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An empirical assessment of factors affecting performance in Norwegian house construction

Master's thesis in Global Manufacturing Management
Supervisor: Marco Semini
June 2022

Master's thesis

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Preface

This master's thesis was written as part of a 2-year master's degree in Global Manufacturing Management with Production Specialization at the Norwegian University of Science and Technology (NTNU). It was written in the 4th and final semester of the study program and consisting of 30 credits.

The thesis was written in collaboration with Mestergruppen, who provided data and assistance throughout the semester. I would especially like to thank Lars-Fredrik Forberg at Mestergruppen and Tor Teppan at Saltdalshytta for their assistance and guidance along the way, as working with construction was a new and exciting experience.

I would like to thank my supervisor Marco Semini at NTNU, for excellent guidance, ideas, and feedback throughout the semester. I would also like to thank my fellow students for their perspectives and feedback while writing this thesis.

Trondheim, June 2022

Magnus Roald Christensen

Abstract

BACKGROUND: The construction industry is a significant contributor to the society and economy, yet it is often criticized for a lack of performance. Especially time and cost performance are frequently highlighted as areas in need of improvement – if not for external reasons, succeeding in these areas can increase the competitiveness of the organization. In this regard, one segment of the construction industry that has received little attention in research is house construction in Norway.

OBJECTIVE: The overall objective of this thesis is to contribute to the body of knowledge for performance in the house construction context. This is done by fulfilling two research objectives: (1) investigate factors affecting the number of manhours performed by carpenters on-site, in house construction projects, and (2) investigate factors affecting the duration of on-site construction, in house construction projects.

RESEARCH METHODOLOGY: To fulfill the research objectives of this thesis a preliminary study and literature study were conducted to identify factors affecting construction performance. Based on the identified factors, a case study and data analysis were conducted to identify and estimate the effects of factors on construction performance in the context of Norwegian house construction, using multiple regression analysis.

RESULTS: From analyzing 208 construction projects it was found that the number of manhours and construction duration have a statistically significant relationship with project scope and complexity, date of construction start, and construction team (or department). In addition, it shows that the number of manhours has a statically significant relationship with construction during winter and the number of changes to the standard building design.

ORIGINALITY: The research presented in this thesis explores a field that has received little attention in the literature and thereby provides new and useful knowledge on the performance of house construction in Norway. In addition, the analysis in this thesis was conducted using real project records, rather than survey responses, which is a common data collection method in construction research.

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1. Introduction

1.1. Background and motivation

There are many reasons for construction organizations to build faster and reduce costs. Namely, the construction industry is a significant contributor to the overall economy and growth of any country (Zidane and Andersen, 2018). In addition, it is the single largest industry contributing to global greenhouse gas (GHG) emissions, making up 39% of global emissions (IEA, 2019). To this end, construction organizations can reduce emissions by building more efficiently. There are also financial gains to be made from becoming more efficient, as those who are able to deliver projects faster and to a lower cost than the competition will have a competitive advantage (Zidane et al., 2015). Another issue where construction can contribute is in the housing market. In Norway, the purchase price of houses compared to income is higher than ever before (Solheim, 2019). In this regard, the supply of new and affordable housing is a significant factor contributing to the purchase prices of houses (new and used) and market volatility (Paciorek, 2013). Construction organizations can help to relieve pressure on the housing market by building more efficiently and thereby supplying new and affordable housing.

Indeed, there are many reasons for construction organizations to build faster and reduce costs, especially for those involved in house construction in Norway, including contributing to the overall economic growth of the country, reducing GHG emissions of the sector, gaining a competitive advantage, and contributing to the housing market (Zidane and Andersen, 2018, IEA, 2019, Solheim, 2019, Paciorek, 2013). However, several issues arise when trying to improve in these areas (Yang et al., 2010). These issues are described below. Time and cost overruns have become a global phenomenon, which is a situation that occurs when the original schedule or budget has been exceeded (Larsen et al., 2016, Memon et al., 2011, Johnson and Babu, 2020). On average construction projects exceed their original schedule and budget by an average of 61% and 70%, respectively (Barbosa et al., 2017). Poor productivity is also frequently highlighted as a significant issue in the industry (Barbosa et al., 2017, Hasan et al., 2018, Böhme et al., 2018). The issue of poor productivity has been observed in the Norwegian construction industry as well (Statistics Norway, 2022b). Compared to other Scandinavian countries, construction productivity in Norway has decreased over the past 20 years, while other countries have improved or at least decreased less compared to Norway (Todsen, 2018).

The cost of common construction materials has increased over the past years as a result of the COVID-19 pandemic (Figure 1) (Statistics Norway, 2022a). Specifically the cost of wood, rebar, and construction steel has increased by 113%, 52%, and 50%, respectively (Statistics Norway, 2022a). This is especially damaging to the Norwegian construction industry because wood is a primary building material for many types of buildings (Edvardsen and Ramstad, 2014, Schauerte, 2010). Especially in house construction wood is a popular choice of material and is typically used for both cladding and loadbearing construction (Edvardsen and Ramstad, 2014).

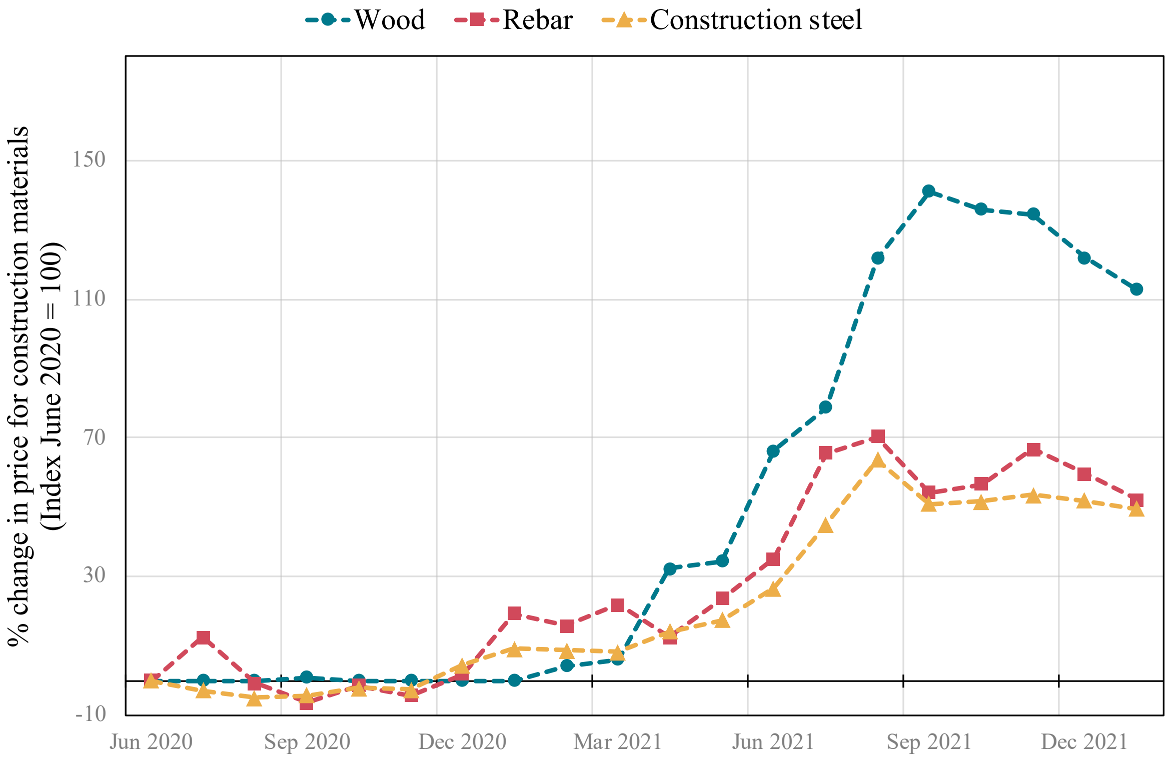

Figure 1: Cost of construction materials (Statistics Norway, 2022a)

To improve the time and cost performance of house construction in Norway, the first step would naturally be to highlight factors affecting the time and cost (Taouab and Issor, 2019, Cha and Kim, 2011). Although construction performance is a well-explored concept in the literature, there is a lack of research that is relevant to house construction in Norway. Namely two issues arise when transferring findings from other studies to house construction in Norway. First, construction in Norway is vastly different from that of other countries, due to government regulations, climate and environment, resource availability (human and material), and building designs. For example, Hasan et al. (2018) performed a literature review on delay factors, in which studies from Europe only made up 6% of all studies. In addition, none of the studies from

Europe was related to house construction. Second, house construction is vastly different from other types of construction. For example, Zidane and Andersen (2018) identified the most common delay factors for Norwegian construction projects, but they consider a broad definition of construction, including building projects (hospitals, schools hotels, offices, facilities, etc.), renewals of existing buildings, and road and railway projects.

It is therefore a need for more research on factors affecting time and cost performance in the context of house construction in Norway. In the next subchapter, the research problem is described in more detail.

1.2. Problem description

There are many reasons for organizations to measure and evaluate their performance. For instance, performance measurement plays a vital role in continuous improvement; a core concept of lean philosophy where one makes incremental improvements to performance over time (Sarhan and Fox, 2013, Nicholas, 2018). An important reason for this is that continuous improvement relies on knowledge of where to direct resources so that improvement efforts have the greatest impact, and performance measurement is one method for highlighting areas of an organization that is lacking or with improvement potential (Nicholas, 2018, Andersen and Fagerhaug, 2002). Hence, to improve performance, one must first measure the performance (Yang et al., 2010, Taouab and Issor, 2019, Cha and Kim, 2011).

"*When you can measure what you are speaking about, and express it in numbers, you know something about it…[otherwise] your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in thought advanced to the stage of science*." (Lord Kelvin, 1824-1907). That is before any improvement initiatives aimed at construction time and cost performance can be deployed, one must identify the factors affecting time and cost. In addition, one must measure the effects that these factors have on time and cost performance.

When the factors have been identified and their effects on performance are known, construction organizations will be able to develop and deploy effective improvement initiatives. In addition, it will enable them to prioritize resources and their effort towards improving factors with the greatest impact on performance. It will also enable organizations to predict how certain changes or new factors will influence their performance. For example, if one specific lean construction technique greatly influences performance then an origination without this technique can roughly predict quantitatively how much their performance will improve by introducing said technique. As another example, if construction strategy is a factor that greatly influences performance, then we can observe quantitatively how much better or worse each strategy is compared to the other strategies, and organizations can adopt the strategy that results in the best performance.

In the next subchapter, the research objective is presented.

1.3. Research objective

The overall objective of this thesis is to contribute to the body of knowledge on construction performance. Especially time and cost performance of house construction projects in Norway are in focus. This is done by fulfilling two research objectives:

Research objective 1: Investigate factors affecting the number of manhours performed by carpenters on-site, in house construction projects.

Research objective 2: Investigate factors affecting the duration of on-site construction, in house construction projects.

For simplicity, the number of manhours performed by carpenters on-site (research objective 1) and the duration of construction on-site (research objective 2) is referred to as performance in the remaining part of this subchapter.

In both research objectives, "investigate" refers to the identification of factors affecting performance, as well as estimating their effects on performance. That is, estimation of the relationship between performance and a given factor, in which we are interested in how much performance changes when the factor increases by one unit. When the effects on performance are known for several factors, we can say something about which factors are the most important, or at least the most influential, concerning performance.

“Factors” refers to descriptive factors of the building that was built and the construction process associated with it. The factors studied in this thesis were developed and based on relevant research and data availability at the collaborating contractor (both topics are described in more detail later). The factors (or variables) are contract sum (the price the customer must pay), number of changes to the standard design, number of carpenters that worked at the project, construction during the winter, starting date of on-site construction, team/department owning and building the project, and the standard building design built. Description and motive of factors are presented in subchapter 3.4.

In the next subchapter, the research scope is presented.

