td>Project owner financial difficulties</td>
</tr>
<tr>
<td>C15</td>
<td>-0.6</td>
<td>Shortage of budget for labour as a result of strategic behavior within project organization</td>
</tr>
</tbody>
</table>

The respondents found it difficult to relate the amount of CAPEX to DLH, however, some respondents managed to “translate” the impact of such a “high-level” complexity to DLH.

* Project J: “The CAPEX of the project is related to the complexity Shortage of experienced construction workers and this was explained as follows. Large projects (in terms of CAPEX) require more labour resources, however, there was a shortage of experienced construction workers. As a result, the percentage of experienced construction workers for large projects is significantly lower than the percentage of experienced construction workers for projects with lower capital expenditures. For this project, this was underestimated by the cost estimator.

* Project E: The amount of capital expenditures is just a number, however, when the capital expenditures exceed a certain amount is becomes difficult to deal with the increasing number of interfaces in different levels of the capital project organization. These interfaces could be organizational or technical. Managing the organizational interfaces on a project site level, however, is extremely difficult. Tools are used to implement successful interface management but in practice the impact of those tools should be further improved. On the project site level this means that information flows may interfere and this cause communication problems.

The scores of the other complexities in this category (C13, C14, C15) rather say something about if they were applicable to the project than whether they had an impact on DLH. Therefore the scores are not representative with respect to the relationship that should have been measured (Figure 25). Also no clear examples could be given by the respondents about this relationship.

4.3.1.4 Complexity category 4: International

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C16</td>
<td>-1.1</td>
<td>Number of different nationalities</td>
</tr>
<tr>
<td>C17</td>
<td>-0.1</td>
<td>Different time zones</td>
</tr>
<tr>
<td>C18</td>
<td>-1.1</td>
<td>Communication problems due to cultural differences</td>
</tr>
</tbody>
</table>

The reason why the complexity category International scores that high is because there are only three complexities in this category, of which two complexities had a high impact score: C16 and C18. These complexities seem to be interrelated and this was also mentioned by the respondents, who all shared the same opinion with regard to its impact on DLH.

The respondents argue that capital projects in the construction industry form a complex communication environment because there are always many stakeholders involved at all stages of the project. Communication problems may arise at different levels in a capital projects organization, i.e. between a construction manager and project manager or between a construction manager and construction workers. The efficiency of the construction process, however, is significantly influenced by the quality of communication between the people on the project site. The diversity of information together with the high number of nationalities within the construction teams often lead to “poor quality communication” or miscommunication. This subsequently results in unnecessary job rework and unproductive time, which means an increase in labour hours. An example was given by Respondent P:

* Project P: “Even if relatively simple information is translated in eight different languages and shared with a group of construction workers with different nationalities, e.g. safety instructions
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...for construction workers, still not everyone knows how to safely perform their work. This definitely slows down the construction process.”

It should be noted that the impact of the complexities C16 and/or C18 on DLH is less impactful if construction workers speak English or speak in the same language as the construction manager. However, if construction workers come from low-cost labour countries this is usually not the case. Therefore it is important that construction managers have the right communication skills, so clear instructions can be given to the construction workers. According to the respondents, the impact of this complexity is usually underestimated by a cost estimator. However, despite the high average score, the impact on the accuracy of the labour hours estimate is relatively small compared to other complexities in the framework, such as frequency of design changes and poor ground conditions.

The third complexity in this category is Different time zones. Most respondents argued that this complexity is more likely to be applicable in the engineering phase of a capital project because in this phase multiple workforces around the world are working together engineering the project. This in contrast to the execution phase; in this phase the project is often controlled from one central point so there are no different time zones involved. Hence this aspect of project complexity, thereby referring to Different time zones, cannot be related to DLH and should be removes from the framework according to the respondents.

4.3.1.5 Complexity category 5: Team/Organization

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Rounded average of category: (-0.4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C19 Level of construction worker participation in decision making</td>
<td>(-0.1)</td>
</tr>
<tr>
<td>C20 Appropriate delegation of owner responsibilities to contractors</td>
<td>(-0.1)</td>
</tr>
<tr>
<td>C21 Match between matrix structure of project and department structure of organization</td>
<td>(-0.1)</td>
</tr>
<tr>
<td>C22 Frequent changes in laborers</td>
<td>(-0.8)</td>
</tr>
<tr>
<td>C23 Presence of joint venture partners</td>
<td>(-0.8)</td>
</tr>
<tr>
<td>C24 Trust in project team</td>
<td>(-0.8)</td>
</tr>
<tr>
<td>C25 Clear schedule drive</td>
<td>(-0.4)</td>
</tr>
<tr>
<td>C26 Social activity opportunities construction workers</td>
<td>(0)</td>
</tr>
<tr>
<td>C27 HSSE awareness under construction workers</td>
<td>(-0.2)</td>
</tr>
<tr>
<td>Corruption</td>
<td>(0)</td>
</tr>
</tbody>
</table>

This category scores second last compared to the other complexity categories. However, the category includes two high scoring complexities which are Frequent changes in laborers (-0.8) and Trust in project team (-0.8).

Regarding the first one, a majority of the respondents argue that a high turnover of construction workers has a negative impact on DLH because when new construction workers are hired, they are not familiar with the project site. More specifically, it takes time to get familiar with the way of working, tools and machinery and the other people working on site and this has a negative impact on the productivity of the workforce. Additional construction workers are hired for various reasons:

* To catch up a delay and increase output;
* The contract period of the construction workers has expired and therefore they leave the project;
* The contractor did not manage to hire the right people for the right activities.

When a project is carried out according to schedule as determined on the FID, this complexity seems to be less important. As cost estimators work out their estimate under the assumption that the project will be executed according to schedule (taking into account schedule contingencies), this may explain why this complexity is underestimated by cost estimators. Several of the project owners believe that cost estimators should be more aware of the implications of high labour turnover in a capital project.

The complexity Trust in project team appeared to have a high negative impact on DLH. In this context, project team refers to the team consisting of people from the project owner, contractor(s) and if
applicable consultant(s). The level of trust among the team members determines the information that is shared and also the quality of information is influenced by the level of trust. It was derived from the interviews that a lack of trust hampers the process of decision making in case poor quality information is shared among the team members. It is a needed enabler for cooperation during all project phases. The importance of trust within a project team and how this is related to project success was very clear for most respondents: the more trust, the more openness and communication, the higher the probability of project success. However, none of the respondents, except one, could relate the level of trust to DLH by means of providing practical examples. The respondent who could provide an example argued that if less and poor quality information is shared on project-team level, this inevitably leads to poor instructions or communication on “lower” levels within a capital project organization, thereby referring to the communication to construction workers. This may have a negative impact on DLH, as explained in Paragraph 4.3.1.4.

The complexity Presence of joint venture partners also has a high negative impact on DLH. However, during the interviews it turned out that the respondents merely focused on how to deal with this complexity rather than providing examples on how this complexity would have an impact on DLH. In the view of the respondents, having a joint venture partner increases the number of interfaces and this makes a project more complex from an organizational point of view. In case there is non-alignment between the objectives of the joint venture partners, the number of interfaces (and thus the organizational complexity) would be even higher. As a result, it usually takes more time to build trust, which slows down the decision making process. In the worst case, joint venture partners do not spend time on building trust and make quick decisions because they do not want to delay the project. However, this does not resolve the non-alignment of the joint venture partners’ project objectives and this may eventually result in conflicts. If not, it certainly increases “to some extent” the inability to manage the project properly. Trust seems to be a key factor when it comes to dealing with this kind of organizational complexity. Moreover, if there is trust between the project team members, this will most likely reduce the effects of strategic behavior in the tendering procedure. Strategic behavior is an important factor with regard to inaccurate estimates (Brunes & Lind, 2014; Cantarelli et al., 2011).

The complexity Health, Safety, Security and Environment awareness under construction workers has a significant impact on DLH according to the respondents. However, the average score of this complexity is relatively low due to the high variance in the responses. The relation between HSSE awareness and labour productivity was clearly explained by:

- Project B: “Fundamental to delivering capital projects in the international oil and gas market is delivering a safe project. The effort to get HSSE awareness under construction workers is the effort to deliver a safe site. If you don’t have a safe site you don’t have a productive site.”
- Project C: “We work with a zero harm policy, which means causing no harm to anyone anytime while at work. Thus, HSSE plays an important role, especially during construction. If rules regarding HSSE are not clearly communicated to construction workers, this will cause delays because in that case construction workers do not know how to safely perform their work.”

All companies have a clear commitment to HSSE and therefore one would expect that the impact of HSSE on DLH is well known by cost estimators. Respondent M (cost estimator), however, explains that it is very difficult to relate HSSE with labour hours because it is an underlying factor. Safety requirements and rules might be clear and quantifiable, though this does not apply to the behavior of construction workers and its effect on labour hours. There is no straightforward way to accurately measure the impact of HSSE awareness on labour hours, although there is for safety accidents on the project site.

There are two complexities in this category which did not impact DLH at all. The impact scores with regard to the complexity Corruption are zero. In fact, all respondents indicated that this complexity
was not applicable to their project and even if so, there is no direct link between Corruption and DLH. Also the complexity Social activity opportunities construction workers did not have any impact on DLH. Although the respondents related to the projects that are performed in Asia argued that it is important to keep the workforce “satisfied”, social activity opportunities will not increase labour productivity significantly. Especially if construction workers are hired from low-cost labour countries it is more important to provide good food and a place to sleep than to provide social activity opportunities. A cost estimators does not need to take this complexity into account when working out a labour cost estimate.

4.3.1.6 Complexity category 6: Technology

Rounded average of category: (-0.6)

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>C29 Open to new technologies for construction activities by project stakeholders (-0.5)</td>
<td></td>
</tr>
<tr>
<td>C30 Adequate IT infrastructure and application in project (-0.2)</td>
<td></td>
</tr>
<tr>
<td>C31 Design errors made by designers (-1.0)</td>
<td></td>
</tr>
<tr>
<td>C32 Technical dependencies between construction tasks (-0.5)</td>
<td></td>
</tr>
<tr>
<td>C33 Contradicting norms and standards (-0.6)</td>
<td></td>
</tr>
<tr>
<td>C34 Frequency of design changes due to technical reasons (-1.3)</td>
<td></td>
</tr>
<tr>
<td>C35 Adequacy of method of construction (-0.3)</td>
<td></td>
</tr>
<tr>
<td>C36 Strict technical quality requirement(s) (-0.3)</td>
<td></td>
</tr>
<tr>
<td>C37 Level of experience by project team with new technology (-0.4)</td>
<td></td>
</tr>
</tbody>
</table>

Frequency of design changes due to technical reasons (-1.3) and Design errors made by designers (-1.0) are among the highest contributing complexities within this category. All respondents indicated that the design changes in construction projects are caused by, but certainly not limited to, technical shortcomings during the project. Hence this complexity is interpreted in its broadest sense by all respondents. For the projects considered, design changes made by the project owners were frequent and caused disruption and delays due to rework or additional work. The rework required additional hiring of resources, including labour, and according to the respondents this significantly increased DLH. Small design changes occur more frequent but are usually covered by cost contingencies. Thus, small design changes may have an impact on DLH but this does not translate into an overrun on labour cost.

The respondents of project D, E and Q explicitly mentioned that scope changes were made by the project owner while the project end date was approaching. These results came as no surprise; changes of design plans during construction are not uncommon in the construction industry and this is described in project management literature (Project Management Intitute, 2008). The following causes were given for the initiation of scope changes:

* Lack of stakeholder engagement during planning: scope changes were needed to satisfy internal and external stakeholders;
* Poor engineering: design errors;
* Change in business needs or benefits over the project life cycle;
* Project resources change: availability of labour, materials or budget;
* Implementation of new technology: when a new technology becomes economically viable during the construction phase of the project which requires adjustments in the design. For example, more efficient distillation units in chemical plants or refineries.