1.4. Research scope

In this thesis, house construction in Norway is in focus. Typical characteristics include the use of wood as a primary building material (cladding and load-bearing structures), a combination of prefabrication and traditional construction, and the use of catalog houses (Smith, 2009, Edvardsen and Ramstad, 2014, SINTEF, 2015). These characteristics are described in more detail in subchapter **Error! Reference source not found.**.

Construction projects are performed through a series of phases or steps that aims to achieve an objective by using allocated resources and within a specified timeframe (Lessing et al., 2015, Mesly, 2017). There exist various perspectives on how to divide and organize the construction process into phases or steps, however, typical steps for house construction in Norway can be summarized as shown in Figure 2 (Eikeland, 2001, Ingvaldsen and Edvardsen, 2007, Bygg21, 2015, Pan and Goodier, 2012, Bargstädt, 2015). Although the construction process consists of many activities, in this thesis the focus is aimed at the steps where a physical structure is built on site. Consequently, any prefabrication processes, or other types of off-site construction, are excluded from the scope of this thesis. However, on-site construction activities are sometimes influenced by previous steps in the construction process. Sometimes, it is, therefore, necessary to address or highlight concepts that are not strictly related to on-site construction activities. For example, the contract sum and building design are two factors studied in this thesis that originate outside on-site construction, however, both influence the work of on-site construction activities.

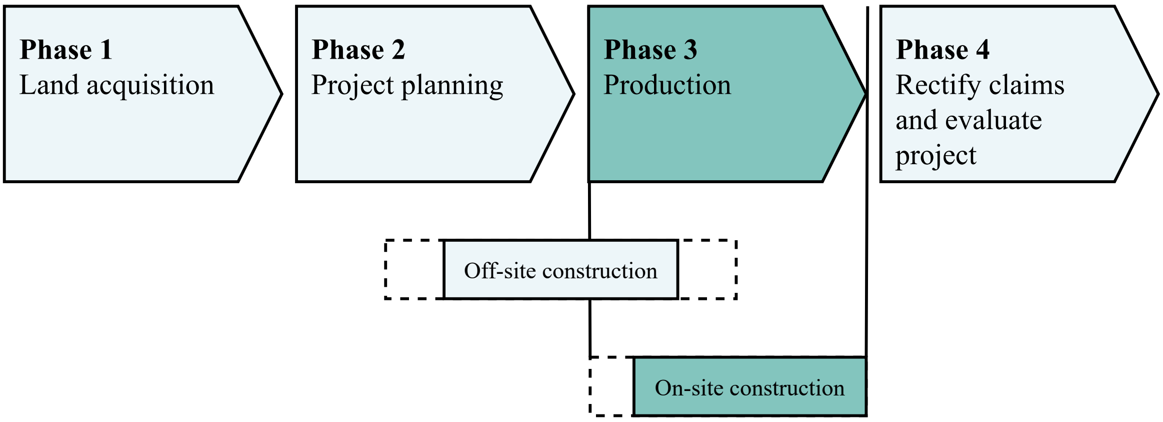

Figure 2: Typical process of a house construction project in Norway

As part of this thesis, the performance of house construction projects is measured. Two performance measures are considered, in which the number of construction days with on-site construction activities is considered a measure of time performance (research objective 2), and the number of manhours performed by carpenters on-site is considered a measure of cost performance (research objective 1). Description and motive for these measures are presented in subchapter 3.4. Other types of performance are outside the scope of this thesis (e.g., customer satisfaction, health, and safety, sustainability, etc.).

The factors studied in this thesis are contract sum (the price the customer must pay), number of changes made to the standard design, number of carpenters that worked on the project, construction during the winter, on-site construction start date, team/department owning and building the project, and the standard building design built. Description and motive for these factors are presented in subchapter 3.4. The scope of this thesis is therefore constrained to these factors. Although, discussion of other factors is relevant at times.

1.5. Thesis structure

This thesis consists of six chapters. A brief description of each chapter is presented below.

Chapter 1: Introduction

Background context and motivation for the research problem are presented. The research objective and scope are also presented.

Chapter 2: Theoretical background

Relevant theoretical concepts are described, including relevant construction concepts, performance measurement and assessment in construction, factors affecting construction performance, and the application of multiple regression (in general and in a construction context).

Chapter 3: Research methodology

The research strategy and relevant techniques are presented, including the presentation of a preliminary study, literature study, case study, and data analysis using multiple regression.

Chapter 4: Data analysis and results

The application of multiple regression analysis to fulfill the research objective is presented. In this chapter, construction projects are analyzed to identify factors affecting construction performance, as well as estimate their effects on performance.

Chapter 5: Discussion

Results from the data analysis are discussed from the perspective of the collaborating contractor (the owner of the projects analyzed). Limitations and further work of this thesis are also presented.

Chapter 6: Conclusion

The main findings of this thesis are presented.

2. Theoretical background

This chapter describes theoretical concepts relevant to the work presented in this thesis. It consists of five parts. (1) Construction characteristics are described so that a fundamental understanding of the construction process is established. In addition, terminology and concepts related to construction are used throughout this thesis. (2) Performance assessment is described, especially for construction performance. That is, performance definition and performance measurement are described. In addition, common construction performance measurements are described. These concepts are important to the analysis of performance, as presented later in this thesis. (3) Factors affecting construction performance are described so that relevant factors (or variables) could be designed and analyzed in the data analysis part of this thesis. (4) Multiple regression analysis (concepts and their application) is described as it was the research technique of choice for data analysis. (5) The application of multiple regression analysis in the construction context is presented so that an understanding of previous relevant work is established.

2.1. Construction

In this subchapter, relevant construction concepts are defined.

2.1.1. Construction project

The construction of a building or structure is typically performed as a project. According to Samset (2014), a project consists of an objective that requires a specified workload, in which certain activities must be performed within an agreed-upon timeframe and budget. According to Project Management Institute (2017), from the project manager's perspective, a project is a series of overlapping activities. Rolstadås et al. (2020) characterize projects as work with time and resource constraints, that is performed as a temporary endeavor, consisting of interdisciplinary activities, and is highly complex.

On the surface, construction projects are not much different from other types of projects. According to Lessing et al. (2015) and Mesly (2017), a construction project is a series of activities that aims to achieve an objective by using allocated resources and within a specified timeframe. However, beneath the surface, construction projects face challenges unique to the industry. According to Silva et al. (2016), construction projects are high in risk and complexity because construction organizations have a wide divergence of project sites, experience high pressure and demand, involve many project participants, stakeholders have different objectives, and utilize increasingly complex construction techniques. In house construction, organizations often build a few standard designs, and thus some repetitive elements exist. However, repetitive elements in project deliverables and activities do not change the fundamental and unique characteristics of the project work (Project Management Institute, 2017).

2.1.2. Production systems and prefabrication

According to Edvardsen and Ramstad (2014), the use of prefabricated elements and modules is becoming more common for house construction in Norway. That is when parts of or the entire physical structure are produced in a factory off-site and transported to the construction site. In comparison, traditional construction is when construction materials and components are delivered to the construction site and then built. There are many benefits to using prefabrication, namely access to lifting equipment, use of automized tools, and working in a stable working environment regardless of the outside environment. Especially for house construction, prefabrication offers better moisture control, which can be a challenge considering that most houses in Norway are built using wood as a primary building material. In addition, prefabrication is well suited for house construction as a relatively high volume is needed to justify the investment needed to build a factory for prefabrication.

In practice, there are different ways to combine traditional construction and prefabrication techniques to form a unique production system. In Norway, many house contractors use a combination of the two and even customizes the degree of prefabrication for each project, where they consider project scope/size, location, and labor availability (Edvardsen and Ramstad, 2014). Gibb (2001) proposed four generic production systems for construction with respect to the degree of off-site production used. Jonsson and Rudberg (2015) improved upon the work by Gibb (2001) and proposed a framework for classifying production systems with respect to the degree of off-site assembly and the degree of product standardization (**Error! Reference source not found.**). Note that off-site assembly is different from prefabrication, in which off-site assembly refers to the assembly of sub-assemblies (e.g., doors, furniture, light fittings, etc.) individually or in prefabricated elements before they are transported to a construction site.

The degree of off-site assembly considers four types of production systems:

- *Component manufacture and sub-assembly (CM&SA)*: When a low degree of off-site assembly is used, in which most production and assembly are carried out on-site. This is the same as traditional construction, where most or all value-adding activities take place on-site.

- *Prefabrication & sub-assembly (PF&SA)*: When a high degree of prefabrication is used, sub-assemblies are delivered to the construction site. Most of the assembly is therefore performed on-site. For example, walls are prefabricated, but windows and doors are installed on-site.

- *Prefabrication & pre-assembly (PF&PA)*: When there is some degree of prefabrication and assembly off-site. For example, windows are installed in prefabricated walls off-site and then delivered to a construction site.

- *Modular buildings (MB)*: When a high degree of off-site production and assembly is used, with volumetric modules fabricated to a high level of completion off-site, and the only work performed on-site is the assembly of the modules and finishing operations.

The degree of product standardization consists of five categories: *Pure customization*: The product is customized from the start; *Tailored customization*: Involves a basic product that can be customized in the fabrication stage; *Customized standardization*: Products are made to order from standardized components; *Segmented standardization*: Products are made in response to the needs of different groups of customers with the product being standardized for each group; *Pure standardization*: The end product is the same and the customer does not get involved before taking possession of the product.

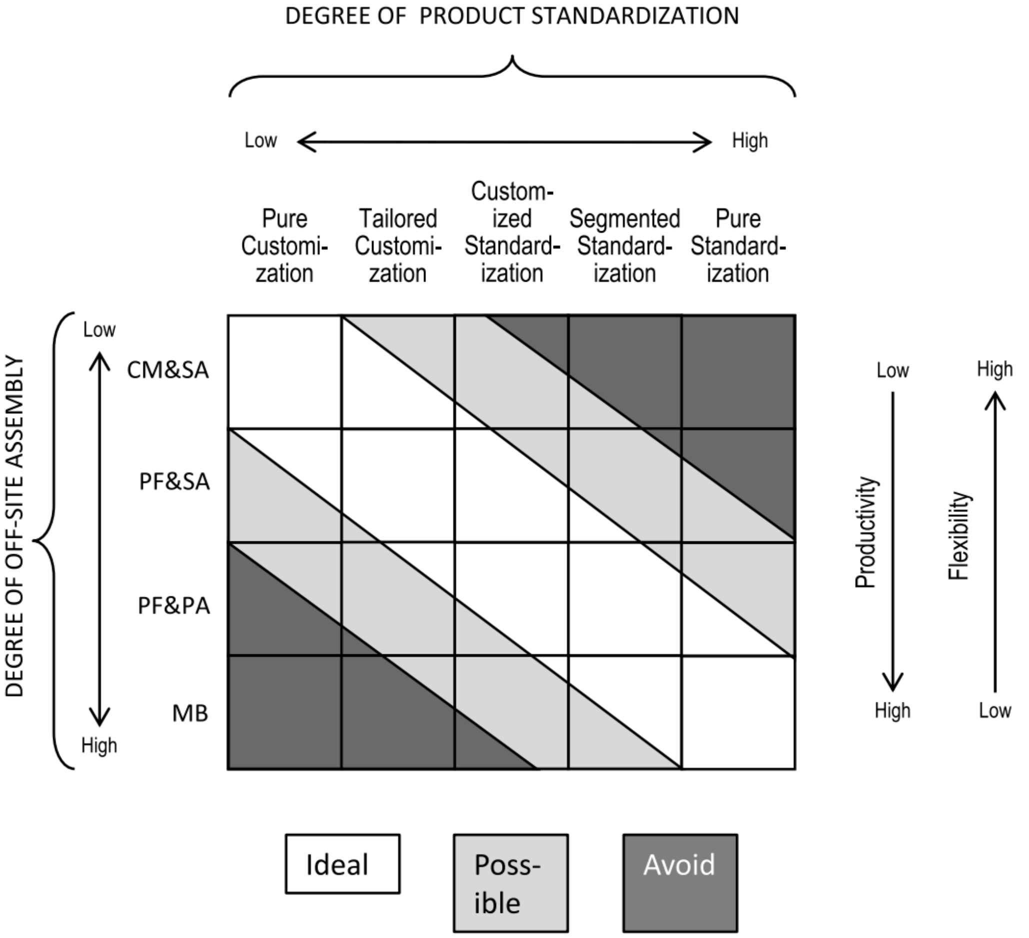

Figure 3: Framework for classifying construction production systems and manufacturing outputs (Jonsson and Rudberg, 2015)

2.1.3. Wooden houses in Norway

Norway, among other Scandinavian countries, has a long history of using wood as a primary building material for house construction (even for load-bearing construction), which has enabled Norway and other Scandinavian countries to perfect the process for prefabrication of wooden houses (Smith, 2009). According to Schauerte (2010), approximately 90% of all existing houses in Scandinavia are wooden houses.

Edvardsen and Ramstad (2014) described four common types of wooden houses in Norway:

- *Single-family house*: A detached building designed to house one family. By detached, it means that the building is at least 8.0 meters from any potential neighbors. Such houses may also have one or two additional apartments, typically on the basement level or as a separate smaller building.

- *Double-family house*: A building that is designed to house two families, living in two separate units or sections of the building. The two units must be approximately the same size. The building may be split vertically and/or horizontally to divide the two units from each other.

- *Chain house*: A building that consists of two or more independent houses, yet connected through some type of intermediate construction, typically a garage, shed, or similar. The houses may be arranged vertically and/or horizontally. Chain houses are also sometimes referred to as single-family houses in a chain.

- *Townhouse*: A building with multiple homes or units that are connected using a shared partition such that two units share the wall separating them from each other. The units may be arranged vertically and/or horizontally.

2.2. Performance measurement and evaluation

This subchapter presents core concepts related to performance measurement and evaluation in a construction context. Especially time and cost performance are in focus, as they are relevant to the research objectives of this thesis. At the end of this subchapter, some relevant previous studies are presented to illustrate how performance may be measured and evaluated in a construction context.

2.2.1. Construction performance – definition and concepts

Andersen and Fagerhaug (2002) use the synonyms *efficiency* and *accomplishment* to describe performance. In a business context, they describe the performance as a measure of how well various activities are carried out to produce a certain level of performance. Tangen (2005) describes the performance as a holistic concept that is composed of economic and operational aspects of an organization. That is, performance can include almost any objective of competition and manufacturing excellence whether it is related to cost, flexibility, speed, dependability, or quality.

The process of measuring and evaluating performance is referred to as performance measurement. Bititci et al. (1997) define performance measurement as the process of determining how successful an organization or group of individuals has been in attaining their objectives. Neely et al. (2002) defines performance measurement as the process of quantifying the efficiency and effectiveness of past action, in which a performance measure (or indicator) is defined as a parameter and used to quantify the past actions.

In the construction context, most organizations rely on some type of performance measurement framework; a complete set of performance measures and indicators derived in a consistent manner according to a forward set of rules or guidelines (Yang et al., 2010, Browne et al., 1997). Among these, the *European Foundation for quality management excellence model*, the *balanced scoreboard model*, and the *key performance indicators model* are the most common in the construction industry (Yang et al., 2010). Such frameworks typically aim to capture and evaluate some holistic idea of performance. For example, the balanced scoreboard is designed to translate the organization's strategy into tangible objectives and measures (Andersen and Fagerhaug, 2002). This is achieved by evaluating organizational performance from four distinct perspectives: financial, customers, innovation and improvement, and internal processes (Kaplan and David, 1992).

Construction performance is typically measured at one of three levels: organization, project, or stakeholder, of which the project level is the most common (Lin and Shen, 2007). That is, the scope of performance measurement is limited to one or a cluster of construction projects. Some construction organizations simply measure organizational performance as the average value of the organization's project performance (KPI Working Group, 2000). Since construction projects, like most other types of projects, are designed to meet some type of specifications, project performance is often perceived as one's ability to adhere to the initial specifications (Pinto and Pinto, 2020). That is, adhering to the project constraints, including a budget, timeframe, available resources, and so on.

To measure and evaluate the performance of construction projects, many rely on productivity measures, or at least some variation of it (Ahmad et al., 2020, Arashpour and Arashpour, 2015, Vogl and Abdel-Wahab, 2015). However, the meaning of productivity varies depending on its context (Hasan et al., 2018). Generally (not limited to construction), Tangen (2005) finds that the terms productivity and performance are used interchangeably, along with efficiency, effectiveness, and profitability. To clarify this terminology, they proposed the triple-P model (Figure 4). In their model, productivity is at the core and has a straightforward operational definition. That is a ratio of output quantity (i.e., correctly produced products that fulfill their specifications) to input quantity (i.e., all resources consumed in the transformation process). He emphasizes that productivity is purely a physical phenomenon and must therefore be defined as one. Profitability is also a ratio of output to input, but it represents a monetary relationship rather than a physical one. Performance is an umbrella term for excellence and includes both profitability and productivity, as well as other non-cost factors such as quality, speed, delivery, and flexibility. In addition, effectiveness and efficiency are cross-functional when it comes to the three terms above. Effectiveness represents the degree of desired results achieved, and efficiency represents how well resources were utilized during the transformation process.

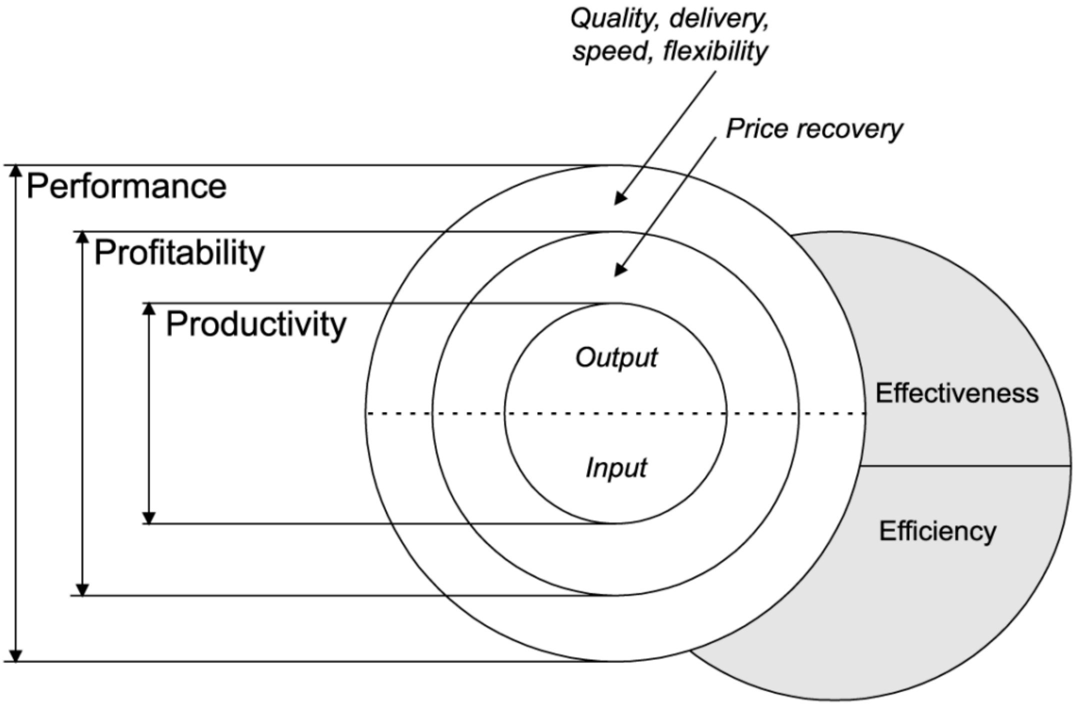

Figure 4: Triple-P model (Tangen, 2005)

2.2.2. Construction performance indicators and measures

Performance measures, and especially indicators, are commonly used to quantify performance or other related concepts (e.g., profitability and productivity). According to Franceschini et al. (2018), performance indicators are important concepts for performance measurement and evaluation, because (when designed properly) they consistently represent reality. They emphasize that using indicators to "distill" large volumes of data is especially important in today's environment, where organizations are becoming increasingly complex and collect more data than ever.

The terms indicators and measures are however often used interchangeably. To clarify, Andersen and Fagerhaug (2002) use the term performance measure when they refer to a specific measurement being made. APICS Dictionary (2022) describe performance measures as the actual value being measured or the raw values collected. Takim and Akintoye (2002) describe performance measures as something that can be measured with some degree of precision and without ambiguity. Mbugua et al. (1999) describe performance indicators as something that specify the measurable evidence necessary to prove that a planned effort has achieved the desired result. According to Andersen and Fagerhaug (2002), performance indicators are often derived from multiple performance measures that have been aggregated and/or transformed into a gauge for interpreting performance. An organization may have several performance indicators, however, only those that focus on the aspects of aspects that are critical for the current and future success of the organization, are labeled as key performance indicators (KPIs) (Parmenter, 2015)

In a construction context, performance indicators derived from time, cost, and quality performance are the three basic and most important indicators for construction projects (Chan and Chan, 2004). These are however not unique to construction. They are more commonly known as the Iron Triangle or the Triple Constraint; a concept that is used to effectively communicate the interrelationships between time, cost, and quality performance (Figure 5) (Pollack et al., 2018). The Iron Triangle is especially useful for evaluating project performance, including construction projects, as it emphasizes the most important constraints of any project (Pinto, 2010). In addition, time, cost, and quality performance is regarded as crucial for achieving success in any construction project (Walker, 1995).

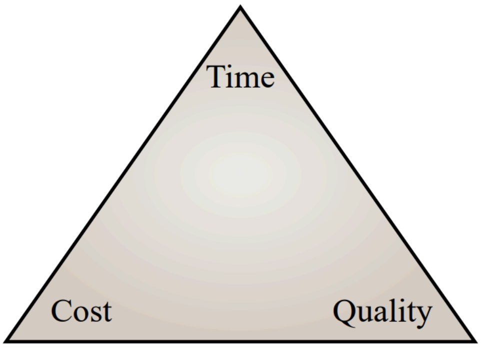

Figure 5: The Iron Triangle (Time, cost, and quality)

Toor and Ogunlana (2010) argue that shifting in functions of buildings, changing demands of users and evolving environmental regulations make the traditional performance indicators (i.e., time, cost, and quality) obsolete. Therefore, they propose that these indicators can no longer be the sole determinant for the performance of construction projects. Instead, they believe that future projects will be evaluated on their operational flexibility, maintainability, energy efficiency, sustainability, and contribution to the overall well-being of the end-user. To address these issues, they propose a general framework for measuring and evaluating the performance of construction projects, consisting of nine performance criteria (Figure 6).

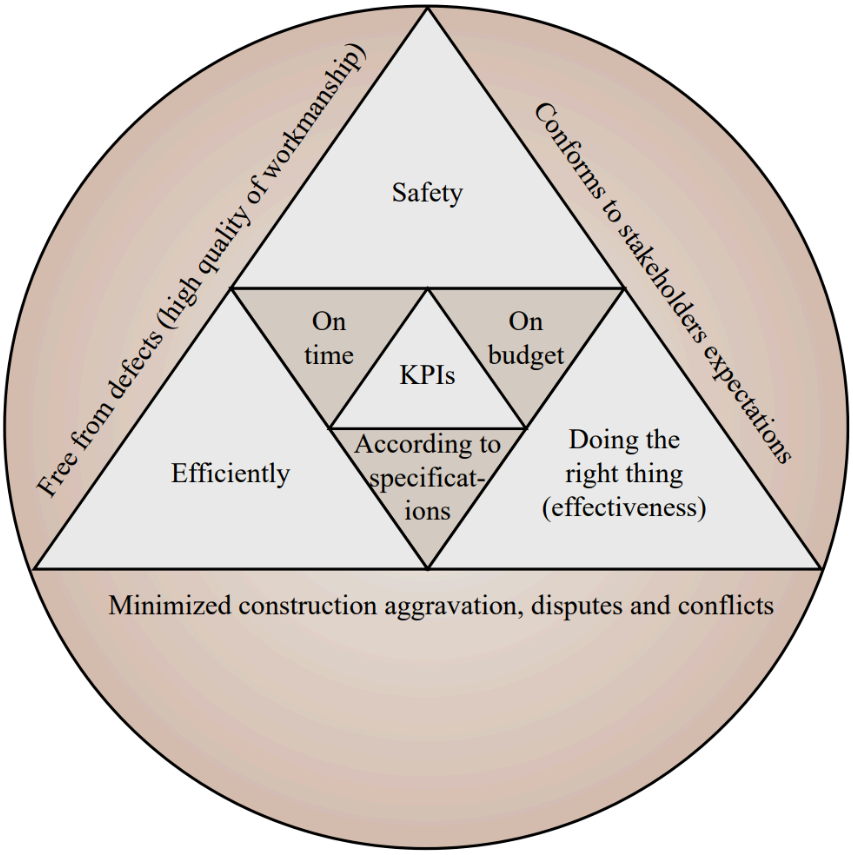

Figure 6: Performance measurement criteria for construction projects. Adopted from Toor and Ogunlana (2010)

Although the performance of construction projects can be viewed from various perspectives, time and cost performance, and indicators of these performance dimensions, remain at the core of performance measurement in the construction context. The next two sections describe construction time and cost performance in more detail.