Regarding the first point, lack of stakeholder engagement, Respondent G argued the following:

* Project G: “Better stakeholder analysis and engagement in the initial phases of the project would have limited the impact the labour cost and total cost overrun. Due to the lack of stakeholder engagement, the design of the onshore pipeline was changed halfway through the initial project schedule. As the design was made in the late 90s, vendors were gone bankrupt and also warranties of the equipment had already expired. Hence the equipment of the gas plant had to be replaced by new equipment. This all resulted in additional man hours.”
Important to note is that the complexity Design errors made by engineers is a separate complexity in the framework, while the respondents argue that Design errors is part of the complexity Frequency of design changes. Design errors might involve major scope changes of which the impact on DLH is high, because the scope changes typically require (additional) machinery, materials and other resources to be available at the same time, which is very hard to realize. Hence scope changes inevitably lead to schedule delays and extra man hours due to unproductive time. That is in addition to the man hours that are needed to actually implement the scope change. However, one should realize that a major scope change is not part of the initial scope and therefore major scope changes actually should not impact DLH with regard to the initial scope. This was not included in the definition of DLH as discussed in Chapter 2 of this thesis though. Nonetheless, this definitely should be taken into account when interpreting the impact score of major scope changes on DLH. Small scope changes on the other hand may contribute greatly to DLH if they occur frequently.

Technical dependencies between construction tasks must be properly aligned in the planning phase, however, from a project owner perspective it was argued that the people who are responsible for this make the project schedules tight to “win” time en reduce costs. As a result, even minor delays in, for example construction activity A, may cause a major delay in construction activity B. This has a negative impact on DLH because the workforce is unproductive until construction activity A is completed. Respondent L argued that technical dependencies are more easily managed in “small” projects (CAPEX <100 million USD) than large projects (CAPEX > 500 million USD), as the number of interfaces in small projects is usually lower. However, the respondent also stressed that other factors play a role in this, i.e. the experience of the construction workers (C1) and construction managers (C5), the number of subcontractors per work package and the novelty of construction techniques used. Besides this, Respondent L argued that it is impossible to oversee and anticipate on all technical dependencies in large capital projects as there are too many interfaces in this respect. Even contingencies are often not enough to cover the impact of this complexity.

It can be derived from the impact scores that the complexity IT infrastructure and application did not impact DLH significantly. In fact, all respondents argued that the IT infrastructure, thereby referring to internet on site, communication and reporting software/hardware was sufficient. Only Respondent A, D, L and M indicated that this complexity might have increased DLH slightly. The impact of this complexity, however, is in marked contrast to the other complexities in this category. In addition, the oil and gas sector is conservative with regard to implementing new IT applications in order to increase labour productivity, making that this complexity and its “impact” on DLH could be determined even more easily.

4.3.1.7 Complexity category 7: External

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Impact Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>C38 Inclement weather</td>
<td>-0.2</td>
</tr>
<tr>
<td>C39 Legal disputes between project participants</td>
<td>-0.9</td>
</tr>
<tr>
<td>C40 Breach of an asset or site through physical interference</td>
<td>-0.1</td>
</tr>
<tr>
<td>C41 Natural disasters</td>
<td>0</td>
</tr>
<tr>
<td>C42 Stability of project environment</td>
<td>-0.3</td>
</tr>
<tr>
<td>C43 Dependencies of external stakeholders</td>
<td>-0.8</td>
</tr>
<tr>
<td>C44 Poor ground conditions</td>
<td>-0.7</td>
</tr>
<tr>
<td>C45 Government policy</td>
<td>-0.8</td>
</tr>
</tbody>
</table>

In the complexity category external there are four complexities with high average scores. Legal disputes between project participants, Dependencies of external stakeholders, Government policy contribute and Poor ground conditions contribute most to DLH. Apart from these scores, it became clear during the interviews that Government policy is most important in this category. For Project G and S, for example, government policies had a significant impact on DLH.

* Project G: “This complexity did not have an impact on the labour productivity of construction workers in terms of output per hour worked, though it did increase the number of labour hours
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due to unproductive time. This was because the procedure for granting environmental permits changed during the lifetime of the project. More specifically, the government became very conservative in granting environmental permits. The current environmental permit expired in 2007 so we had to apply for a new permit, however no new permit was granted. Hence construction activities were delayed, while construction workers still got paid their “worked” hours.”

Important to note is that although delayed permits may affect DLH negatively, this does not necessarily mean that the labour productivity norms that are used for calculating the labour hours are estimated and/or applied incorrectly. Construction workers may be as productive as estimated, while the overrun on the estimated labour hours is high due the number of “worked” hours during the time that no working permit/environmental permit was granted by the government. Cost estimators should not have to deal with this in the tender stage of the project as it does not fall within their job responsibilities.

* Project S: In this project the government set very specific requirements, so-called local business development requirements. The requirements forced the project owner to work with certain (sub)-contractors, which in turn was obliged to hire local construction workers. It was a difficult job for the contractor to recruit experienced instrumentation engineers and welders and as a result, the total workforce was less productive. The impact of the local business development requirements on the productivity of the workforce was clearly underestimated by the cost estimator and this explains why there was an overrun on labour hours. The overrun on labour hours is not entirely due to the experience of the cost estimator because the local business development requirements were rather vague and not clearly communicated to the contractor and project owner during the time the estimate was made.

The complexity Government policies did not have an impact on DLH for the projects performed in the Netherlands, although for one project the planning phase was shortened so the project could be awarded a subsidy by the government. As a result of this, the general contract was not set up properly and was far from complete. Incomplete contract documents increase the risk of project delays and (labour) cost overruns, which is confirmed by the results of the survey: the actual total cost and labour cost overran the estimate in Project N. The impact of incomplete contract documents is discussed in more detail in Paragraph 4.3.1.2.

The average score of the complexity Legal disputes between project participants is largely explained by the complexities Frequency of design changes and Completeness of contract documents. Although more factors play a role in this context, the following relation between these three variables was often mentioned by the respondents: incomplete contract documents may increase the frequency and/or magnitude of design changes during the execution phase of a project. This subsequently may result in claims/legal disputes. So how does the complexity Legal disputes between project participants relate to DLH? Legal disputes may indicate that the construction phase of the project is not executed according to plan as determined on FID, however, its direct impact on DLH is difficult to assess.

According to the respondents, the complexity Dependencies of external stakeholders is a rather wide-ranging complexity. Though the complexity was often related to Government policy. A clear example was given by Respondent G.

* Project G: “The pressure of external stakeholders for this project was tremendously high. The campaign against this project by local residents resulted in legal disputes and this caused massive schedule delays because important building permits were withdrawn by the local government during the construction phase. The dispute was mainly about the environmental impact of the project. Major changes in the design had to take place so construction activities could continue.
This resulted in rework and hence a disparity in earned and burned labour hours.” The respondent concluded by saying that for Project G, the complexity Dependencies of external stakeholders is related to C11: Environment related regulation of lobbying activities by interest groups.

The impact of the complexity Stability of project environment (economic conditions: exchange rate, oil price, raw material price) appeared to be relatively low. Respondent Q argued the following with respect to this complexity.

* Project Q: “There was a lot of competition amongst the Engineering, Procurement and Construction companies (EPCs), because of the economic collapse in 2009. Nonetheless, the EPCs at that time were desperate to win work because of the economic uncertainty. People were trying to buy work to keep their crews together. A consequence of that was in the delivery there was a lot of pressure on the EPCs to keep their projects cheap. As of consequence of that there was a lack of quality in those projects and this required rework/construction.”

Inclement weather is not an important complexity with regard to DLH. The impact of climactic conditions are usually well known by cost estimators. Only if weather conditions are abnormal, construction activity may be shut down for security reasons. The impact of Poor ground conditions, however, is underestimated by cost estimators. This is because cost estimators rely on site and soil reports, which are often incomplete due to inadequate site investigation prior to starting the design. In practice, the site condition at the start of the construction phase is lower than expected and this hampers construction workers to perform their work effectively. For some projects, additional site preparations were needed to make the project site accessible to construction workers.

Natural disasters may have a major impact on DLH if they occur during the construction phase, however, this complexity was not applicable to the projects that are in the dataset. Moreover, cost estimators usually do not take into account this complexity when working out an estimate since the occurrence of such events cannot be predicted. In addition, if there is serious danger for natural disasters projects will not be started in such environments in the first place. The same applies to the complexity Breach of an asset or site through physical interference. Although this complexity had a major impact on the project schedule for Project G, no one could ever have predicted how the resistance of local residents during this project would have an impact on the labour hours. In this project, labour hours overran in the field because the local residents blocked the entrance to the project site and disrupted construction activities such as drilling.

4.3.1.8 Complexity category 8: Materials/Transportation

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>C46 Operational or ancillary infrastructure limitation in region</td>
<td>-0.2</td>
</tr>
<tr>
<td>C47 Availability of tools and machinery</td>
<td>-0.4</td>
</tr>
<tr>
<td>C48 Availability of power and/or water supply on site</td>
<td>0</td>
</tr>
<tr>
<td>C49 Access to materials within construction site</td>
<td>-0.1</td>
</tr>
<tr>
<td>C50 Access to materials within construction site</td>
<td>-0.1</td>
</tr>
<tr>
<td>C51 Availability of materials</td>
<td>-0.8</td>
</tr>
</tbody>
</table>

Rounded average of category: (-0.3)

This category has the lowest score compared to the other complexity categories (Figure 31). However, the complexities Availability of tools and machinery and Availability of materials turned out to be important with regard to DLH. As many projects in the dataset were executed during the construction boom, materials and heavy equipment such as cranes, floating lifting machines, drills and other equipment were scarce. Equipment and material suppliers could not meet the growing demand and as a result the delivery of materials and equipment to the (sub)contractors was delayed. Due to the late delivery of materials and machinery, additional man hours were needed to catch up the delay/unproductive time.
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With regard to C50, the access to materials within the construction site only appeared to have an impact on DLH for Project L and S. In Project L, the construction materials were poorly accessible because there was congestion on the project site, which was caused by poor engineering of the construction site logistics. In Project L, the problem was that the construction materials were stored relatively far from the place where the construction activities actually were performed. The materials were not relocated as this was too costly. This resulted in unproductive time of the construction workers because they had to wait for the materials, despite the materials were on site already.

4.4 Other findings

4.4.1 Can complexities be assigned to specific project characteristics?

In line with the exploratory character of this research, the projects were categorized into groups in order to discover whether the same complexities are applicable to projects that share the same project characteristic. For example, which complexities are typically relevant in greenfield projects with respect to DLH? And how is this different for brownfield projects? The impact scores and the respondents’ motivations on the complexities were compared for the groups as presented in Table 9 in Paragraph 3.3.1.

No striking differences were found with regard to the project characteristics Sector, Greenfield/Brownfield, Cost overrun (total) and Labour Hours.

With regard to CAPEX, the complexities Frequency of design changes, Communication problems due to cultural differences, Design errors made by designers, Legal disputes between project participants, Shortage of experienced construction workers, Experience construction workers and High amount of CAPEX are mentioned more frequently for projects with CAPEX > 500 million USD than for projects with CAPEX < 500 million USD. This is possibly because most projects with CAPEX under 500 million USD were performed in the Netherlands, making the complexities Communication problems due to cultural differences, Shortage of experienced construction workers and Experienced construction workers less relevant.

For the projects that experienced an overrun on labour cost, the highest scoring complexities are Communication problems due to cultural differences, Trust in project team, Completeness of contract documents and Frequency of design changes. These complexities were less relevant for projects that did not experience an overrun on labour cost.

With regard to Country, the impact of Government policies, Experience of construction workers, Shortage of experienced construction workers, Communication problems, Frequent changes in laborers and Number of different nationalities on DLH is higher when the project is executed outside the Netherlands, Asian countries in particular. The projects in the Netherlands were executed in relatively “easy environments” and therefore transport related complexities and complexities related to the availability and experience of construction workers were not applicable.