2.2.3. Time performance in construction

In a construction context, delivering projects to the agreed delivery date is crucial for achieving project success (Pollack et al., 2018). In addition, regardless of due dates, being able to deliver projects faster than the competition can yield a significant competitive advantage (Zidane and Andersen, 2018).

In its most simple form, the time performance of construction projects may be measured as the duration of completing the project (Eq. 1), measured in the number of days or weeks (Chan and Chan, 2004).

$$\text{Duration} = \text{Practical completion date} - \text{Project commencement date} \qquad \text{(Eq. 1)}$$

Another approach is to measure the speed of construction (Eq. 2), by dividing the gross floor area (m^2) by construction time (Eq. 1) (Chan and Chan, 2004).

$$\text{Speed of construction} = \frac{Gross\ floor\ area\ (m^2)}{Construction\ time\ (days\ or\ weeks)} \qquad \text{(Eq. 2)}$$

A more common measure of time performance is that which describes the relationship between the projects' actual duration and planned duration (Larsen et al., 2016, Johnson and Babu, 2020, Memon et al., 2011). Although different variations of this measure, or indicator, exists, they are typically expressed as a ratio or percentage where a negative sign means that the actual duration was shorter than the planned duration, and a positive sign means that the actual duration was longer than the planned duration (Eq. 3).

$$\%\text{time overrun} = \frac{\text{Actual duration} - \text{Planned duration}}{\text{Planned duration}} * 100\% \qquad \text{(Eq. 3)}$$

2.2.4. Cost performance in construction

Cost is another performance dimension that is crucial for achieving project success, in which one aims to eliminate unnecessary costs and operate within a finite budget (Pollack et al., 2018). Like delivering projects faster, being able to build to a lower cost than the competition yields a significant competitive advantage (Zidane and Andersen, 2018). Chan and Chan (2004) emphasize that when measuring construction cost performance, the cost is not only confined to the tender sum or initial contract sum, rather it is the overall cost that a project incurs from inception to completion, which may include any additional costs that arise from variations, modifications during construction, handling legal claims, and rectifying claims.

In its most basic form, the cost performance of a construction project may be measured as the cost per unit (Eq. 4) (Chan and Chan, 2004). That is, the cost (measured in some currency) is divided by the gross floor area (m^2).

$$\text{Unit cost} = \frac{\text{Contract sum}}{\text{Gross floor area } (\text{m}^2)} \qquad \text{(Eq. 4)}$$

Another common measure is that which describes the relationship between actual costs and planned budget (Eq. 5) (Johnson and Babu, 2020, Larsen et al., 2016, Memon et al., 2011).

$$\%\text{cost overrun} = \frac{\text{Actual costs} - \text{Planned budget}}{\text{Planned budget}} * 100\% \qquad \text{(Eq. 5)}$$

2.2.5. Previous studies

Although some common performance measures (or indicators) have been described in previous sections, it is worth acknowledging how other studies have solved the challenges of measuring construction performance.

In the preliminary study of this thesis, Christensen (2021) measured construction productivity as a ratio of time performing value-adding work to the total time spent on work. To measure this type of productivity, a dedicated observer had to be on the construction site under study. Naturally, this is also the biggest drawback of this type of productivity measure. On the other hand, it enabled the observer to categorize the observed activities as value-adding, non-value-adding, and waste. This way, the final measure, along with the data records, revelated much more insight into potential bottlenecks and root causes for poor productivity, compared to any other productivity measure.

Ingvaldsen and Edvardsen (2007) measured the total factor productivity (TFP) of house construction projects in Norway. That is, a productivity measure that uses multiple input factors to produce an output, and since the measure evaluates output against several intangible inputs, it is interpreted as the collective effect of the variation in output which cannot be accounted for by a change in the combined input (Nasir et al., 2014, Park, 2006, Comin, 2010). In their analysis, Ingvaldsen and Edvardsen (2007) used resources consumed (labor and material), capital invested, and energy consumption as input factors to their TFP calculations. Note that they used a financial perspective on productivity and consequently some of the best practices they identified are best practices because they minimize costs, not necessarily lead to the shortest construction time.

Ahadzie et al. (2008) proposed a competency-based multidimensional conceptual model for measuring the performance of mass house building projects. More specifically, they developed a weighted composite measure of performance outcome, consisting of equally weighted performance dimensions: environmental safety, customer satisfaction, quality, and cost-time. The biggest advantage of their approach is the fact that they were able to combine several performance dimensions, so that in their analysis of factors affecting the composite performance measure, they were able to observe the effects of factors on the composite measure, rather than individually. The biggest drawback of their approach is that calculating the composite performance measure relies on survey responses, making it unsuitable for continuous performance measurement.

2.3. Factors affecting construction performance

This subchapter describes factors affecting the time and cost performance of construction projects, namely factors with the potential to influence the number of manhours performed by carpenters on-site (research objective 1) and the duration of on-site construction (research objective 2) are in focus. Such factors may be divided into two categories: (1) factors that lead to time and cost overrun (sometimes referred to as delay), and (2) factors affecting construction productivity.

2.3.1. Time and cost overrun

Time and cost overruns are evident issues in the construction industry (Olawale and Sun, 2010). That is a situation when the original schedule or budget has been exceeded (Larsen et al., 2016, Memon et al., 2011, Johnson and Babu, 2020). In fact, among the 100 largest construction organizations in the USA, projects exceed their original schedule and budget by 61% and 70%, respectively (Barbosa et al., 2017). The issue of time and cost overruns represents a severe challenge in the industry, as it can have serious consequences for the organization, including loss of profit, disputes between the involved parties, poor quality due to rushing the project, getting a bad reputation, claims submitted by the customer, and loss of skilled employees (Mukuka et al., 2015).

In a literature review, Olawale and Sun (2010) identified several factors affecting time and cost overruns in construction projects in the UK, of which the ten most significant factors include design changes, inaccurate evaluation of the project's time/duration, the complexity of works, risk and uncertainty associated with projects, non-performance of sub-contractors and nominated suppliers, lack of proper training and experience of project managers, discrepancies in contract documentation, low skilled manpower, the conflict between project parties, and unpredictable weather conditions. They argue that effective project control is necessary to combat the issue of time overruns, to which they propose several preventive and corrective measures that organizations can implement. One can therefore argue that project control factors, as proposed by Olawale and Sun (2010), are equally important factors affecting time overruns, although with a positive effect.

The issue of delays in construction projects is closely related to time and cost overruns, in fact, it is sometimes referred to as the cause of time and cost overruns, as well as having a negative effect on efficiency and productivity (Durdyev et al., 2017, Zidane and Andersen, 2018, Larsen et al., 2016, Arditi et al., 2017, Sanni-Anibire et al., 2020). Hence, the definition of delays in construction is much like that of time and cost overruns. Zack (2003) describes it as an act or event that extends the duration of the project. Assaf and Al-Hejji (2006) describe it as a time or schedule overrun that causes the project completion to go beyond the delivery date that was agreed upon by the involved parties.

Sanni-Anibire et al. (2020) performed a meta-analysis on delays in construction, in which they identified a total of 36 causes for delay. The causes were standardized and organized into nine delay categories (Table 1). Specifically for residential construction, included studies originated in Ghana, Kuwait, Nigeria, India, and Jordan. Although these countries and their construction industries are vastly different from that of Norway, the authors emphasize that both developing and developed countries generally experienced similar challenges regarding delays.

Zidane and Andersen (2018) identified similar causes for delay in their literature review, although, in their study, they ranked the delay causes according to frequency and severity as reported by construction professionals in Norway. This ranking resulted in the following top ten delay causes: design changes during construction (change orders); delay in payment of contractors; poor planning and scheduling; poor site management and supervision; incomplete management and supervision; incomplete or improper design; inadequate contractor experience/building methods and approaches; sponsor/owner/client's financial difficulties; and poor labor productivity and shortage of skills. It should be noted that their study was based on building projects (hospitals, schools, hotels, offices, facilities, etc.), renewals of existing buildings, and road and railway projects.

Table 1: Most common delay causes globally. Adopted from Sanni-Anibire et al. (2020)

Category	**Causes of delay**
Material	Shortage in construction materials (unforeseen material damages Slow delivery of materials Waiting for approval of shop drawings and material samples
Manpower	Shortage in manpower (skilled, semi-skilled, unskilled labor) Poor labor productivity Labor disputes and strikes
Equipment	Poor equipment productivity (breakdown/maintenance problems) Shortage in equipment
Contractual relations	Inappropriate construction/contractual management/construction method Slowness in decision making Delay in mobilization Excessive bureaucracy/interference by the owner Delay in approval of completed work/ delay in sub-contractor’s work
Government	Slow permits from municipality/government Government regulations
Financing	Contractor’s financial difficulties Client’s cash flow problems/delay in contractor’s payment Price escalation/fluctuations
Environment	Weather condition Civil disturbances/hostile political conditions
Changes	Design errors/incomplete made by designers (architects an structural drawings) Design variations/change order/increase in scope of work Errors committed due to lack of experience Unexpected foundation conditions encountered in the field Changes in material types and specifications during construction Inaccurate site/soil investigation Frequent change of sub-contractor
Schedule and controlling techniques	Poor site organization and coordination between various parties Poor planning of resources and duration estimation/scheduling Inadequate supervision, inspection, and testing procedures; accidents during Construction/lack of safety measures Poor communication/documentation and detailed procedures Unrealistic time schedule imposed in contract Poor quantification of the contractor or consultant

While others have studied delay causes for general construction, Durdyev et al. (2017) studied delay causes specifically in residential construction projects. They conducted a literature review to identify the most common causes for delay. They then ranked the delay causes according to frequency and severity as perceived by construction professionals in Cambodia. The ranking resulted in the following top ten delay causes: on-site shortage of materials; unrealistic project scheduling; late delivery of materials; shortage of skilled labor; the complexity of the project; labor absenteeism; rain effect on construction activities; design changes; delay by the subcontractor; accidents due to poor site safety; poor communication and coordination; and project size. The delay causes were categorized as related to material and equipment, management, workforce, project, and external. All these categories are represented among the top ten delay causes, which goes to show that delay cannot necessarily be tied to one specific activity, phase, or actor in the construction process. Megha and Rajiv (2013) conducted a similar study, where they ranked delay causes according to frequency and severity as perceived by residential construction professionals in India. Table 2 shows how contractors, developers[1], and architects ranked several categories or sources for delay, including themselves. Their findings show that typical actors face different types of delays.

Table 2: Ranking of categorical delay causes according to frequency and severity, as perceived by contractors, developers, and architects. Adopted from Megha and Rajiv (2013)

Category	Overall	Contractors	Developers	Architects
Labor	1	1	1	8
Materials	2	3	3	4
Design	3	6	2	1
Equipment	4	2	8	5
Project	5	5	5	3
Contractor	6	8	4	2
Developer	7	4	6	6
Consultant	8	7	7	7
External	9	9	9	9

2.3.2. Productivity

Construction productivity is said to be one of the most important factors affecting overall construction performance, and consequently, it has received considerable attention in the literature (Kazaz and Ulubeyli, 2007, Hasan et al., 2018). Researchers have highlighted the

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[1] Developers, sometimes referred to as real-estate developers, are those who purchase raw land, obtain the necessary permits, and builds basic infrastructure (e.g., sewers, water supply, electric lines, streets, etc.)

importance of construction productivity and how it can affect organizational competitiveness (Park et al., 2005), economic production activities (Singh et al., 2000, Tangen, 2005), and profitability (Barbosa et al., 2017, Choi et al., 2013).

There are different types of productivity measurements, namely single-factor, multi-factor, and total-factor productivity (Tran and Tookey, 2011, Ahmad et al., 2020, Lowe, 1987). All types have in common that they measure the ratio of output to input, however, the scope of what constitutes as input and output vary for each type of measurement (Lowe, 1987, Andersen and Fagerhaug, 2002, Park, 2006). In single-factor measures, the input typically captures one aspect or activity of the construction process (i.e., labor, capital, or material), while in multi-factor measures, the input is the sum of several aspects or activities (Tran and Tookey, 2011, Ahmad et al., 2020). Comin (2010) describes total-factor productivity as the portion of output not explained by the inputs used in production. Lowe (1987) proposed a total factor productivity approach for construction, in which the productivity of labor, capital, land, and raw materials are aggregated within a financial framework. Ahmad et al. (2020) find that this terminology (single-, multi-, and total-factor productivity) is used interchangeably among researchers and practitioners, which is clouding the debate concerning construction productivity. For example, they find that ‘productivity’ is often used interchangeably with ‘efficiency’, ‘multi-factor’ with ‘total-factor’, and ‘single-factor’ with ‘partial factor’. Nevertheless, the authors note that single-factor productivity is the most common type of productivity measurement. As such, the remaining part of this chapter refers to single-factor productivity, unless other is specific.

For example, the national statistical institute of Norway measure construction productivity as gross product per manhours spent on-site (Todsen, 2018). Lowe (1987) argues that problems arise when single-factor definitions of construction productivity are employed, as improved labor (or capital) productivity may not necessarily lead to more efficient and cheaper production. Others have also criticized the use of single-factor measurements for being narrow and unable to capture the true scope and economic impact of construction (Ahmad et al., 2020), being prone to measurement errors (Vogl and Abdel-Wahab, 2015), and unable to deal with increasing project complexities (He et al., 2009, Shenhar, 2001).

Hasan et al. (2018) conducted an extensive literature review on construction productivity, including 131 studies describing factors affecting productivity. Among the included studies, most originated in Asian countries (61%), while studies that originated in European countries made up a significantly smaller portion (6%). Although, the authors note that despite regional differences in social, cultural, economic, political, and environmental conditions, the reported productivity factors repeatedly appear in both developing and developed countries. They found the most important productivity factors to be non-availability of materials, inadequate supervision, shortage of skill, lack of proper tools/equipment, incomplete drawings and specifications, poor communication, rework, poor site layout, adverse weather conditions, and change orders.

Barbosa et al. (2017) highlight several root causes for poor construction productivity, as well as propose appropriate solutions. The authors identify four operational root causes that occur in the organization: (1) design process and investment are inadequate; (2) poor project management and execution basics; (3) insufficiently skilled labor at the frontline and supervisory levels; and (4) industry underinvests in digitalization, innovation, and capital. In a survey conducted by the authors, responders (contractors, owners, and suppliers) replied that, from their perspective, root cause no. 1 and 3 are especially important for improving productivity. To solve root cause no. 1, the authors propose that organizations must rethink the design and engineering processes. This includes improving design and process outcomes, ensuring early collaboration from all parties involved in the design, and encouraging repeatability of design across projects. To solve root cause no. 3, the authors propose that organizations must reskill the workforce. This includes building an apprenticeship model, developing frontline training, and ensuring knowledge retention and management.

Barbosa et al. (2017) also find that increasing project and site complexities are a significant factor in poor construction productivity. To solve this issue, the authors propose that organizations need to leverage new technologies by investing in a chief digital/tech/innovation office and team, making 3D BIM universal, introducing drones and unmanned aerial vehicles for scanning, monitoring, and mapping, and using digital collaboration and mobility tools on portable devices. Zhu and Mostafavi (2017) argue that increasing construction complexity is influencing productivity levels. They consider two types of project complexity, detail complexity and dynamic complexity. Detail complexity is time-independent complexity related to structural features of the project (e.g., project size, number of stakeholders, relationships between different component of buildings or facilities, interfaces between different trades and stakeholders, etc.). Since these factors are fixed, the detail complexity of a project does not change over time. Dynamic complexity is time-dependent complexity related to the operational behaviors of the project, including internal factors (e.g., human behavior, material flow, and changes requirement and scope) and external factors (e.g., social, political and economic issues, and weather conditions, etc.). These factors are not necessarily known for certain at the beginning of a project and change over time. To cope with detail and dynamic complexity of construction projects, they highlight absorptive, adaptive, and restorative capacity as three important traits. That is, one's ability to handle the complexity of construction projects, either from the beginning or as they arise during construction. Böhme et al. (2018) identified several root causes that have a negative effect on construction productivity. Among these, complexity of site layout was a common cause for poor productivity. Other factors included poor site coordination and communication, lack of factual approach, lack of process and sub-contractor control, and inclement weather.

Among other objectives, lean construction aims to eliminate waste in the construction process (Nicholas, 2018). Use of lean construction techniques are therefore highly relevant to construction productivity and has received a considerable amount of attention in the literature (Singh and Kumar, 2020). In contrast to traditional construction management, which focus on setting and meeting targets such as schedule and budget, Zhang et al. (2005) proposed a process and site-oriented approach that defines the minimization of resource waste as its key objective. They argue that this approach is has the benefits of emphasizing the importance of an ongoing effort that includes everyone who is in any way involved in planning, controlling, and executing the work. In a case study of brick houses, they find that focusing on waste minimization resulted in drastic productivity improvements. However, despite extensive research on lean construction, the use of such techniques is not included as a factor affecting productivity in literature review studies such as that of Hasan et al. (2018).

Arashpour and Arashpour (2015) found that variability has a negative effect on construction productivity, as well as overall project performance. In terms of construction, external variability factors may refer to extreme weather conditions or nonstationary market demand (El-Adaway, 2012, Ahmad, 1999, Barriga et al., 2005). Internal variability may refer to factors such as unstable workflows, workforce motivation, and quality issues causing rework (Laufer et al., 1999, Palaniappan et al., 2007, Han et al., 2008, Josephson et al., 2002, Arashpour et al., 2012). Arashpour and Arashpour (2015) quantified the effects of variability through a simulation study of multi-story residential buildings. Their findings show that construction productivity is very sensitive to workflow variability in the form of rework and when activities commence. Maraqa et al. (2021) analyzed 18 residential high-rise construction projects and found that implementing lean and BIM improves the workflow by reducing out of sequence work, reducing interference of trade crews with one another, and increasing the degree of work continuity between tasks. Their findings suggest that lean and BIM complement each other, as the effects of one method are accelerated when both methods are used in combination.

Panas and Pantouvakis (2018) find that labor productivity in civil engineering projects increases over time, especially for repetitive activities. This phenomenon is also referred to as the learning curve, which in the construction context means that the cost per unit produced decreases exponentially over time or for each unit produced (Parker and Oglesby, 1972). That is, substantial improvements are made quickly in the beginning but then it gets more difficult to improve as time passes. Pellegrino et al. (2012) studied the construction of 15 multi-story concrete buildings in Italy, which have plenty of repetitive activities. According to the basic principle of the learning curve, workers should become more productive for every building they build (Figure 7-left), however, they find that workers only become more productive at the single structure level (Figure 7-right). They argue that this is a result of differences in management at each building, varying site conditions, and changes to crew composition and coordination. On the other hand, Jarkas (2010) find at best a negligible improvement in productivity as the number of units produced increase, while also studying the construction of several multistory concrete buildings.

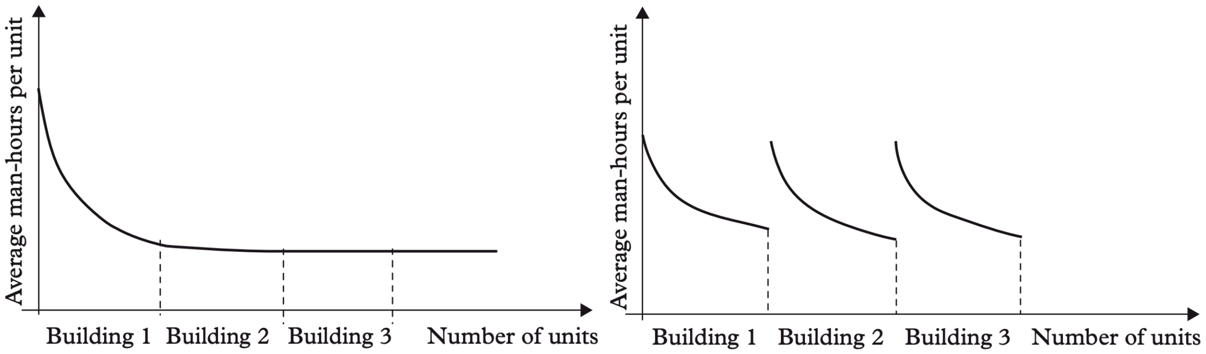


Figure 7: Ideal learning curve for identical buildings and same work conditions (left) and the impact of changing work conditions across consecutive buildings (right) (Pellegrino et al., 2012)

2.4. Multiple regression analysis

Multiple regression analysis (MRA) is a general statistical technique used to analyze the relationship between a single dependent variable and several independent variables Hair (2010). In its most basic form, a multiple regression model is an equation where one dependent variable (Y) is estimated from n independent variables (X), as shown in Eq. 1 (Hair, 2010). Each independent variable is assigned a weight of how much they influence the dependent variable. The weights are referred to as (unstandardized) regression coefficients (b). The regression coefficients can be interpreted as the relationship between the dependent and independent variables.

$$Y_1 = X_1 + X_2 + \cdots + X_n \tag{1}$$

2.4.1. Objectives of regression analysis

Before MRA can be applied to a research problem, the researcher must consider three issues that will define the objectives of the technique, that is, the appropriateness of the research problem, the specification of a statistical relationship, and the selection of the dependent and independent variables (Hair, 2010). These issues are described in more detail below.

Research problems appropriate for multiple regression

According to Hair (2010), the application of multiple regression falls into two broad classes of research problems: prediction and explanation. According to the author, prediction involves the extent to which the regression variate can predict the dependent variable, while explanation examines the regression coefficients (their magnitude, sign, and statistical significance) for each independent variable and attempts to develop a substantive or theoretical reason for these effects of the independent variables on the dependent variable.

Specification of a statistical relationship

Hair (2010) states that MRA is only appropriate when the researcher is interested in a statistical relationship, not a functional relationship. According to the author, a functional relationship is when the impact of each independent variable or factor in an equation is known and thus no error is expected in a prediction. Meanwhile, the author describes a statistical relationship as one where a random component is always present. Moreover, the author characterizes such a relationship by two elements:

(1) When multiple observations are collected, more than one value of the dependent value will usually be observed for any value of an independent variable.

(2) Based on the use of a random sample, the error in predicting the dependent variable is also assumed to be random, and for a given independent variable we can only hope to estimate the average value of the dependent variable associated with it.

Selection of dependent and independent variables

According to Hair (2010), the ultimate success of MRA starts with the selection of variables to include. The author adds that MRA is a dependence technique and therefore the researcher must specify which variable is the dependent variable and which variables are the independent variables. For variable selection, the author suggests that the researcher must consider the following three issues: strong theory, measurement error, and specification error.