4.4.2 Results on Cost Estimate Variance

The interviews were focused on gaining insight on the relationship between project complexity and DLH and therefore no qualitative insights were gathered on project complexity and CEV. However, impact scores on CEV were gathered by means of the online survey. As a part of the exploratory approach, the impact scores on “DLH level” and CEV level” are compared. Since the complexities in the framework are selected based on its “applicability” to the construction phase of capital projects, one would expect that the impact scores on CEV level are lower than on DLH level. The differences between CEV and DLH scores become apparent when looking at the distribution of the complexity scores among the different categories (
Figure 31). For all complexity categories, the average impact scores on CEV are lower than the average impact scores on DLH, although the differences are relatively small. Over the entire dataset, the largest difference was found for the complexity Number of different nationalities. This means that this complexity may cause a disparity in burned and earned labour hours and can be used by cost estimators as a correction factor on the labour hours estimate, while it cannot for the total cost estimate.

Figure 31: Average impact scores per category

In contrast to what was expected, by further analyzing the differences in the average impact scores, it turned out that for some complexities the average impact on CEV level is higher than on DLH. Over the entire dataset, the largest differences were found for:

* Experience project manager: this result indicates that a project manager has more impact on the accuracy of the total cost estimate than on the labour hours estimate. Given the job responsibilities of a project manager, as described in Appendix 3, this was an expected result.
* Legal Disputes between project participants: Apart from the scores, several respondents argued that the impact of this complexity on DLH is rather difficult to assess, while the impact on CEV is much clearer as legal disputes lead to increased cost because there are legal cost related in order to resolve issues. This might explain the difference of the scores on DLH level and CEV level.
* High amount of CAPEX: the respondents found it difficult to relate this complexity DLH, while the relation to CEV was more obvious. However, cost estimators cannot simply use this complexity as a correction factor for the total cost estimate as this complexity is too high-level. The CAPEX of a
capital project impacts the way a capital project is organized at different levels in a capital project organization.

### 4.5 Aggregation and interpretation of the results

This Sub section provides a wrap up of the online survey- and interview results, with a focus on interpreting the results. This Sub section is the final step towards the conclusions of this research.

**The importance of labour productivity**

In Chapter 1 and Chapter 2 of this thesis the author mentioned several times that labour cost may comprise 20 to 50% of the overall project cost of a capital project and this was supported by various sources (Hickson & Ellis, 2014; PMI, 2008; Soham & Rajiv, 2013). It was argued that variations in labour cost could have a major impact on the total cost of a capital project and with this, the focus of the research quickly moved to labour productivity. However, when looking at the results of the online survey and reasoning back from labour productivity to the total cost of a project, it becomes clear that:

- There is not a one-on-one relationship between labour productivity and the accuracy of the labour cost estimate. Though 70% of the respondents indicated that the accuracy of the labour cost estimate was much or very much influenced by DLH. The more inaccurate the labour hours estimate, the more inaccurate the labour cost estimate, thereby validating assumption A2 (Paragraph 1.1.3);
- The ratio between the labour cost and total cost for the projects in the dataset was relatively low; the narrow majority of the projects has a labour cost/total cost ratio of less than 20% and, as far as the respondents could indicate, there are no projects in the dataset with a ratio greater than 40%.

Hence the impact and importance of labour productivity in relation to the total cost performance of a capital project might not be as high as was assumed at the beginning of this research.

**The relationship between project complexity and the accuracy of the labour hour estimate**

All respondents see that capital projects in the construction industry are becoming more complex and this is in line with the literature as presented in the theoretical framework of this thesis (Accenture, 2013; Bosch-Rekveldt, 2011; EY, 2014; Vidal & Marle, 2008a; Williams, 2002). In Paragraph 4.2.1 it became clear that project complexity cannot be disregarded when it comes to the accuracy of the labour hours estimate. In fact, 80% of the respondents indicated that the accuracy of the labour hours estimate was much or very much influenced by the complexity of the project. The more complex the project, the lower the accuracy of the labour hours estimate. This indicates that there is a negative causal relationship between these two, thereby validating assumption A1 (Paragraph 1.1.3).

Following the differentiation of project complexity by (Baccarini, 1996), organizational complexity seems to be more important than technical complexity in this respect. Bosch-Rekveldt, Jongkind, Mooi, Bakker, & Verbraeck (2011) and Vidal and Marle (2008) also recognize the importance of organizational complexity over technical complexity, although their statements are made in a slightly different context.

**The interrelatedness of project complexity**

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8 The respondents already had seen the complexity framework, so they knew how project complexity was defined by the author of this thesis. Given the 80% score on the relationship, the respondents must have seen factors that were relevant to their project. Note that the results cannot be generalized to population, i.e. all capital projects in the construction industry.
Despite that many respondents recognized the importance of project complexity (as discussed above), many respondents found it difficult to relate specific elements of project complexity to Delta Labour Hours as well as to score its impact, because:

1. The complexities in the framework were too specific or too high level (i.e. the abstraction level);

Especially the complexities High amount of capital expenditures, Number of main contract types and Shortage of budget for labour as a result of strategic behavior within project organization could be difficult related to DLH.

Greater project size in terms of CAPEX significantly increases on site management challenges due to the increased number of different tasks, resources, stakeholders and so on (Rilo et al., 2012). However, according to the respondents the CAPEX of a project is “just a number” and therefore it cannot be directly related to the productivity of construction workers on site. Also the Number of main contract types does not seem to be correlated to DLH, it even may be related to the size of the project in terms of CAPEX.

Although many respondents recognize that strategic behavior may influence the accuracy of the overall cost estimate of a project, which is in line with literature by (Brunes & Lind, 2014; Cantarelli et al., 2011), the complexity Shortage of budget for labour as a result of strategic behavior within project organization and its relation to the accuracy of the labour hours estimate was too specific according to the respondents.

2. The complexities were interrelated so assessing the direct impact of the complexities is a rather difficult task for the respondent;

It appeared that many of the complexities in the framework were interrelated. More specifically, some complexities in the framework were “part of”, “caused by” or “the result of” other complexities. As a result of this interrelatedness, the respondents’ motivations on each complexity score quite often involved other complexities and therefore the direct impact could only be substantiated to a limited extent. Some examples that illustrate the interrelatedness of complexities in the framework: the complexity Legal disputes between project participants may have been caused by the Frequency of design changes, requested by the project owner as a result of Incomplete contract documents. Or, Design errors made by designers in the engineering phase may lead to more Design changes in the construction phase.

As a consequence of the interrelatedness, it proved to be difficult to gather sufficient insights on the one-on-one relationship between project complexities and DLH to make recommendations for cost estimators. In line with this, the impact scores of the complexities do not always provide a realistic picture of the direct impact of the complexities on Delta Labour Hours.

The interrelatedness of project complexity is inherent to complexity. This was already recognized by (Senge, 1994) and discussed in Sub section 2.4 of this thesis:

- Detail complexity: many components with a high degree of interrelatedness;
- Dynamic complexity: the potential to evolve over time (self-organization and co-evolution) and limited understanding and predictability.

Knowing that the interrelatedness of project complexity could possibly hamper the process of gathering qualitative insights and direct impact scores of the complexities, it did not prevent the author of investigating the relationship between project complexity and DLH. There is limited understanding on this relationship and the exploratory character of this research helps to gain more insights in this relationship.
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3. The respondent could not rely on labour productivity data regarding the execution phase

For some projects, the contract form used was a lump-sum contract and therefore the owner was not always aware of the true cost structure (and labour cost progression as experienced by the (sub-) contractors). Hence the respondent could not relate project complexity to DLH.

The implications on the results of this research
Given the abovementioned three reasons, and relating this to the objective that was set at the beginning of this research, which is (1) to deepen understanding and to provide qualitative insights on the relationship between project complexity and labour productivity, and (2) to translate the gained insights into recommendations for cost estimators, it can be argued that the research objective is only partially met.

In other words, the results are partially inconclusive, thereby emphasizing the word partially, because some aspects of project complexity that are relevant according to the respondents could be filtered out of the survey- and interview results. Relevant aspects of project complexity in this specific context refer to the complexities that mainly drive the disparity between the actual and estimated labour hours, caused by rework or ineffective work. The complexities that are not relevant either do not have an impact on DLH or the impact is well understood and accounted for by a cost estimator in the labour hours estimate. The complexities that are relevant are listed in Box 1.

<table>
<thead>
<tr>
<th>Category 1: Difficult to estimate the impact</th>
<th>Category 2: Less difficult to estimate the impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Frequency of design changes (C34)</td>
<td>• Experience of construction workers (C1)</td>
</tr>
<tr>
<td>• Design errors made by designers (C31)</td>
<td>• Shortage of experienced construction workers (C6)</td>
</tr>
<tr>
<td>• Completeness of contract documents (C7)</td>
<td>• Frequent changes in laborers (C22)</td>
</tr>
<tr>
<td>• Trust in project team (C24)</td>
<td>• Government policy (C45)</td>
</tr>
<tr>
<td>• Communication problems (C18)</td>
<td></td>
</tr>
<tr>
<td>• HSSE awareness under construction workers (C27)</td>
<td></td>
</tr>
</tbody>
</table>

Box 1: Relevant complexities with regard to Delta Labour Hours

A distinction has been made between complexities from which the impact is difficult to estimate and complexities from which the impact is expected to be less difficult to estimate. Placement in one of the categories is based on the level of interrelatedness with other complexities in the framework and the difficulty to quantify the impact. The complexities that are more interrelated and less easy to quantify are placed in Category 1 and the complexities that are less interrelated to other complexities and easier to quantify are placed in the Category 2. Three remarks have to be made regarding the complexities in Box 1.

First of all, the complexities Frequency of design changes and Design errors made by designers cannot be seen separately because design errors might involve design/scope changes. Scope changes typically require (additional) machinery, materials and other resources to be available at the same time, which is very hard to realize. Hence scope changes may lead to schedule delays and extra man hours due to unproductive time. Because of this the impact on DLH will be high, however, one should realize that a major scope change is not part of the initial scope and therefore major scope changes actually should not impact DLH with regard to the initial scope. Based on this argument, the complexity Frequency of design changes should be removed from Box 1. In addition, estimating the impact of design changes on the labour cost estimate is difficult or even impossible. Design errors and/or scope changes are the result of a series of events, which the cost estimator cannot anticipate when in the process of working out the estimate. The same applies to the complexity Trust in project team, as the level of trust will
depend on many factors as well, for example on: the type of contract used, the number of JV partners and previous experience on projects with same client or project owner.

Secondly, the complexities Experience of construction workers and Shortage of experienced construction workers are interrelated and therefore one could better combine these complexities and speak of Experience of construction workers. Experienced construction workers are key for performing construction tasks efficiently. In fact, the productivity of construction workers is considered one of the best indicators of production efficiency of capital projects (Rojas & Aramvareekul, 2003). Therefore it was not unexpected that many respondents indicated the importance of an experienced workforce to the performance of capital projects. Although the availability of experienced construction workers did not seem to be an issue for the projects that were performed in the Netherlands, as they were relatively small in size of CAPEX and man hours, it was an issue for the projects performed outside the Netherlands (especially Asian countries). This often had a negative impact on the accuracy on the number of labour hours. An important underlying factor, however, was that many of these projects were executed during the construction boom and during this time the labour market was very tight. In addition, the economic conditions made that many people were moving between jobs within the construction industry which resulted in a high turnover rate of construction workers during the execution of construction projects. This had a negative impact on the productivity of the workforce.

Thirdly, the complexity Government policy may relate to policies regarding labour, environment or (other) local content. It should certainly be taken into account as it may have an impact on the availability and experience of construction workers. Government policies proved to be an important factor for several projects in the dataset because government policies (which resulted in local business development requirements for some projects) forced contractors to hire local construction workers that were less experienced. Knowing the local law and its implications for capital projects is therefore of utmost importance for cost estimators.
CONCLUSIONS & RECOMMENDATIONS
5 Conclusions and recommendations

This chapter encompasses the conclusions of this research and the answer to the main research question (Q1). Recommendations for further research are made in Sub section 5.2.