Strong theory is the idea that variable selection should be based on a strong theoretical background. Heinze et al. (2018) explain that modern statistical software packages offer a variety of variable selection algorithms (e.g., backward elimination, forward selection, stepwise forward/backward, best subset selection, LASSO, etc.), in which the algorithms use one or several tuning parameters to compare and select among competing models (i.e., models with different combinations of variables). However, such algorithms do not possess background knowledge of the research problem and therefore the researchers should always exert judgment in the variable selection (Heinze et al., 2018, Hair, 2010).

Measurement error refers to the degree to which the variable is an accurate and consistent measure of the concept being studied, more specifically, it is a measure of how nonrepresentative an observed value is from the true value (Hair, 2010). According to Williams et al. (2013), measurement error is problematic as it causes relationships to be underestimated (i.e., bias regression coefficients) and increases the risk of Type II error (i.e., false negatives). Measurement error applies to both dependent and independent variables, however, it is especially important for the dependent variable (Hair, 2010). There are many potential sources for measurement error and therefore Hair (2010) argues that "all variables used in multivariate techniques must be assumed to have some degree of measurement error".

Specification error concerns the selection of independent variables, in which irrelevant variables are included or relevant variables are omitted (Hair, 2010). According to Hair (2010), the inclusion of irrelevant variables impacts the regression variate and thus reduces the interpretability of the model, as well as making testing of statistical significance of the independent variables less precise and reducing the statistical and practical significance of the analysis. The author also explains that excluding relevant variables can seriously bias the results and negatively affect any interpretation of them.

In addition to the issues above, Hair (2010) notes that for any multiple regression model, there should be a 5:1 ratio of samples to number of independent variables. That is, for every independent variable in the analysis, there should be at least five samples.

2.4.2. Regression equation and estimation methods

A linear regression model with multiple terms (i.e., multiple independent variables) can be described using the following equation:

$$y = \beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n + \varepsilon \tag{1}$$

Notation:

y = observed dependent variable
β_0 = y-axis intercept. Value of the dependent variable when all other parameters are set to zero
β_n = n-th regression coefficient
X_n = n-th independent variable
ε = error term

The formulation in Eq.1 is however generic and not fitted to any actual data. To describe the relationship between the dependent and independent variables one must first fit the model to data. In this regard, note that a perfect relationship between the dependent and independent variables is the exception rather than the rule, as relationships are rarely direct, and measurements are rarely error-free (Hutcheson, 2011). The best one can do is to calculate a line of *best-fit* to approximately describe the relationship between the variables (Hutcheson, 2011). This is done by estimating the intercept (β_0) and regression coefficients (β_n) for each of the independent variables (Hutcheson, 2011). Once fitted to the data, the regression model is expressed using the following equation:

$$\hat{y} = b_0 + b_1 X_1 + \cdots + b_n X_n \tag{2}$$

Notation:

$\hat{y}$ = estimated dependent variable

b_0 = fitted intercept value

b_n = n-th fitted regression coefficient

X_n = n-th independent variable value

Several different methods for estimating the regression equation exist (Luo, 2017, Lipsitz, 1992), of which Ordinary Least Squares (OLS) is regarded as the most common method (Hair, 2010, Hutcheson, 2011). The OLS method is performed by using the *least-squares procedure* which aims to minimize the sum of squared error (SSE) in the regression model, that is, minimizing the difference between the observed (y) and the estimated ($\hat{y}$) values (Hair, 2010, Hutcheson, 2011).

The coefficient of determination (R^2) is a statistical measure that is used to assess the goodness of fit for a regression model. According to Hair (2010), R^2 is a measure of the proportion of the variance of the dependent variable about its mean that is explained by the independent variables. The coefficient varies between 0 and 1 (Hair, 2010). If the regression technique is applied correctly, the larger the R^2 value, the greater the explanatory power of the regression model, and thus the better estimation of the dependent variable (Hair, 2010). R^2 should however not be confused with the correlation coefficient (r), also called Pearson's correlation coefficient. According to Hair (2010), the correlation coefficient describes the relationship between two variables, in which the value of r varies between -1 and +1, where +1 indicates a perfect linear relationship, 0 indicates no relationship, and -1 indicates a perfect negative relationship.

One should however be cautious when interpreting the coefficient of determination, Pearson's correlation coefficient, and other types of statistical properties. Matejka and Fitzmaurice (2017) created a collection of datasets that have the same values for mean, standard deviation, and Pearson's correlation coefficient, yet appear vastly different from each other when plotted (**Error! Reference source not found.**). They emphasis that one should use statistical properties and visualizations in combination with each other.

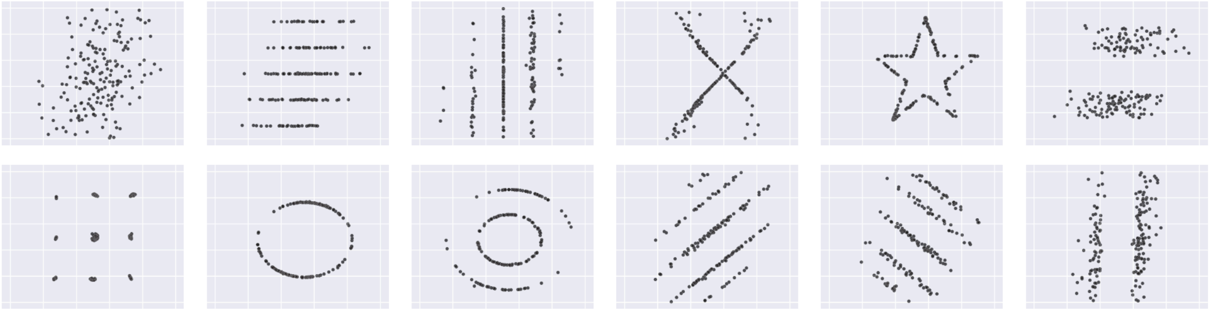


Figure 8: A collection of data sets. While different in appearance, each has the same summary statistics (mean, std. deviation, and Pearson's corr.) to 2 decimal places. ($\bar{x}$ =54.02, $\bar{y}$ = 48.09, sd_x = 14.52, sd_y = 24.79, Pearson's r = +0.32) (Matejka and Fitzmaurice, 2017)

2.4.3. Assumptions for linear regression

When using multiple linear regression, one makes several assumptions about the relationship between the dependent variable and the independent variables, as well as the model's prediction error (Hair, 2010). Violating the assumptions can cause bias coefficients (i.e., over or under-fitting) and unreliable confidence intervals (Chatterjee and Hadi, 2013). For these reasons, testing assumptions is an essential part of any MRA, or indeed any statistical technique (Williams et al., 2013). Hair (2010) proposes four assumptions to be examined. These are linearity of the phenomenon measured, constant variance of the error terms (i.e., homoscedasticity), independence of the error terms (i.e., no autocorrelation), and normality of the error terms distribution. In addition, Daoud (2017) argues that no or little correlation among the independent variables (i.e., no multicollinearity) is required for a reliable model. These assumptions are described in more detail below.

Linearity of the phenomenon measured

The linearity of the relationship between dependent and independent variables represents the degree to which the change in dependent variable is associated with the independent variable (Hair, 2010). Moreover, the concept of correlation is based on a linear relationship, thus making it a critical issue in regression analysis (Hair, 2010). To evaluate the linearity of a given relationship, one can create residual plots, in which the independent variable is plotted against the residuals or partial residuals if there are multiple variables in the model (Hair, 2010). To better visualize potential trends in the data, one may also estimate a nonparametric regression model, of which, locally weighted scatterplot smoothing (LOESS) is a popular alternative (Fox and Weisberg, 2018).

Constant variance of the error terms (homoscedasticity)

According to Hair (2010), the presence of unequal variance (heteroscedasticity) is one of the most common assumption violations. Heteroscedasticity can be identified by plotting standardized or studentized residuals against the dependent variable values and comparing them to the null plot, as this will show a constant pattern if the variance is not constant (Hair, 2010, Williams et al., 2013). In addition to these visualizations, Lavene's test of equality of error variance and Breusch-Pragan test for heteroscedasticity are popular tests for testing the variance of error terms.

Independence of the error terms (no autocorrelation among variables)

Independence of the error terms, or no autocorrelation of the error terms, means that the predicted value is not related to any other prediction: that is, they are not sequenced by any variable (Hair, 2010). Violating this assumption results in biased estimates of standard errors and significance, though the estimates of the regression coefficients remain unbiased, yet inefficient (Chatterjee and Hadi, 2013).

Normality of the error terms distribution

Normally distributed errors are not required for regression coefficients to be unbiased, constant, and efficient, but it is required for trustworthy significance tests and confidence intervals in small samples (Cohen et al., 2014). The larger the sample, the lesser the importance of this assumption (Williams et al., 2013).

The simplest method for testing normality is with a histogram of residuals and conducting a visual check if the distribution approximates that of a normal distribution (Hair, 2010). For small samples, a better method is the use of normal probability plots (Hair, 2010), which is a special case of the Q-Q probability plot for a normal distribution.

In addition to the graphical methods described above, the Anderson-Darling test is a popular formal method to test normality (or other distributions) of samples. In fact, Razali and Wah (2011) compared four of the most common methods used to test normality and found that the Anderson-Darling test is the second most powerful method, closely behind the Shapiro-Wilks test. The Anderson-Darling test is particularly relevant when testing for normal distribution as it puts more weight to the tails of the distribution (Farrell and Rogers-Stewart, 2006), which is frequently the way non-normality makes itself known (Nelson, 1998).

No correlation between independent variables (no multicollinearity)

In order to perform multiple regression and produce reliable results, we assume that there is no or little correlation between the independent variables (Belsley et al., 2005, Slinker and Glantz, 1985). Correlation between independent variables is also commonly described as collinearity (correlation between two variables) and multicollinearity (correlation between two or more variables) (Hair, 2010). When multicollinearity is present, unstable estimates of the coefficients may occur, that is, the standard errors and confidence intervals for the coefficient estimates will be inflated (Belsley et al., 2005). This means that testing for multicollinearity is particularly important when the analysis is for explanatory purposes, as it consists of analyzing regression coefficients (Williams et al., 2013).

The variance inflation factor (VIF) is commonly used to quantify and identify multicollinearity among the independent variables in a multiple regression model (Belsley et al., 2005, Cohen et al., 2014). In other words, the factor is a measure of variance in a specific independent variable, that cannot be explained by any of the other independent variables (Hair, 2010). According to Craney and Surles (2002), because no formal cutoff value or method exists to determine when VIF is too large, although typical suggestions for a cutoff point are ≥ 5 or ≥ 10. Instead, the authors suggest that better use of VIF is to create model-dependent cutoff values. The authors argue that their method for calculating model-dependent cutoff values removes personal bias in selecting conservative and lenient VIF cutoff values while maintaining unbiased estimates of the parameter coefficients for the original variables.

2.4.4. Null hypothesis

In statistics, the null hypothesis is used test the statistical significance between two variables (Hair, 2010). The default null hypothesis (H_0) states that no relationship exists between a given pair of variables. For a multiple regression model, H_0 can be formulated as $H_0\colon \beta_x = 0$, in which x denotes a given independent variable and β denotes its unstandardized regression coefficient. The alternative hypothesis (H_α) states that a statistically significant relationship between a given pair of dependent and independent variables does exist. With the same notation as above, the alternative hypothesis can be formulated as $H_\alpha\colon -\ \beta_x \neq 0.$

Before the null hypothesis can be tested, the researcher must select a significance level (α). That is, how confident the researcher wants to be that a detected relationship is in fact significant and not just a chance occurrence. Some common values of α used in hypothesis testing are 0.01, 0.025, 0.05, and 0.01 (Hair, 2010).

Figure 9 shows possible outcomes of a null hypothesis test. By comparing the p-value to the previously selected α value, one can decide whether to reject the null hypothesis or not. If $p > \alpha$ then the null hypothesis is not rejected. If $p < \alpha$ then the null hypothesis is rejected. The probability of types I and II error is calculated as α and β, respectively. Note that in this context β is not the unstandardized regression coefficient, but rather it is the probability for type II error. Given that power is known (probability of correctly rejecting the null hypothesis), β is calculated as $\beta = 1 - power$. As for the power, according to Hair (2010), the researcher should aim for a value of 0.80. That is, there is an 80% probability of detecting a relationship that really exists.