Capital projects in the construction industry routinely overrun their pre-tender cost estimates. The inability to make accurate cost estimates is an urgent complication since the estimates provide substantial information for decision making, cost scheduling and resource management. However, in practice a difference has been observed in ‘burned’ (actual) and ‘earned’ (estimated) labour hours for construction activities, which possibly affects the labour cost estimate. Project complexity is frequently mentioned as being an important factor with respect to the accuracy of cost estimates. However, it is unclear how and to what extent the existence of project complexity can affect the accuracy of labour hour estimates of construction workers. As estimating labour productivity is vital for determining labour hours, the following research question was presented in Sub section 1.3:

Q1: How do project complexities influence labour productivity during the execution phase of capital projects in the construction industry and what are the implications for the accuracy of labour hour estimates?

5.1 Conclusions

In order to answer the main research question, four Sub questions were formulated (S1, S2, S3 and S4). The Sub questions mainly guided the author in the process of setting the theoretical framework of this research. The answers to the Sub questions will be discussed before answering the main research question, starting with S1. Next S4 will be answered and then S2 and S3. This specific order is used because the answer on the research question will then logically follow from the Sub questions.

Answering the sub research questions

S1: How are project performance, labour productivity and project complexity positioned in this research?

In order to position the three main topics of this research, a clear definition of project performance (Sub section 2.2), labour productivity (Sub section 2.3) and project complexity (Sub section 2.5) was set based on findings in the literature. The following causal model illustrates how these topics are related in this research.

![Figure 32: Causal relationship between project complexity, labour productivity and project performance](image)

The model includes two hypothesized causal relationships, A1 and A2, which both are validated in this research by 20 professionals in the construction industry. Regarding the first causal relationship, it can be concluded that project complexity plays an important role with respect to the accuracy of the labour hours estimate. Sixteen respondents (80%) indicated that the accuracy of the labour hours estimate
was much or very much\(^9\) influenced by the complexity of the project and that it has a negative impact on the accuracy of the labour hours estimate (Paragraph 4.2.1), thereby validating assumption A1 (Paragraph 1.1.3). Project complexity makes that cost estimators underestimate rather than overestimate the number of labour hours for the construction activities to be performed, i.e. the actual labour hours are greater than the estimated labour hours. In this respect, the respondents argued that technical complexity plays a minor role compared to organizational complexity and this is in line with literature by Bosch-Rekveldt et al. (2011), although their statements are made in a slightly different context. Moreover, Vidal and Marle (2008) argue that approximately 70% of project complexity factors are organizational.

**S4:** To what extent does a difference in labour hours contribute to a variance in labour cost?

This question relates to the second hypothesized causal relationship (A2) and helps to place the impact of inaccurate labour hours on the total labour cost of a capital project into perspective. The relationship has been validated by the same panel of professionals that validated the first causal relationship. Fourteen respondents out of twenty respondents (70%) indicated that the accuracy of the labour cost estimate was much or very much influenced by the accuracy of the labour hours estimate (Paragraph 4.4.2). More specifically, this causal relationship has a positive correlation, meaning that the labour cost estimate becomes more inaccurate when the labour hours estimate becomes more inaccurate. With this, also assumption A2 is validated (Paragraph 1.1.3).

If additional hours are required to complete construction activities, this may lead to a more-than-proportional increase in labour cost. Not only construction workers need to be paid for the additional hours, but also extra budget is also needed for indirect labour. One should realize that for every additional hour, day or week a construction worker needs to finish construction activities, there should be staff, machinery (and housing) available for construction workers. Hence the indirect cost associated with additional labour hours are usually high and may have a significant impact on the accuracy of labour cost estimate. However, the impact of an overrun on labour hours might be reduced if construction workers from low cost labour countries are hired.

Although both causal relationships were validated and showed relevance for the projects that is being in the dataset (Paragraph 4.1.4), these results cannot be generalized to population, i.e. all capital projects in the construction industry. Furthermore, there is no “one-on-one” relationship between project complexity, the accuracy of the labour hours estimate and the accuracy of the labour cost estimate.

**S2:** How can project complexity be operationalized and which complexities are assumed to have an impact on labour productivity?

When referring to project complexity it is important to state clearly the type of complexity being dealt with (Baccarini, 1996). Therefore project complexity is operationalized/divided into complexities, which is possible since project complexity is regarded a project characteristic. A thorough literature review resulted in a complexity framework consisting of 51 complexities which are further categorized into eight categories: Experience, Contracts, Financial, International, Team/Organization, Technology, External and Materials/Transportation. The detailed steps taken to achieve such a framework can be found in Appendix 1.

All complexities in the framework were assumed to have an impact on labour productivity, and thus on the accuracy of the labour hour estimate, but it turned out that many complexities in the framework were not applicable to the projects in the dataset (Paragraph 4.3.1). By excluding irrelevant complexities in the framework, it turned out that many complexities in the framework were not applicable to the projects in the dataset (Paragraph 4.3.1). By excluding irrelevant

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\(^9\) Very much is the highest score on a five point scale.
complexities, the number of complexities in the framework could significantly decreased (from 51 to 32 complexities), thereby increasing the usability of the framework (Paragraph 5.2.2).

S3: How can the impact of complexities on labour productivity be measured?

In this research a survey-interview approach was used to measure the impact of complexities on labour productivity, which comprises a scoring element and a “motivation” element (Sub section 3.1). The scoring element encompasses the scoring of the complexities that are in the complexity framework, while the motivation element leaves room for the respondent to elaborate on the impact scores. It was expected that this approach would be sufficient to measure the impact of the complexities on labour productivity. However, it turned out that it is difficult to measure or indicate the impact of complexities on labour productivity using this approach, because:

1. The complexities in the framework were too specific or too high level (i.e. the abstraction level);
2. The complexities were interrelated so assessing the direct impact of the complexities is a rather difficult task for the respondent;
3. The respondent could not rely on labour productivity data regarding the execution phase.

Especially the interrelatedness of the project complexities in the framework make it difficult to measure the direct impact of a complexity on labour productivity. As a consequence of this, the impact scores of the complexities as presented in (Paragraph 4.3.1) do not always provide a realistic picture of the direct impact of the complexities on Delta Labour Hours.

Answering the main research question
The main research question can be answered by synthesizing the answers on the Sub questions.

Q1: How do project complexities influence labour productivity during the execution phase of capital projects in the construction industry and what are the implications for the accuracy of labour hour estimates?

The main finding is that it is difficult to indicate how specific project complexities, thereby referring to the complexity framework that has been set up for this research, influence labour productivity of construction workers during the execution phase of capital projects in the construction industry. Despite this, the implications of project complexity for the accuracy of labour hours estimates are rather clear: project complexity decreases the accuracy of the labour hours estimate. More specifically, project complexity makes that cost estimators often underestimate the labour hours for the construction activities to be performed, i.e. the actual labour hours are greater than the estimated labour hours.

Mainly due to the interrelatedness of the complexities, it proved to be difficult to gather sufficient insights on the one-on-one relationship between project complexities and DLH to make recommendations for cost estimators. In line with this, the impact scores of the complexities do not always provide a realistic picture of the direct impact of the complexities on Delta Labour Hours. As a result, cost estimators cannot apply accurate adjustment factors to labour hours estimates based on the impact scores of the complexities. To summarize, the relationship between project complexity and DLH is relevant (Paragraph 4.2.1) but rather difficult to grasp and quantify for most complexities. However, the impact of the complexities Experience of construction workers, Frequent changes in laborers and Government policy are assumed to be less difficult to estimate.

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10 The labour hours estimate as presented at the Final Investment Decision and as part of the labour cost estimate
5.2 Recommendations for further research

In this Sub section recommendations for further research are presented. The recommendations are twofold and will be discussed separately: recommendations for cost estimators to improve labour cost estimates (Paragraph 5.2.1) and recommendations with regard to the current research approach (Paragraph 5.2.2).

5.2.1 Recommendation for cost estimators to improve labour hour estimates

Availability of (experienced) labour, government policy and HSSE awareness
If construction workers are hired from low cost labour countries it is important to thoroughly assess the availability of qualified construction workers in the scheduled construction phase, but also after the construction phase. The goal should be to limit the turnover of construction workers, as a high turnover of construction workers reduces the productivity of the labour workforce significantly.

- Information regarding the skills and availability construction workers should be gathered and this could be done by filling in a questionnaire by both the project owner and (sub)contractor. The effect of possible local business development requirements on the availability and quality of the workforce should also be discussed here as well as the HSSE awareness of construction workers;
- Subsequently, use a sample scope to uncover the ambiguity with regard to the productivity of the available workforce. A sample scope encompasses estimating a small part of the original scope. If differences arise in the estimates of the (sub)contractor and client, one could analyze the sample scope estimate in order to reveal where mistakes are made so this could be avoided if the real project is executed.

5.2.2 Recommendations with regard to the current research approach

It can be derived from the previous Paragraph that the chosen research approach resulted in a rather limited set of recommendations for cost estimators on how to improve their estimates. Other research approaches may lead to other, but not necessarily better results. If one would like to use the same approach as this research it is recommended to implement changes in the complexity framework. Based on the feedback provided by the respondents and the gained experience on the research topics during the research, several adjustments to the complexity framework can be made in order to improve the validity and usability of the framework. More specifically, the framework should consist of a concise set of unambiguous and relevant complexities. Hence the following adjustments are proposed:

Adjustments to the complexity framework

- Reduce the amount of complexities by excluding irrelevant complexities or combining complexities;

  * Excluding
    - C4: Experience contractor could be excluded as this complexity is already partly covered by C2, C3 and C5.
    - C11: Environment related regulation or lobbying activities by interest groups. Projects performed in countries or regions with an autocratic (government) system are usually not subject to environmental constraints or lobbying activities by environmental interest groups and in countries with a more democratic (government) system it appeared that the impact is not that high. Therefore it would be better to combine this complexity with C43: Dependencies of external stakeholders. Also C45, government policy should be combined with Dependencies of external stakeholders.
- C12: High amount of CAPEX. This complexity is more likely to be an indicator of the complexity of a capital project rather than it has an impact on DLH.
- C16 and C18: These complexities are interrelated and hence one of the complexities can be excluded from the framework.
- C17: Different time zones. This complexity is not applicable in the construction phase of capital projects.
- C19: Level of construction worker participation in decision making should be interpreted as high participation in decision making by construction workers. It appeared that construction workers are actually never involved in decision making, both in autocratic and democratic project structures. Therefore this complexity should be excluded from the framework.
- C20: Appropriate delegation of owner responsibilities to contractors should be excluded as it is part of the complexity Experience of project owner.
- C26: Social activity opportunities construction workers appeared relevant in only a few projects. More social activity opportunities increase the morale under construction workers which increases productivity, however, the impact of this on DLH is significantly low compared to, for example, financial problems of the (sub-) contractor in the construction phase.
- C28: Corruption. Although this complexity might have a big impact on the total cost estimate of a capital project, this complexity could cannot directly be related to DLH. Furthermore, the negative connotation of this complexity makes people to not openly speak about it.
- C37: Level of experience by project team with (new) technology should be excluded as this is covered by C2, C4 and C5.
- C40: Breach of an asset or site through physical interference.
- C41: Natural disasters, C38: inclement weather and C44: Poor ground conditions could be combined into one complexity. The following complexity is proposed: Physical condition project site (poor initial ground conditions or conditions affected by inclement weather).
- Experience contractor and Experience cost estimator could be excluded if the survey is filled in by a contractor or cost estimator working for a contractor. Also C13 and C14 could be excluded, depending on whether the respondent is working for a contractor company or the project owner.

Combining
- C1: Experience construction workers and C6: Shortage of experienced construction workers could be combined as these complexities have the same impact on DLH. A shortage of experienced construction workers means that the overall experience of the construction workforce will be lower.
- C8: Contractual conflicts between contractor and consultant should be combined with Legal disputes between project participants. In most projects, legal disputes arise from contractual conflicts and therefore its impact is considered equal.
- C31: Design errors made by designers should be combined with Frequency of design changes because design changes are, amongst others, caused by design errors made in the engineering phase.
- C48: Availability of power and/or water supply on site falls under Availability of tools and machinery and should therefore be excluded. The same applies to C51: Availability of materials.
- C49 and C50 can be combined into one complexity, which is Adequate access and transportation of materials on project site.

* Add complexities to framework if frequently mentioned by the interviewees;

The respondents mentioned that key aspects were missing around:
- Effective leadership client/contractor
- Stakeholder alignment on business targets, Client/JV/Contractor values and ways of working;
- Local capability development aspirations
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- Adequate transportation of people on project site\textsuperscript{11}

* Re-name complexities in order to reduce ambiguity;
  - C34: Change Frequency of design changes due to technical reasons in Frequency of minor
design changes. Major design changes are not part of the initial scope and therefore should
not have an impact on DLH
  - C22: Change Frequent changes in laborers in High turnover of construction workers;
  - Dependencies of external stakeholder should subsequently be changed to Dependencies/
  Requirements of external stakeholders
  - C47 should be changed to Availability of tools, machinery and materials as two more
  complexities are now included in this complexity

* Re-categorize complexities;

The interrelatedness of the complexities in the framework makes it difficult to assign the complexities to specific categories. Re-categorizing the complexities into broader categories may help to better distinguish the complexities but this is up to the researcher.

When all adjustments are implemented, except from re-categorizing the complexities, the number of complexities can be reduced to 32 complexities. The “new” framework is presented on the next page (Table 13). If one would prefer to execute a large scale survey based on this framework, the next step would be to process the changes in the survey and distribute the survey. It is recommended to distribute the survey in one specific sector within the construction industry, preferably the oil and gas sector because most projects in the dataset of this research were performed in this sector. In this way one could look into similarities or differences with regard to the impact scores. Interviews could help in verifying whether adjustments to the framework have increased the usability of the framework. This all may provide insight in whether the approach of the research is a valid approach for gaining insight in the relationship between project complexity and labour productivity.

Improvements regarding the online survey
It is recommended to change the five point Likert scale (as presented in Paragraph 3.3.1) to a seven point Likert scale in order to increase validity and reliability in the results (Wittink & Bayer, 1993). Since the “new” framework does not include the complexities which appeared to be irrelevant anymore, the differences in impact scores of the high scoring complexities (at least in this research) will become more apparent by using a seven point Likert scale. This may help the researcher to better distinguish the complexities that have a high impact on the accuracy of the labour hours estimate and the complexities that have a low impact on the accuracy of the labour hours estimate.

The online survey contains a lot of questions and should be shortened because this will improve the response rate, especially in case a survey approach is chosen rather than a survey-interview approach (Sub section 3.2.3). As the focus is mainly on Delta Labour Hours, questions with respect to Cost Estimate Variance could be excluded. There should be more understanding on the relationship between project complexity and DLH, before starting to investigate how the complexities on CEV level and the complexities on DLH level are related.

\textsuperscript{11} Note that the first three suggested complexities are covered by complexities that are already in the framework (C1, C2, C5, C35)
<table>
<thead>
<tr>
<th>Complexity category</th>
<th>Complexities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cat.1: Experience</strong></td>
<td>C1  Experience construction workers</td>
</tr>
<tr>
<td></td>
<td>C2  Experience project manager</td>
</tr>
<tr>
<td></td>
<td>C3  Experience cost estimators</td>
</tr>
<tr>
<td></td>
<td>C5  Experience construction manager</td>
</tr>
<tr>
<td><strong>Cat.2: Contracts</strong></td>
<td>C7  Completeness of contract documents</td>
</tr>
<tr>
<td></td>
<td>C8  Contractual conflicts between contractor and consultant</td>
</tr>
<tr>
<td></td>
<td>C9  Number of main contract types</td>
</tr>
<tr>
<td></td>
<td>C10 Changes to the terms of ownership or terms of the ownership/IV/ Production Sharing agreement</td>
</tr>
<tr>
<td><strong>Cat.3: Financial</strong></td>
<td>C13 Contractor financial difficulties</td>
</tr>
<tr>
<td></td>
<td>C14 Project owner financial difficulties</td>
</tr>
<tr>
<td></td>
<td>C15 Shortage of budget for labour as a result of strategic behavior within project organization</td>
</tr>
<tr>
<td></td>
<td>C18 Communication problems due to cultural differences</td>
</tr>
<tr>
<td><strong>Cat.4: International</strong></td>
<td>C20 Appropriate delegation of owner responsibilities to contractors</td>
</tr>
<tr>
<td></td>
<td>C21 Match between matrix structure of project and department structure of organization</td>
</tr>
<tr>
<td><strong>Cat.5: Team/organization</strong></td>
<td>C22 High turnover of construction workers</td>
</tr>
<tr>
<td></td>
<td>C23 Presence of joint venture partner(s)</td>
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<tr>
<td></td>
<td>C24 Trust in project team</td>
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<td></td>
<td>C25 Clear schedule drive</td>
</tr>
<tr>
<td></td>
<td>C27 (HSSE) awareness under construction workers</td>
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<tr>
<td></td>
<td>C29 Open to new technologies for construction activities by project stakeholders</td>
</tr>
<tr>
<td><strong>Cat.6: Technology</strong></td>
<td>C30 Adequate IT infrastructure and application in project</td>
</tr>
<tr>
<td></td>
<td>C32 Technical dependencies between construction tasks</td>
</tr>
<tr>
<td></td>
<td>C33 Contradicting norms and standards</td>
</tr>
<tr>
<td></td>
<td>C34 Frequency of minor design changes</td>
</tr>
<tr>
<td></td>
<td>C35 Adequacy of method of construction</td>
</tr>
<tr>
<td></td>
<td>C36 Strict technical quality requirement(s)</td>
</tr>
<tr>
<td><strong>Cat.7: External</strong></td>
<td>C41 Physical condition project site (poor initial ground conditions or conditions affected by inclement weather)</td>
</tr>
<tr>
<td></td>
<td>C42 Stability of project environment</td>
</tr>
<tr>
<td></td>
<td>C43 Dependencies/requirements of external stakeholders</td>
</tr>
<tr>
<td></td>
<td>C46 Operational or ancillary infrastructure limitation in region</td>
</tr>
<tr>
<td><strong>Cat.8: Materials/Transportation</strong></td>
<td>C47 Availability of tools, machinery and materials</td>
</tr>
<tr>
<td></td>
<td>C49 Adequate access and transportation of materials on project site</td>
</tr>
</tbody>
</table>

*Table 13: Complexity framework after applying adjustments*
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6 Reflection

In this Chapter I will provide a personal reflection on this research. First I will reflect on scientific and practical relevance of this research. Next I will present the limitations of this research and after that I will reflect on the research process. This chapter concludes with some lessons learned during the research.

6.1 Scientific and practical relevance

6.1.1 Scientific relevance
In this research a complexity framework was created based on scientific literature and used for investigating the relationship between project complexity and the accuracy of the labour hours estimate. The research revealed that project complexity has a negative impact on the accuracy of the labour hours estimate, as a consequence of incorrectly estimating the productivity of construction workers. So far, project complexity has particularly been linked to the total cost estimate or labour cost estimate (Doyle & Hughes, 2000; Enshassi et al., 2013; Trost & Oberlender, 2003). However, translating the one-on-one impact on the accuracy of the labour hours estimate for each of the complexities that are in the complexity framework proved to be rather difficult. This is due to the high degree of interrelatedness of project complexity aspects. On the basis of feedback provided by experts in the construction industry, an attempt was made to decrease the interrelatedness and ambiguity of the complexities in the framework. This provides a general preliminary basis for any more detailed studies into the relationship between project complexity and the accuracy of labour hours estimates for capital projects in the construction industry (Paragraph 5.2.2). Though it is not expected that translating the direct impact of each single complexity into labour hours will be possible.

6.1.2 Practical relevance
Following on what is mentioned above, the number of recommendations for cost estimators who prepare tender estimates for capital projects in the construction is limited. Hence the practical relevance of this research is lower than was aimed for at the start of this research. Although cost estimators cannot use this information to make very detailed adjustments to the labour productivity norms they use for setting up labour hour estimates, the results provide an overview of complexities and how they were relevant or not relevant in a specific project context. They can use the complexity framework as a checklist and further develop it into a shortlist of the total complexity framework just as in Sub section 4.5. In this Sub section the shortlist was made based on the expert experiences and impact scores of the complexities, but in practice this can be done using experience from similar projects.

Further development of the complexity framework and the approach on applying the framework, thereby taking into account the interrelatedness as a characteristic of project complexity, could assist in better identifying areas of project complexity which affect the accuracy of labour hour estimates. If the complexity framework is seen as a scoring list that can be filled in before the start of a capital project and after project completion, the impact of complexities on the accuracy of the labour hour estimate could become more apparent.

6.2 Research limitations

6.2.1 Number of interviewees/projects
The analysis of the results is based upon the information that was provided by twenty respondents. Depending on the availability of the contacted persons and their willingness to be interviewed, the
dataset eventually consists of twenty projects that are relatively different from each other. For example, the dataset includes projects with CAPEX exceeding 3 billion USD and projects with CAPEX around 80 million USD. Therefore, the average scores of the complexities as presented in Chapter 4, are based on projects with quite different project characteristics. Although several projects in the dataset share the same characteristics, such as sector or total labour hours, still no similarities in their answers could be found. If the dataset would contain more projects, this would increase the validity of the results.

6.2.2 Bias and subjectivity
As can be derived from the research objective, qualitative insights are gathered on the relationship between project complexity and the accuracy of the labour hours estimate. Both the impact scores and the motivations on the impact scores are shaped by the perspectives of the interviewees, thereby creating a possible bias in the results. In addition, the interviewees fulfilled different roles in capital projects and this was done in order to include multiple viewpoints. Although no major differences were found between the impact scores of people with different roles, it still may be that the results were affected by this since project directors were overrepresented in the dataset and construction managers underrepresented. Furthermore, despite the aim to include an even amount of projects within each sector in the construction industry, oil and gas projects are overrepresented in the dataset.

6.2.3 Complexity framework
Project complexity is gaining increasing attention by researchers and practitioners and therefore a lot of (scientific) literature on this topic could be found when starting this research. For the development of the complexity framework, a selection of the literature was made based on a set of criteria. In this way it was possible to analyze a wide variety of complexity factors and labour productivity factors. Although clear criteria were set for making a selection of the articles, some other complexities might have been included or even excluded if more criteria were set. Also the step after having selected the literature as basis for the complexity framework could have been more precise. The approach used as described in Appendix 2 resulted in a rather long list of complexities, thereby not excluding complexities that were not even relevant for the scope of this research. The quality of the complexity framework could have been better if more time was spent on setting the right criteria.

6.3 Research process
The starting point of this research was the rather broad question of Accenture to map and to quantify productivity/performance losses of capital projects in the oil and gas sector and to map innovative solutions for this. Pretty quickly, labour productivity and project complexity were linked to the performance of capital projects, as these topics are getting more attention in project management literature and practice in this context. Subsequently, the scope of the project was set to labour cost performance, thereby focusing on the labour hours estimate. With this, labour cost estimating became one of the main topics of this research. It should be mentioned that I was not fully familiar with literature about project complexity and labour cost estimating in the construction industry. Some courses within the SEPAM curriculum focus on complexity in complex adaptive systems, however, project complexity is a different field of research. Hence much time was spent on studying these topics in order to understand “the basics” and draw meaning from it. Though the SEPAM course Strategic management in large engineering projects helped in understanding topics regarding project performance and contracting.

After knowledge gaps with regard to the relationship between project complexity, labour productivity and project performance were identified, a research proposal was written. The initial goal of the proposed research at that time was to investigate how labour productivity norms, used for labour cost estimating, could be improved. For this purpose, detailed labour cost estimates of completed capital
projects were required, including labour productivity norms applied in those estimates. Also (and most importantly), data regarding labour productivity progress in the construction phase was required to perform the research as proposed at that time. There have been many attempts to gather these data but without success. Data was either poorly documented, confidential or just not available.