		The null hypothesis (H_0) is…	
		True	False
Decision to…	Do not reject	Correct interference (Probability = 1 – α)	Type II error (Probability = (β))
	Reject	Type I error (Probability = (α))	Correct interference (Probability (power) = 1 – β)

Figure 9: The null hypothesis Adopted from Hair (2010)

2.4.5. Strengths and weaknesses

There are many benefits to using multiple regression as the research technique of choice, although, it is perhaps most known for its simplicity, flexibility, and applicability to almost any research problem (Hair, 2010). Still, one should be aware of some of its drawbacks. According to Vromen (1995), it can only handle a limited number of inputs and outputs at a time, which reduces its applicability. This is particularly important when the phenomenon studied has many variables. If too many variables are used in a regression model, the results become biased and are no longer suitable for interpretation. Tangen (2005) argues that regression models can only determine average values, which probably do not occur in any of the units examined. That is, in reality, none of the units have average values in all variables analyzed and thus the regression model represents an unrealistic unit. To this end, the flaw of averages is also worth considering. That is, the idea that average values can be misleading as they do not depict a complete or comprehensive view of the data under examination (Savage and Markowitz, 2009). Because of these weaknesses, among others, when developing and interpreting regression models one should have a perspective of "*all models are wrong, but some are useful*" (George Box, 1976).

2.5. Multiple regression applied to construction

Statistical methods, such as multiple regression analysis, are one of the most frequently used research techniques to analyze construction performance data (Yang et al., 2010). This subchapter presents studies that have applied multiple regression to predict and/or evaluate factors affecting construction performance, with an emphasis those relevant to the research objectives in this thesis. In addition, this subchapter put emphasis on how multiple regression was applied to solve the research problem, rather than their findings.

Dissanayaka and Kumaraswamy (1999) used multiple regression analysis to explain factors affecting the time and cost performance of building projects in Hong Kong. The dependent variables in their analysis were derived from survey responses. To measure time and cost performance they measured the ratio of time and cost overrun, respectively. The survey responses were also used to derive over 30 independent variables. They used backward elimination to deduce the number of insignificant variables from the models, in which variables that were not significant predictors at a 95% confidence interval were removed one at a time. Their models, one for time performance and one for cost performance, achieved R^2 values of 0.839 and 0.858, respectively. The model for time performance identified the following independent variables as significant predictors: levels of design complexity, levels of construction complexity due to sub-contracting, change orders/variations, client type, levels of client confidence in the construction team, and levels of project team motivation and goal orientation. The other model identified the following independent variables as significant predictors for cost performance: levels of client confidence in the construction team, risk retained by the client for quantity variations, levels of construction complexity related to new technology, and payment modality.

Othman et al. (2006) explained factors affecting construction time performance, except they did not use survey responses, instead they used real data records which they had accessed through a federal database. Their dataset consisted of 224 public civil engineering projects in Malaysia. They estimated time overrun in these project using attributes such as percentage difference between estimate and awarded bid, tender type, contract class, geographical region, and project delay due to various causes, they were able to estimate time overrun. These variables were selected among many other potential variables, using stepwise regression, yielding a R^2 value of 0.731.

Walker (1995) used multiple regression analysis to analyze survey responses from 33 general construction projects in the USA. In their analysis they find that construction duration can be estimated using construction cost, time overrun, work type, degree of emphasis on quality, degree of people-oriented management, degree of communication between construction and design teams, and use of technology. From this analysis the authors suggest that construction management team performance plays a vital role in determining construction time performance. In terms of developing the regression model, they find that it is necessary to apply a Log transform to construction duration and construction cost such that the data is more normally distributed. With this transformation applied, their regression model achieved an R^2 value of 0.9987.

Rasool and Al-Zwainy (2016) analyzed and predicted labor productivity in 50 Iraqi general construction projects, in which productivity was estimated using worker age, worker experience, number of workers, building height, level of excursion, and security conditions on site. Their analysis also show that the logistic regression technique achieved better prediction accuracy compared to the linear regression technique, in which the linear model achieved an R^2 value of 0.762 and the logistic regression model achieved an R^2 value of 0.830.

Thomas and Sudhakumar (2014) analyzed factors affecting masonry productivity in 2 high rise construction projects in India, in which they found that mode of employment of labor, overtime, work complexity, and delay in material deliveries were statistically significant independent variables. These variables were selected among other potential independent variables, using stepwise regression. They also found that Log10 of productivity produced the best results. Their final model achieved an R^2 value of 0.783.

Xiao and Proverbs (2003) studied factors affecting the overall performance of contractors by analyzing hypothetical high-rise concentered framed buildings in Japan, the UK, and the USA. They calculated overall performance as a function of cost, time, quality, and sustainable development, in which each category consists of several performance indicators. For example, cost is a function of construction cost, cost certainty, and client satisfaction on cost. Moreover, each of the indicators were assigned weights for their potential to influence overall performance. Significant variables affecting overall performance was found to be contractor's past performance on similar projects, commitment towards lifetime employment, perceived importance of time performance, relationship with subcontractors, and the number of design variation during construction. These variables were selected using stepwise regression.

A summary of studies presented in this subchapter is shown in Table 3.

Table 3: Application of multiple regression analysis in a construction context

Author(s)	**Objective/Context**	**Variables**
Dissanayaka and Kumaraswamy (1999)	Explain factors affecting construction duration. 46 survey responses from construction stakeholders in Hong Kong	Estimate the ratio of actual duration to estimated duration using factors associated with procurement system, project characteristics, team performance, client characteristics, and contractor characteristics.
Rasool and Al-Zwainy (2016)	Predict construction productivity of brickwork. 50 Iraqi construction projects	Estimate construction productivity using worker age, worker experience, number of workers, building height, level of excursion, and security conditions on site
Othman et al. (2006)	Explain factors affecting construction time performance. 244 public sector civil engineering projects (drainage, roads, and sewerage) in Malaysia	Estimate the ratio of actual duration to estimated duration using percentage difference between estimate and awarded bid, tender type, contract class, geographical region, and project delay due to various causes
Thomas and Sudhakumar (2014)	Explain factors affecting masonry productivity. 2 high rise construction projects in India	Estimate productivity using mode of employment of labor, overtime, work complexity, and delay in material deliveries
Xiao and Proverbs (2003)	Explain factors affecting overall contractor performance. Hypothetical high-rise concrete framed buildings in Japan, the UK, and the USA	Estimate overall performance (time, cost, quality, and sustainable development) using contractor's past performance on similar projects, commitment towards lifetime employment, perceived importance of time performance, relationship with subcontractors, and the number of design variation during construction.
Walker (1995)	Explain factors affecting construction time performance. 33 survey responses from general construction projects in the USA	Estimate Log of construction duration using Log of construction cost, time overrun, work type, degree of emphasis on quality, degree of people-oriented management, degree of communication between construction and design teams, and use of technology

3. Research methodology

This chapter presents relevant research methodologies used throughout this thesis.

3.1. Preliminary study

The work presented in this thesis builds upon a preliminary study, in which the objective was to measure on-site construction productivity and highlight potential root causes for poor productivity in house construction projects (Christensen, 2021). Experiences gained and findings from the preliminary study are relevant to the work presented in this thesis.

As part of the preliminary study, the author (same as in this thesis) performed productivity measurements at two construction sites over a period of two weeks. This required detailed knowledge of relevant construction phases and plans, as each measurement was manually mapped to specific a phase and activity. In addition, the observer had to label each observation as value adding, non-value adding, or waste, depending on whether the observed activity was according to plan or not. This experience and insight into the construction process gave the researcher a good basis for evaluating and discussing construction concepts. Note that the contractor and construction projects in focus of the preliminary study are the same as in this thesis (the case study in this thesis is presented in subchapter 3.3).

In the preliminary study it was found that different carpenters spent only 65% of their time on value adding activities, 25% on non-value adding activities, and 10% on waste activities. The findings suggests that a considerable potential for improvement exists. In addition, it was found that carpenters on each of the two sites under study, had vastly different productivity levels despite building the same type of building, working under the same management, and in the same environment.

Certain findings in the preliminary study are relevant to this thesis. Most notably, it was found that different carpenter crews (each consisting of two carpenters) had significantly different productivity levels, despite building the same type of building, working under the same management, and working in the same environment.

3.2. Literature study

According to Ridley (2012), a literature study provides a theoretical background for the research topic and gives an overview of current research, including current issues, questions, and discussions in the field. For similar reasons, Cooper et al. (2006) argue that insight obtained through a literature study assists the researcher in their work.

A literature study was conducted to develop a fundamental understanding of current research on core theoretical concepts relevant to this thesis. Relevant concepts studied are very much like those presented in the research scope (subchapter 1.4). That is, construction and performance. In addition, multiple regression analysis was included as a core concept as it was the research technique of choice (subchapter 3.4). The three core concepts described above overlap with each other and create additional research topics to consider, of which two were included in the literature study (Figure 10).

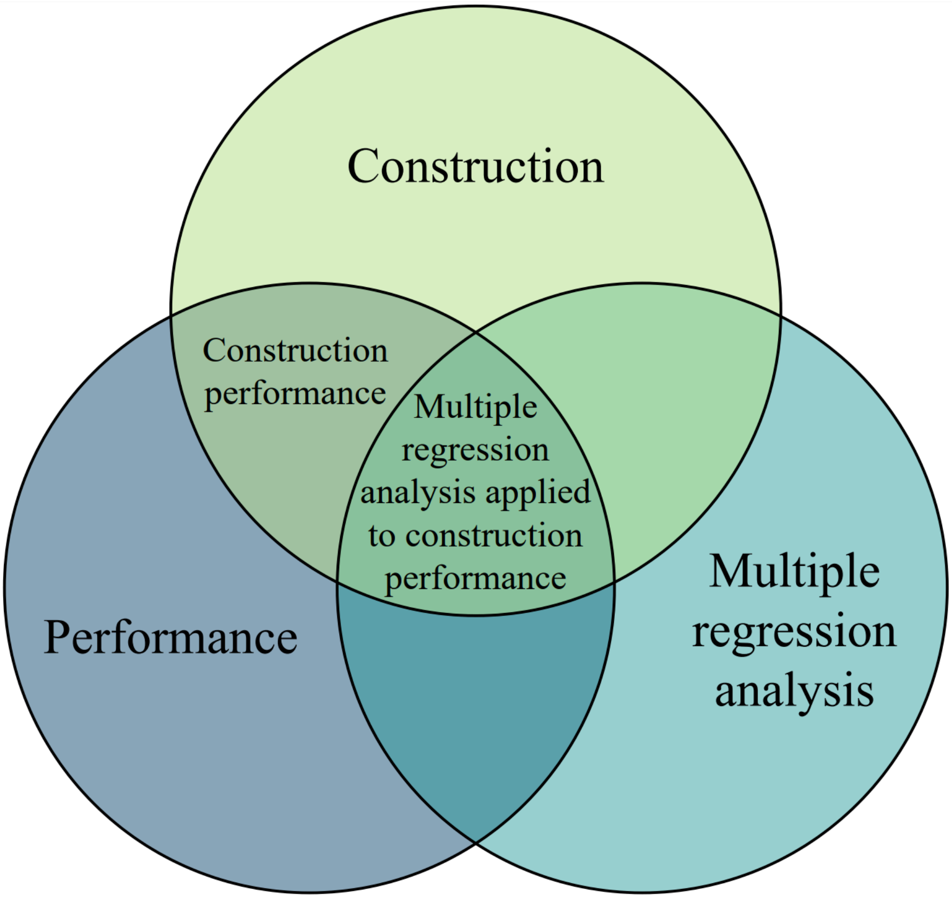


Figure 10: Core concepts researched in the literature study

Relevant queries were created using search terms from four distinct categories (Table 4). Naturally, not all combinations were equally useful. In practice, queries were created according to need. Search terms from different categories were combined using the Boolean operator “AND”. For example:

```
“construction” AND “time performance” AND “benchmarking”
```

Search terms within the same category were combined using the Boolean operator “OR”. For example:

```
(“residential construction” OR “house building”) AND “performance”
```

Table 4: Search terms used in the literature study

Category	Search terms	
Context	Construction	Residential construction
	Construction project	Norway
	House building	
Descriptive	Definition	Process
	Characteristics	
Performance dimension	Performance	Cost overruns
	Time performance	Productivity
	Time overruns	Delay
	Cost performance	Best practices
Method	Literature review	Multiple regression analysis
	Benchmarking	Measurement
	Assessment	Evaluation

According to Karlsson (2010), an easy method of determining the quality of published studies is to look at the number of citations, in which a study with many citations is more likely to be of high quality, compared to one with few citations. He notes, however, that this approach is less applicable for studies that have been recently published. For example, those published within the past three years. This approach to filtering results was adopted for the literature study in this thesis. In particular, the approach was used to quickly look over query results, before reading the abstract of relevant articles, and then reading the full articles.