I realized that inaccurate estimates are a real problem for capital projects and that investigating the relationship between project complexity to the accuracy of labour hour estimates is relevant but also ‘complex’ because of the availability of data and the nature of project complexity. Hence the purpose of this research became exploratory oriented. Given the availability of data the research scope and methodology had to be adjusted, which delayed the research in the early stages of the project. Time has been lost, but after redefining the research scope and its objectives (see Chapter 2 and Chapter 3), the research gained momentum. It really helped that the outcomes and findings of the literature study on project complexity and labour productivity could be translated to the online survey design and interview design relatively easily. Although the interrelatedness of project complexity cannot be avoided (Sub section 2.4), in hindsight it would have been better to spend more time on validating the framework so I could have dealt earlier with the ambiguity of the complexities that are in the framework as well as the usability of the framework during the interviews.

The process of approaching people for an interview, scheduling the interviews and distributing the surveys prior to the interview went smoothly. All 20 interviews could be conducted in less than three weeks. Although the research objective, online survey and interview content were communicated and sent to the interviewee prior to the interview, not all interviewees could provide me with the qualitative insights on the relationship between project complexity and labour productivity I was looking for. During the interviews it turned out that the relationship of some project complexities and labor productivity is difficult to describe as well as to provide examples on this relationship. Several explanations for this are given in Sub section 4.5, of which the two most important ones relates to the availability of labour productivity data and the interrelatedness of project complexity. As a result, it proved to be hard to relate the results of the research with academic literature, thereby closing the loop of the research process. However, much effort was put on interpreting the gathered data and this certainly revealed some interesting insights on how project complexity impacts the accuracy of the labour hours estimate. Nonetheless, the research could have benefited if more emphasis was put on the research design, so the research method could have been better adapted in relation to the data needed for analyses. For example, a case study with multiple interview rounds might have led to other, more useful results. However, it is uncertain whether this would have led to “better” results.

All in all, I believe that this research succeeded in clearly addressing and motivating the research problem. Furthermore, the results confirm the relevance of project complexity with regard to labour hours estimating in capital projects within the construction industry. However, the overall research process has not led to satisfying results, to my opinion, as the research objective is only partially met. Despite this, I think that project complexity is a very challenging topic and therefore one should not be disappointed when a ‘complex’ problem like this does not lend itself for definite answers to this specific research issue if a certain research approach is chosen.

It is a fact that this research has been an educative and challenging experience to me. During the research I gained a lot of knowledge regarding the concepts of labour cost estimating and project complexity as well as how projects in the construction industry are managed. Accenture provided me with the opportunity to perform my master thesis project within a stimulating, dynamic and professional environment and I really enjoyed my time at Accenture during my internship. I learned a lot about the way of working in this company and consultancy in general. Looking back at the research (process), I can say it was a valuable research experience.
6.4 Lessons learned

During my research, important lessons were learned on how to manage a master thesis project from a process perspective. Below are some specific examples of lessons learned:

* Interviews. Planning, preparing, conducting and documenting the interviews is a very time consuming process. Although many people had told me this, it was the first time I experienced it myself. In hindsight I think I could have saved time on the interpretation of the interview outcomes if I spend some more time on accurately documenting the interview outcomes after each interview. Furthermore, I conducted several dry runs of the interview, although I learned most during the interviews with the respondents. The first interviews helped me to manage time more efficiently during later interviews and to get more useful information. I agree with Browne (2011), who argues that “The success of interviews depends heavily on the skill and personality of the interviewer, especially in unstructured or semi-structured interviews – for example, in getting people to provide answers to questions that give useful information and in keeping the conversation going”.

* Survey results. The online survey generated a huge amount of data and - together with the interview results – this resulted in a rather big data file. I have spent some time on trying to quantify the survey and interview results, however, it would have been better to spend this time on interpreting the data in a qualitative way. It is important to keep the objective of your research in mind, which for this research was to provide qualitative insights rather than quantitative insights.

* Stakeholders. Besides myself there were two stakeholders in this master thesis project: Delft University of Technology and Accenture Netherlands. It may not come as a surprise that the interest of these stakeholders were not always in line with each other during the research. Hence during this master thesis project it was very important to manage the expectations of the involved stakeholders and I learned that the best way to manage the expectations is to communicate with everyone on a frequent basis. Furthermore, it is important to be open about what can be delivered within the agreed time schedule. Eventually, there should be a balance between the expectations of all involved stakeholders on the one hand and what is realistic in terms of scope on the other hand.
Towards accurate labour hour estimates for capital projects in the construction industry

MSc Thesis Ewout Vossen

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Appendix 1: Complexity framework approach

A selection of key concepts of project complexity is discussed in Sub section 2.4. Sub section 2.4 concluded with complexity frameworks and regarding these frameworks it was mentioned that several authors try to create better understanding on (managing) project complexity by operationalizing project complexity. When project complexity is operationalized, this basically comes down to a list with project complexities categorized in different categories (Bosch-Rekveldt, 2011; Vidal & Marle, 2008a; Whitty & Maylor, 2009). The ambiguity of project complexity makes it difficult to create a standardized list or commonly-agreed list of project complexity factors. However, creating such a list is necessary in order to make it possible to quantify project complexity.

In this research it is hypothesized that project complexity affects labour productivity of construction workers during the execution phase of capital projects in the construction industry, resulting in a deviation between earned and burned hours. Subsequently, this deviation leads to inaccurate labour cost estimates. It was found in literature that cost estimators often underestimate the labour hours by construction workers to complete their construction activities.

The following question is raised: what are the relevant complexity factors that may impact labour productivity and subsequently lead to a difference in earned hours and burned hours? If we translate this question into an objective: the ultimate objective is to create a complexity framework with complexities that may contribute to the deviation in scheduled and real labour hours of construction workers: Delta Labour Hours. The complexity framework consist of 51 factors/complexities which are categorized into 8 categories.

Figure 33 visualizes the approach that is used to create such a complexity framework. As can be derived from this figure, the final complexity framework builds on existing literature regarding project complexity and labour productivity factors. Studies into factors influencing labour productivity were included in this approach and this was done because we are also looking for factors that can be related to labour productivity and have a link with project complexity. In other words, we assumed that literature on labour productivity factors could contain relevant complexities which may be found in project complexity literature.

The first step was to make a selection of existing literature which serve as input for this approach. The complexity frameworks that are discussed in Sub Section 2.4 (Bosch-Rekveldt, 2011; Maylor et al., 2008; Vidal & Marle, 2008b), provided a good starting point. Furthermore, the research by (Remington & Turner, 2009), and (Confidential, 2015) was included. The mentioned studies cover a wide range of project complexity operationalizations. The studies on labour productivity factors are selected based on the following criteria: the study should include a clear description of labour productivity factors that are related to construction activities in the construction industry; the study should include a clear categorization of labour productivity factors that are related to construction activities in the construction industry, the study should include factors that can be related to project complexity factors. Many articles were found that meet the above mentioned criteria. A thorough study of the articles learnt that there was a lot of overlap in factors in those articles. The articles that were eventually chosen are identified as being most suitable for this research as these articles are most complete in terms of meeting the criteria.
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Figure 33: Approach to create a complexity framework for this research

The second step was to reduce the amount of factors, because (too) many factors were gathered with the selected literature: an overview of literature and their corresponding factors is presented in Table 14 on the next page. In order to create a framework that can be used in the online survey and during the interview, the amount of complexities had to be reduced. Making a selection of these factors is a rather difficult task, as you do not want exclude factors which later turn out to be relevant. A suitable method to reduce the number of factors is to look at the Relative Importance Index (RII), because most studies that were selected use some sort of RII.

Relative importance index = \[ \frac{\sum W}{AN} \]

where \( w \) is the weighting given to each factor by the respondents of the respective study, ranging from 1 to 5, \( A \) is the highest weight (i.e. 5 in the study) and \( N \) is the total number of samples. The RII is expressed in a number ranging from 0 to 1 or percentage.

In order to reduce the number of complexities, the following rules regarding the RII were used:

Rule 1: \( \text{RII} > 90\% \) include
Rule 2: \( \text{RII} = 70-90\% \) include, but only if factor is also mentioned (in 70%-100% range) in the other selected articles
Rule 3: \( \text{RII} < 80\% \) exclude, except if the factor is mentioned in >90% range in the other selected articles

The above approach has led to a reduction of 104 factors, there are now 387 factors on the list. The next step to further reduce the amount of factors is to delete duplicates in the list. In this way the number of factors could be lowered from 387 to 178. Although the number of factors is lowered significantly, there are still too many factors on the list. Hence a third step was needed to further reduce the factors on the list. The number of complexities could be further reduced by grouping certain variables, for example: the factors rain, high temperature were grouped into “weather conditions”, the factors skill of construction workers and experience of construction workers were grouped into “experience of construction workers”. The steps taken and list of factors was continuously validated by practitioners working in the construction industry. The number of factors is eventually reduced to...
51 complexities, which are subsequently categorized into 8 categories. The categories are: Experience, Contracts, Financial, International, Team/Organization, Technology, External and Materials/Transportation. During the interview there was time for the interviewee to comment on the complexity framework. In the first column of the table below you can see how the complexities that are presented in Appendix 2 relate to the selected literature.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Categories</th>
<th>After applying RII rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Bosch-Rekveldt, 2011) 47 factors</td>
<td>Project complexity</td>
<td>Most/least contributing elements are mentioned</td>
</tr>
<tr>
<td><em>Relate to complexity:</em> C2-C6, C9, C12, C16-C18, C32, C33, C34, C37, C38, C42, C45</td>
<td>Technical: 17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Organizational: 16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>External: 14</td>
<td></td>
</tr>
<tr>
<td>(Vidal &amp; Marle, 2008b) 70 factors</td>
<td>Project complexity</td>
<td>n.a.</td>
</tr>
<tr>
<td><em>Relate to complexity:</em> C1-C6, C16, C23, C29, C32, C43, C51</td>
<td>Organizational: 49</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technology: 21</td>
<td></td>
</tr>
<tr>
<td>(Maylor et al., 2008) 109 factors</td>
<td>Managerial complexity</td>
<td>n.a.</td>
</tr>
<tr>
<td><em>Relate to complexity:</em> C1, C2, C4, C5, C6, C17, C21, C23, C32, C37, C45</td>
<td>Mission: 33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Organization: 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delivery: 22</td>
<td></td>
</tr>
<tr>
<td>(Hickson &amp; Ellis, 2014) 42 factors</td>
<td>Labour productivity factors</td>
<td>18</td>
</tr>
<tr>
<td><em>Relate to complexity:</em> C18, C35, C36, C47, C49</td>
<td>Management: 24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technological: 12</td>
<td></td>
</tr>
<tr>
<td>(Remington &amp; Turner, 2009) 50 factors</td>
<td>Project complexity</td>
<td>n.a.</td>
</tr>
<tr>
<td><em>Relate to complexity:</em> C1, C2, C4, C5, C9, C17, C29, C37, C42, C43, C45</td>
<td>Goals: 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stakeholders: 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interfaces/Interdependencies: 10</td>
<td></td>
</tr>
<tr>
<td>(Muhwezi, Acai, &amp; Otim, 2014) 80 factors</td>
<td>Labour productivity factors</td>
<td>23</td>
</tr>
<tr>
<td><em>Relate to complexity:</em> C1, C2, C4, C5, C8, C13, C14, C24, C26, C28, C31, C38, C39, C44, C45, C51</td>
<td>Consultant: 18 (9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contractor: 27 (6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Client: 15 (7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>External: 20 (1)</td>
<td></td>
</tr>
<tr>
<td>(Gundecha, 2012) 40 factors</td>
<td>Labour productivity factors</td>
<td>4</td>
</tr>
<tr>
<td><em>Relate to complexity:</em> C1-C5, C27, C31, C34, C36, C39, C47, C48, C50</td>
<td>Manpower: 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>External: 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communication: 5</td>
<td></td>
</tr>
<tr>
<td>(Robles, Stifi, Ponz-tienda, &amp; Gentes, 2014) 35 factors</td>
<td>Labour productivity factors</td>
<td>11</td>
</tr>
<tr>
<td><em>Relate to complexity:</em> C1, C7, C14, C22, C25, C28, C47, C50</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Human</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Management or organizational</td>
<td></td>
</tr>
<tr>
<td>Confidential report 18 factors</td>
<td>Labour productivity factors</td>
<td>7</td>
</tr>
<tr>
<td><em>Relate to complexity:</em></td>
<td>Project complexity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technology</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regional risk and regulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td></td>
</tr>
<tr>
<td>Total 491 factors</td>
<td>Project complexity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Project risk management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Service</td>
<td></td>
</tr>
</tbody>
</table>

Table 14: Literature related to the complexity framework
### Appendix 2: Complexity framework

<table>
<thead>
<tr>
<th>Complexity category</th>
<th>Complexities</th>
<th>Average score (DLH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat.1: Experience</td>
<td>C1 Experience construction workers</td>
<td>-0.9</td>
</tr>
<tr>
<td></td>
<td>C2 Experience project manager</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C3 Experience cost estimators</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C4 Experience contractor</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C5 Experience construction manager</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C6 Shortage of experienced construction workers</td>
<td>-0.8</td>
</tr>
<tr>
<td>Cat.2: Contracts</td>
<td>C7 Completeness of contract documents</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C8 Contractual conflicts between contractor and consultant</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>C9 Number of main contract types</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>C10 Changes to the terms of ownership or terms of the ownership/JV/Production Sharing agreement</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C11 Environment related regulation or lobbying activities by interest groups</td>
<td>-0.4</td>
</tr>
<tr>
<td>Cat.3: Financial</td>
<td>C12 High amount of capital expenditures (CAPEX)</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C13 Contractor financial difficulties</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C14 Project owner financial difficulties</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C15 Shortage of budget for labour as a result of strategic behavior within project organization</td>
<td>-0.6</td>
</tr>
<tr>
<td>Cat.4: International</td>
<td>C16 Number of different nationalities</td>
<td>-1.1</td>
</tr>
<tr>
<td></td>
<td>C17 Different time zones</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C18 Communication problems due to cultural differences</td>
<td>-1.1</td>
</tr>
<tr>
<td>Cat.5: Team/organization</td>
<td>C19 Level of construction worker participation in decision-making (low responsibility)</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C20 Appropriate delegation of owner responsibilities to contractors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C21 Match between matrix structure of project and department structure of organization</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C22 Frequent changes in laborers</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td>C23 Presence of joint venture partner(s)</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td>C24 Trust in project team</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td>C25 Clear schedule drive</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C26 Social activity opportunities construction workers</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C27 (HSSE) awareness under construction workers</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>C28 Corruption</td>
<td>0</td>
</tr>
<tr>
<td>Cat.6: Technology</td>
<td>C29 Open to new technologies for construction activities by project stakeholders</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C30 Adequate IT infrastructure and application in project</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>C31 Design errors made by designers (unclear and inadequate details in drawing)</td>
<td>-1.0</td>
</tr>
<tr>
<td></td>
<td>C32 Technical dependencies between construction tasks</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>C33 Contradicting norms and standards</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>C34 Frequency of design changes due to technical reasons</td>
<td>-1.3</td>
</tr>
<tr>
<td></td>
<td>C35 Adequacy of method of construction</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>C36 Strict technical quality requirement(s)</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>C37 Level of experience by project team with (new) technology</td>
<td>-0.4</td>
</tr>
<tr>
<td>Cat.7: External</td>
<td>C38 Inclement weather (rain, wind, low temperature)</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>C39 Legal disputes between project participants</td>
<td>-0.9</td>
</tr>
<tr>
<td></td>
<td>C40 Breach of an asset or site through physical interference</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C41 Natural disasters</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C42 Stability of project environment</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>C43 Dependencies of external stakeholders</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td>C44 Poor ground conditions</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>C45 Government policy</td>
<td>-0.8</td>
</tr>
<tr>
<td>Cat.8: Materials/Transportation</td>
<td>C46 Operational or ancillary infrastructure limitation in region</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>C47 Availability of tools and machinery</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C48 Availability of power and/or water supply on site</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C49 Adequate transportation materials on site</td>
<td>-0.4</td>
</tr>
<tr>
<td></td>
<td>C50 Access to materials within construction site</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>C51 Availability of materials</td>
<td>-0.8</td>
</tr>
</tbody>
</table>
The following Table includes comments with regard to the complexities it is clear what the complexity is about.

<table>
<thead>
<tr>
<th>Complexities</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10</td>
<td>Changes refers to process of renegotiating contracts after the final investment decision</td>
</tr>
<tr>
<td>C13</td>
<td>Financial viability of the contractor during the project</td>
</tr>
<tr>
<td>C14</td>
<td>Financial viability of the contractor during the project</td>
</tr>
<tr>
<td>C17</td>
<td>For example when the project is not operated from one central point</td>
</tr>
<tr>
<td>C21</td>
<td>This complexity focuses on the alignment between the matrix structure of the project and department structure of the organization.</td>
</tr>
<tr>
<td>C22</td>
<td>Turnover of construction workers during the construction phase of a project</td>
</tr>
<tr>
<td>C23</td>
<td>The number of Joint Venture partners during the project</td>
</tr>
<tr>
<td>C30</td>
<td>IT infrastructure related to communication on the project site, but also between project managers.</td>
</tr>
<tr>
<td>C33</td>
<td>Norms and standards related to construction activities on the projects site. This complexity does not relate to norms and standards used by cost estimators.</td>
</tr>
<tr>
<td>C40</td>
<td>For example: hostage taking, act of terrorism</td>
</tr>
<tr>
<td>C42</td>
<td>Economic conditions: exchange rate, oil price, raw material price, etc</td>
</tr>
<tr>
<td>C45</td>
<td>Restrictions/Regulation set by the government with regard to construction workers/contractors</td>
</tr>
<tr>
<td>C46</td>
<td>For example: related to the remoteness of the site location</td>
</tr>
</tbody>
</table>
Appendix 3: List of Interviewed People

<table>
<thead>
<tr>
<th>Name</th>
<th>Date (in 2015)</th>
<th>Company</th>
<th>Role</th>
<th>Years of experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anonym</td>
<td>February 9</td>
<td>Anonym</td>
<td>Project manager</td>
</tr>
<tr>
<td>2</td>
<td>February 11</td>
<td>Anonym</td>
<td>Cost estimator</td>
<td>16-20</td>
</tr>
<tr>
<td>3</td>
<td>February 12</td>
<td>Anonym</td>
<td>Project manager</td>
<td>11-15</td>
</tr>
<tr>
<td>4</td>
<td>February 12</td>
<td>Anonym</td>
<td>Cost estimator/controller</td>
<td>&gt;25</td>
</tr>
<tr>
<td>5</td>
<td>February 13</td>
<td>Anonym</td>
<td>Construction manager</td>
<td>&gt;25</td>
</tr>
<tr>
<td>6</td>
<td>February 16</td>
<td>Anonym</td>
<td>Project director</td>
<td>0-5</td>
</tr>
<tr>
<td>7</td>
<td>February 16</td>
<td>Anonym</td>
<td>Cost estimator</td>
<td>0-5</td>
</tr>
<tr>
<td>8</td>
<td>February 17</td>
<td>Anonym</td>
<td>Project manager</td>
<td>16-20</td>
</tr>
<tr>
<td>9</td>
<td>February 17</td>
<td>Anonym</td>
<td>Project director</td>
<td>5-10</td>
</tr>
<tr>
<td>10</td>
<td>February 18</td>
<td>Anonym</td>
<td>Project manager</td>
<td>5-10</td>
</tr>
<tr>
<td>11</td>
<td>February 19</td>
<td>Anonym</td>
<td>Project director</td>
<td>16-20</td>
</tr>
<tr>
<td>12</td>
<td>February 20</td>
<td>Anonym</td>
<td>Project director</td>
<td>0-5</td>
</tr>
<tr>
<td>13</td>
<td>February 24</td>
<td>Anonym</td>
<td>Project director</td>
<td>&gt;25</td>
</tr>
<tr>
<td>14</td>
<td>February 24</td>
<td>Anonym</td>
<td>Project director</td>
<td>11-15</td>
</tr>
<tr>
<td>15</td>
<td>February 25</td>
<td>Anonym</td>
<td>Project manager</td>
<td>11-15</td>
</tr>
<tr>
<td>16</td>
<td>February 25</td>
<td>Anonym</td>
<td>Cost estimator/controller</td>
<td>21-25</td>
</tr>
<tr>
<td>17</td>
<td>February 27</td>
<td>Anonym</td>
<td>Project director</td>
<td>11-15</td>
</tr>
<tr>
<td>18</td>
<td>March 4</td>
<td>Anonym</td>
<td>Project director</td>
<td>&gt;25</td>
</tr>
<tr>
<td>19</td>
<td>March 5</td>
<td>Anonym</td>
<td>Project manager</td>
<td>5-10</td>
</tr>
<tr>
<td>20</td>
<td>March 10</td>
<td>Anonym</td>
<td>Project director</td>
<td>21-25</td>
</tr>
</tbody>
</table>

**Brief role descriptions:**

Project director: the project director has overall operational and management responsibility in completing a project. The project director leads a team of project managers from an executive level, meaning that (s)he has the authority to make key decisions. The project director reports to C-level management.

Project manager: The project manager competence is a critical factor affecting project planning, scheduling, and communication (Belassi and Tukel, 1996). His goal is to ensure that the most efficient resources are used (for his part of the project) and the different interests involved are satisfied. The project manager reports to the project director and communicates with the project team on site.

Construction manager: The role description of a construction manager is very diverse. In general construction managers are responsible for running and managing a construction site. They prepare the project site and communicate with a wide variety of actors during construction, for example the client, subcontractors, suppliers and workforce.

Cost estimator: A cost estimator prepares estimates during several stages in the project life cycle. Hence a cost estimator is also responsible for setting up the estimate for use in selecting vendors and subcontractors, also called the tender estimate. Furthermore the cost estimator may be involved at controlling the cost during the execution phase of a project, i.e. making sure the actual cost stay within the estimated cost.
Appendix 4: Survey

Survey about project complexity and labour productivity

Welcome to the survey about project complexity and labour productivity. This survey is part of a master thesis research project executed by a student of Delft University of Technology.

The survey can broadly be divided into four parts, which are listed below.

Part A: Introductory questions;
Part B: Project characteristics;
Part C: Project complexity and labour productivity;
Part D: Cost estimation and strategic behaviour.

Please note that:

- Your responses are completely anonymous. Future publications about this research will never refer to any project, company or person involved.
- Responses will only be saved after you have completed the survey.
- You can only take the survey once, but you can edit your responses after you have completed the survey, until the survey is closed 3 days before the interview.
- The survey will take about 30 minutes to complete.
- You can respond with don’t know if the question does not apply to your job responsibilities.

Thank you for your effort and kind cooperation.

Ernst Vanson
Delft University of Technology
Systems Engineering, Policy Analysis and Management

* Required

Part A: Introductory questions

Your responses are completely anonymous. Future publications about this research will never refer to any project, company or person involved.

1. Your name *
   Please fill in your name

2. Company name *
   Please fill in your company name

While filling in this survey, please answer all questions for a recent, completed project you were involved in. Please answer the rest of the survey questions from the perspective of the role you choose below.

3. What was your role in this project? *
   You may have changed roles during the project. Please choose what was your last role.
   Mark only one oval.
   - Project Director
   - Project Manager
   - Construction Manager
   - Scheduler
   - Cost Estimator
   - Other

4. How many years of working experience do you have in the role chosen in the previous question? *
   Mark only one oval.
   - No experience
   - Less than 5 years
   - 5 to 10 years
   - 11-15 years
   - 16-20 years
   - 21-25 years
   - More than 25 years

5. Was the project performed in the Netherlands? *
   Mark only one oval.
   - Yes
   - Other

6. For a recent, completed project you were involved in, please indicate the sector within the process industry wherein the project was performed.*
   Think about a project where construction activities were performed, for example piping, installing equipment, etcetera.
   Mark only one oval.
   - Bulk Materials Handling
   - Food Engineering
   - Oil and Gas
   - Chemicals
   - Pharmaceuticals
   - Engineering, Procurement and Construction

Towards accurate labour hour estimates for capital projects in the construction industry
MSc Thesis Ewout Vossen

7. In which part of the oilgas value chain were the construction activities performed?
   - Mark only one oval:
     - Upstream
     - Midstream
     - Downstream

6. Please indicate how you would categorize your project. *
   - Mark only one oval:
     - Onshore – greenfield
     - Onshore – brownfield
     - Offshore – greenfield
     - Offshore – brownfield
     - Other: ____________________

5. Please indicate how you would categorize your project.
   - Mark only one oval:
     - Greenfield
     - Brownfield
     - Not applicable
     - Other: ____________________

Part B: Project characteristics

10. What was the planned duration of this project as determined on the Final Investment Decision?
    The Final Investment Decision is made at the end of Phase 1, see Figure below.
    - Mark only one oval:
      - 0 – 2 years
      - 3 or 4 years
      - 5 or 6 years
      - More than 6 years

11. What were the main construction activities your project team was involved in during the project? *
    Construction Activity 1
    ____________________

12. Construction Activity 2
    ____________________

13. Construction Activity 3
    ____________________

14. Most of the activities I performed within the project were [choose below] related
    - Mark only one oval:
      - Business
      - Engineering
      - Finance
      - Other: ____________________

15. What is the approximate maximum of people (including construction workers) working simultaneously on the project? *
    For Phase 2 of the project, as indicated in the figure above, the maximum is between:
    - Mark only one oval:
      - < 50 people
      - 50-100 people
      - 100-150 people
      - 151-200
      - Other: ____________________

Part B: Project characteristics, continued
Questions regarding your most recent, completed project.
16. What was the estimated capital expenditure of the project? *
   Estimate at the Final Investment Decision. The Final Investment Decision is made at the end of Phase 1.
   Mark only one oval.
   □ Less than 20 million USD
   □ 20-40 million USD
   □ 40-60 million USD
   □ 60-80 million USD
   □ 80-100 million USD
   □ 100-500 million USD
   □ 500 million - 1 billion USD
   □ > 1 billion USD
   □ Do not know or do not want to share

18. Was the labour cost estimate met in this project? *
   Please note: LABOUR cost estimate. This includes Phase 2 as visualized in the figure above.
   Mark only one oval.
   □ Labour cost estimate was exceeded by more than 20%
   □ Labour cost estimate was exceeded by 11 to 20%
   □ Labour cost estimate was exceeded by up to 10%
   □ Labour cost estimate and realization were about similar
   □ Realized labour costs were up to 10% less than the estimated costs
   □ Realized labour costs were between 11 to 20% less than the estimated costs
   □ Realized labour costs were more than 20% less than the estimated costs
   □ Do not know or do not want to share

Part C: Project complexity and labour productivity

Cost Estimate Variance (CEV) can be described as the difference between "Scheduled Cost" and "Real Cost". In other terms, it is the difference between the "Budgeted Cost of Work Scheduled" and "Actual Cost of Work Performed". This is visualized in the figure below.

Cost Estimate Variance (CEV) = Budgeted Cost of Work Scheduled - Actual Cost of Work Performed

When there is a cost overrun, the CEV is NEGATIVE (-), this means that "Actual Cost of Work Performed" > "Budgeted Cost of Work Scheduled".

When there is no cost overrun, the CEV is POSITIVE (+), this means that "Actual Cost of Work Performed" < "Budgeted Cost of Work Scheduled".

Part C: Project complexity and labour productivity

Sub category: International component

Questions regarding your most recent, completed project
Towards accurate labour hour estimates for capital projects in the construction industry
MSc Thesis Ewout Vossen
### Part C: Project complexity and labour productivity

**Sub category: technology**

Questions regarding your most recent, completed project

**22. Please indicate how strongly the following complexities contributed to a variance in budgeted costs and actual cost**

Cost Estimate Variance (CEV) can be described as the difference between budgeted and actual cost. Mark only one oval per row.

<table>
<thead>
<tr>
<th>Greatly negative CEV</th>
<th>Slightly negative CEV</th>
<th>Neutral</th>
<th>Slightly positive CEV</th>
<th>Greatly positive CEV</th>
<th>Do not know / Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open to new technologies for construction activities by project stakeholders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adequate IT infrastructure and application in project (digital solutions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency of design changes due to technical reasons (for example, technical risks: defects, replacement or substitution of material)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical dependencies between construction tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contracting norms and standards, clarity of technical specifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strict technical quality requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adequacy of method of construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design errors made by designers (unclear and inadequate details in drawings)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of experience by project team with (new) technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sub category: external**

Questions regarding your most recent, completed project

**23. Please indicate how strongly the following complexities contributed to a variance in budgeted costs and actual cost**

Cost Estimate Variance (CEV) can be described as the difference between budgeted and actual cost. Mark only one oval per row.

<table>
<thead>
<tr>
<th>Greatly negative CEV</th>
<th>Slightly negative CEV</th>
<th>Neutral</th>
<th>Slightly positive CEV</th>
<th>Greatly positive CEV</th>
<th>Do not know / Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclement weather (rain, wind, low temperature)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor ground conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural disasters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dependencies of external stakeholders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability of project environment (economic conditions: exchange rate, oil price, raw material price, etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government policy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legal disputes between project participants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breach of an asset or site through physical interference (hostage taking, act of terrorism)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Part C: Project complexity and labour productivity

**Sub category: materials/transportation**

Questions regarding your most recent, completed project
## Part C: Project complexity and labour productivity

### Sub category: Financial

Questions regarding your most recent, completed project:

25. Please indicate how strongly the following complexities contributed to a variance in budgeted costs and actual cost.

Cost Estimate Variance (CEV) can be described as the difference between budgeted and actual cost.

Mark only one oval per row.

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Greatly negative CEV</th>
<th>Slightly negative CEV</th>
<th>Neutral</th>
<th>Slightly positive CEV</th>
<th>Greatly positive CEV</th>
<th>Do not know / Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>High amount of capital expenditures (CAPEX)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractor financial difficulties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project owner financial difficulties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shortage of budget for labour as a result of strategic behavior within project organization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part C: Project complexity and labour productivity

Sub category: contracts

Questions regarding your most recent, completed project:
26. Please indicate how strongly the following complexities contributed to a variance in budgeted costs and actual cost.

Cost Estimate Variance (CEV) can be described as the difference between budgeted and actual cost. Mark only one oval per row.

<table>
<thead>
<tr>
<th>Complexity of contract documents</th>
<th>Greatly negative CEV</th>
<th>Slightly negative CEV</th>
<th>Neutral</th>
<th>Slightly positive CEV</th>
<th>Greatly positive CEV</th>
<th>Do not know / Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractual conflicts between contractor and consultant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of main contract types</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes to the terms of ownership or terms of the ownership agreement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venture Production Sharing agreement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment related to the public by interest groups</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

27. To what extent do you think the Cost Estimate Variance with regard to labour was caused by Delta Labour Hours (i.e., labour productivity was lower than expected)? Delta Labour Hours can be described as the difference between scheduled and real labour hours. Cost Estimate Variance (CEV) can be described as the difference between budgeted and actual cost. Mark only one oval.

- Very little
- Little
- Neutral
- Much
- Very much
- Do not know or do not want to share

Part C: Project complexity and labour productivity

Labour hours are an important input for making labour estimates for construction workers in the execution phase of a project. Regarding this phase, “Delta Labour Hours” (DLH) can be described as the difference between “Scheduled labour hours” and “Real labour hours” (hours billed at the completion of the project).

Delta Labour Hours (DLH) = Scheduled labour hours - Real labour hours

- A negative (−) DLH means that “Real labour hours” > “Scheduled labour hours”: More labour hours needed than scheduled.
- A positive (+) DLH means that “Real labour hours” ≤ “Scheduled labour hours”: Less labour hours needed than scheduled.

28. Category: International component

- Mark only one oval.
  - Number of different nationalities
  - Different time zones
  - Communication problems due to cultural differences

29. 

- Mark only one oval.
  - Number of different nationalities
  - Different time zones
  - Communication problems due to cultural differences
30. *
Rank 3. 
Mark only one oval.
- Number of different rationalities
- Different time zones
- Communication problems due to cultural differences

Part C: Project complexity and labour productivity

Please rank the complexities using the drop-down list.

Rank 1: Highest impact on Delta Labour Hours
Rank 2: Second highest impact on Delta Labour Hours
Rank 3: Third highest impact on Delta Labour Hours

31. Category: experience *
Rank 1. 
Mark only one oval.
- Experience construction workers
- Experience project manager
- Experience cost estimators
- Experience contractor
- Experience construction manager
- Shortage of experienced construction workers

32. *
Rank 2. 
Mark only one oval.
- Experience construction workers
- Experience project manager
- Experience cost estimators
- Experience contractor
- Experience construction manager
- Shortage of experienced construction workers

33. *
Rank 3. 
Mark only one oval.
- Experience construction workers
- Experience project manager
- Experience cost estimators
- Experience contractor
- Experience construction manager
- Shortage of experienced construction workers

Part C: Project complexity and labour productivity
Part C: Project complexity and labour productivity

Please rank the complexities using the drop-down list.

Rank 1: Highest impact on Delta Labour Hours
Rank 2: Second highest impact on Delta Labour Hours
Rank 3: Third highest impact on Delta Labour Hours

37. Category: technology

Mark only one oval.

☐ Open to new technologies for construction activities by project stakeholders
☐ Adequate IT infrastructure and application in project (digital solutions)
☐ Frequency of design changes due to technical reasons (for example, technical risks: defects, replacement or substitution of materials)
☐ Technical dependencies between construction tasks
☐ Contradicting norms and standards (clarity of technical specifications)
☐ Strict technical quality requirement(s)
☐ Adequacy of method of construction
☐ Design errors made by designers (unclear and inadequate details in drawing)
☐ Level of experience by project team with new technology

Part C: Project complexity and labour productivity

Please rank the complexities using the drop-down list.

Rank 1: Highest impact on Delta Labour Hours
Rank 2: Second highest impact on Delta Labour Hours
Rank 3: Third highest impact on Delta Labour Hours
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Part C: Project complexity and labour productivity
Please rank the complexities using the drop-down list.

Rank 1: Highest impact on Delta Labour Hours
Rank 2: Second highest impact on Delta Labour Hours
Rank 3: Third highest impact on Delta Labour Hours
Part C: Project complexity and labour productivity

Please rank the complexities using the drop-down list.

Rank 1: Highest impact on Delta Labour Hours
Rank 2: Second highest impact on Delta Labour Hours
Rank 3: Third highest impact on Delta Labour Hours

52. What was the expected TOTAL amount of labour hours in Phase 2 of your last completed project?
A rough estimate is sufficient
Mark only one oval:

Part D: Cost estimation and strategic behaviour
53. What percentage of the TOTAL cost estimate of your last, completed project is for LABOUR? 
Mark only one oval:

- 0-10%
- 10-20%
- 20-30%
- 30-40%
- Over 40%
- Other: ______________________

54. Do you think understanding of project complexities helps to improve the accuracy of labour cost estimates? 
Mark only one oval:

- Very little
- Little
- Neutral
- Much
- Very much
- Do not know

Strategic behaviour

Strategic behaviour can be described as conscious behaviour arising among a small number of competitors or players, in a situation where all are aware of their conflicting interests and interdependence of their decisions.

55. Please indicate to what extent strategic behavior in a capital project organization influences labour cost estimates. 
Mark only one oval:

- Very little
- Little
- Neutral
- Much
- Very much
- Do not know

Concluding

Please note that your responses are completely anonymous. Future publications about this research will never refer to any project, company or person involved.

Thank you for your effort and kind cooperation
Appendix 5: Labour productivity norms

Figure 34: Labour productivity norm (Vliet, 2011)
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