The main databases used in the literature study include Google Scholar, Web of Science, Science Direct, Taylor & Francis, Springer, Oria (NTNU's library search engine).

3.3. Case study

A case study was conducted for the purpose of doing a closer investigation of one specific contractor that builds typical Norwegian houses. According to Hafiz (2008) a case study enables the researcher to answer "how" and "why" types of questions while taking into consideration how a phenomenon is influenced by the context within which it is situated. He emphases that a case study is an excellent opportunity for a novice researcher to gain tremendous insight into a case.

Case study design and strategy

Yin (2003) describes three types of case studies: explanatory, explorative, and descriptive. Among these, an explorative case study aims to explore those situations in which the intervention being evaluated has no clear, single set of outcomes. That is, an investigation of a distinct phenomenon that is characterized by a lack of preliminary research. According to Casula et al. (2021), explorative case studies are especially relevant for formulating and testing statistical hypotheses.

The explorative case study design was adopted in this thesis. That is, there is a lack of preliminary research describing factors affecting time and cost performance of house construction projects in a context of the Norwegian construction industry. It is therefore necessary to explore and investigate the relationships between various factors that may or may not affect construction time and cost performance in this context, and in the process establish a better understanding of how the factors influence performance. The case study in this thesis and its work can be summarized in three steps (Figure 11). A brief description of step is provided below, however, each is described in more detail later in this thesis.

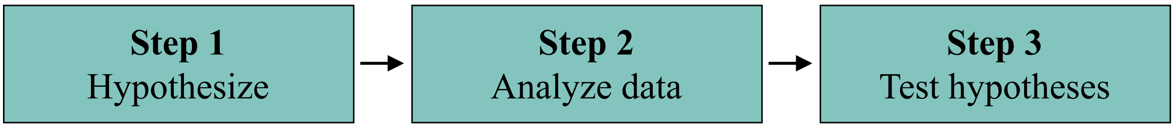


Figure 11: Case study research strategy

In step 1, several hypotheses about factors affecting performance in Norwegian house construction was created. Each hypothesis is targeted at the relationship between one specific factor and one specific performance measure. The performance measures are similar to those described in research objectives 1 and 2. That is, the number of manhours performed by carpenters on-site is a measure of cost performance (research objective 1) and the duration of on-site construction is a measure of time performance (research objective 2). The factors included in the analysis were derived from the literature and previous studies that have documented the effects that certain factors have on construction performance. However, as described previously, there is a lack of literature describing factors affecting construction performance in the context of Norwegian house construction. Therefore, the literature that was used to derive these factors were not limited to house construction. In fact, most were in the context of general construction (i.e., from road and rail construction to construction of high-rise apartments). In addition, data availability of the collaborating contractor was considered. Because of this it was not feasible to reproduce the exact same factors described in the literature, as many of these studies identify factors by using surveys and thus describe factors at a very detailed level. In step 2, data from 208 construction projects was analyzed using multiple regression. Two regression models were created, one for each performance measure (from research objectives 1 and 2). In the analysis, factors affecting construction performance are referred to as the independent variables and the performance measure is referred to as the dependent variable. In step 3, the regression models and their results were used to conduct several statistical tests, including testing of the hypotheses created in step 1. The outcome of each hypothesis was either "supported" or "not supported", in which a supported hypothesis means a statically significant relationship was identified between a given independent variable (factor) and performance measure (either manhours or duration). The hypotheses (step 1) and the data analysis (step 2) are presented in subchapter 3.4, and the results from testing the hypotheses (step 3) are presented in subchapter 4.3.

About the case contractor

The case study was in collaboration Mestergruppen, who is one of Scandinavia's largest actors within the sectors for constructions goods and materials, house construction, and real estate development. Mestergruppen owns or partner with several house contractors across Scandinavia. One of these contractors is Saltdalshytta, who is the focus of the case study in this thesis. From this point and forward, Saltdalshytta is referred to as the case contractor.

The case contractor has produced over 7000 cabins in Norway since 1979. They emphasize build quality that lasts, design flexibility, and affordable prices. They build cabins in a few standard designs, however, each design comes in many different sizes and shapes. In addition, the case contractor allows customers to make changes to the standard design if they so desire. In this case study, three of their standard cabin designs are in focus. These are Aurora, Smart, and Jubileum (Figure 12).

Figure 12: Standard cabin models. Aurora (left), Smart (middle), and Jubileum (right)

The construction process at the case contractor

The case contractor builds what the industry calls "kataloghus", which means catalog or directory house. That is, when the project is relatively standardized (or preplanned) and the buildings are based on a few standard models. Therefore, the construction process for such houses is quite different from other types of construction. Consequently, the steps involved in building "kataloghus" is also different from other types of construction. There are several ways to divide and describe the construction process for such houses. Figure 13 shows one alternative to describing the construction process at the case contractor, as seen from the perspective of the customer and the case contractor. In this visualization, each step of the process is performed in a sequential fashion, however, in reality some of these may overlap with each other.

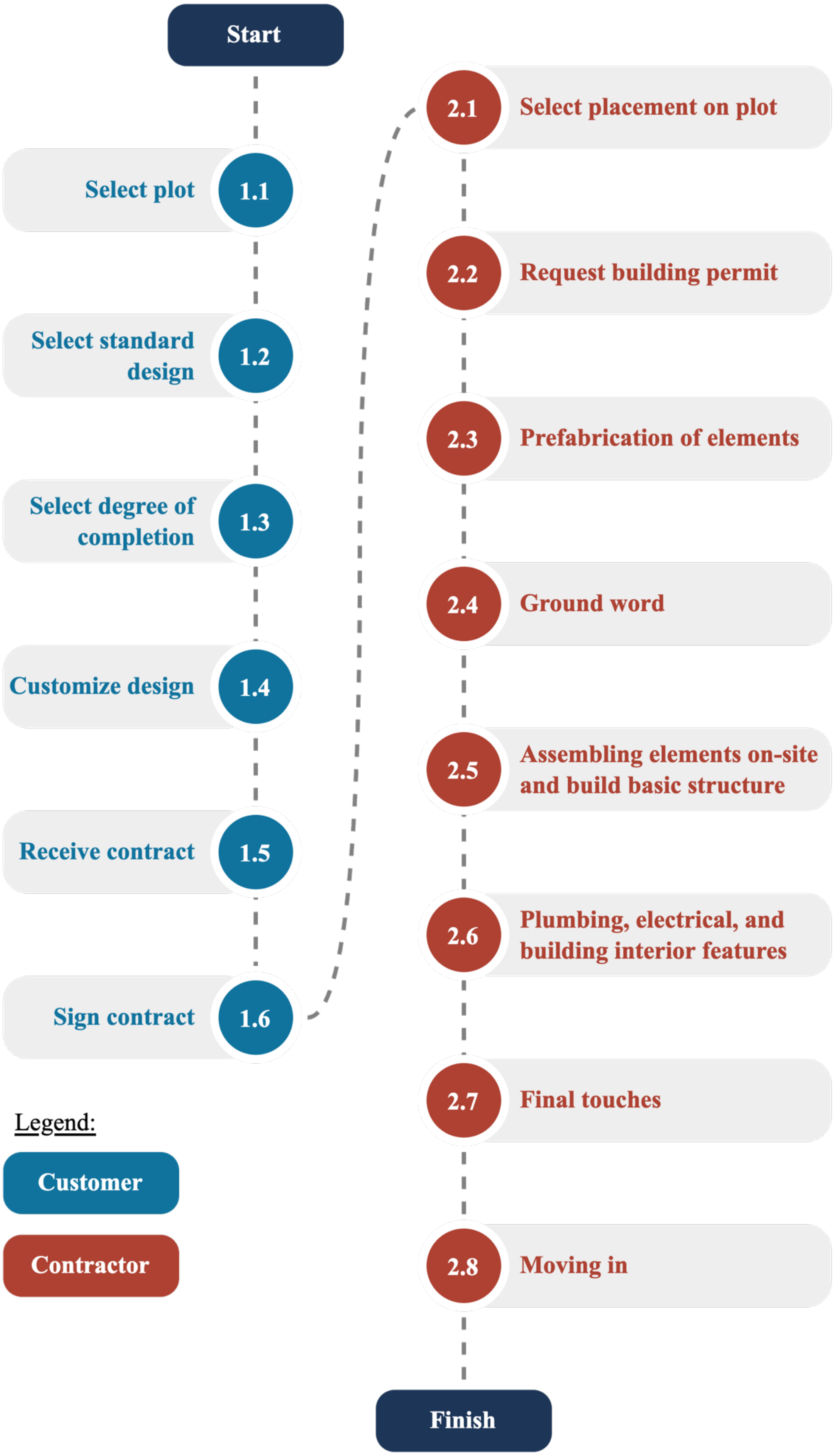


Figure 13: The construction process viewed from the customer's and contractor's perspective

From the customers perspective, the process starts with selecting a plot, one they already own or through the case contractor. Then they select one of several possible standard designs (e.g., Aurora, Smart, etc.). They must also specify the degree of completion. That is, how much of the construction do they want the case contractor to do and how much do they want to do themselves. Some choose to do a lot themselves to save money, but most let the case contractor build the cabin to absolute completion. They are then faced with the option to make changes to the standard design. For example, the case contractor offers many different alternatives for cladding, decorative moldings, floorboards, doors, and much more. When all the changes are submitted and accepted, the customer receives a contract with all the necessary details. Finally, when they sign the contract, the construction process starts at the case contractors' end.

From the case contractors' perspective, they start by choosing where on the plot to place the cabin. This is done in collaboration with the customer. When the placement is decided, a request for building permission is submitted to the respective municipality. Once approved, prefabrication starts. That is, wall elements and load bearing structures are produced in a factory. Meanwhile, groundwork is performed on the construction site, including pouring a concrete foundation, as well as preparing for plumbing and electrical installations. When the prefabricated elements and load bearing structures arrive to the construction site, they are assembled by carpenters, along with some work to the exterior parts of the structure. Once the basic structure has been completed, work on the inside begins. This includes installation of isolation in wall elements, installing floorboards, internal walls, building the kitchen, laying tiles, and so on. Plumbing and electrical installations are also performed at this point. After some final touches and preparations, the cabin is ready for the customer to move in.

An important detail regarding the construction process and its steps is that the case contractor leverages the use of subcontractors from project to project. There is also some variation from team to team (teams are presented later). In some cases, carpenters hired at the case contractor performs all of the activities, and in other cases the entire construction process is outsourced to subcontractors. However, this is the exception rather than the norm. In most projects, subcontractors are used to pour concrete and built the foundation, do the plumbing, and install electrical installations. The remaining work is performed by carpenters at the case contractor.

We recall that the scope of this thesis is limited to the construction activities performed on-site. In terms of the steps show in Figure 13, we are only concerned with what happens at and between steps 2.4 and 2.8.

Production system

The framework for classifying construction production systems and manufacturing outputs is used to characterize the case contractor (Jonsson and Rudberg, 2015). Figure 14 shows where the case contractor is situated in the classification matrix, with respect to degree of product standardization and degree of off-site assembly, in which the case contractor is marked by a red "X". An explanation of these characteristics and explanation of why they match the case contractor is provided below.

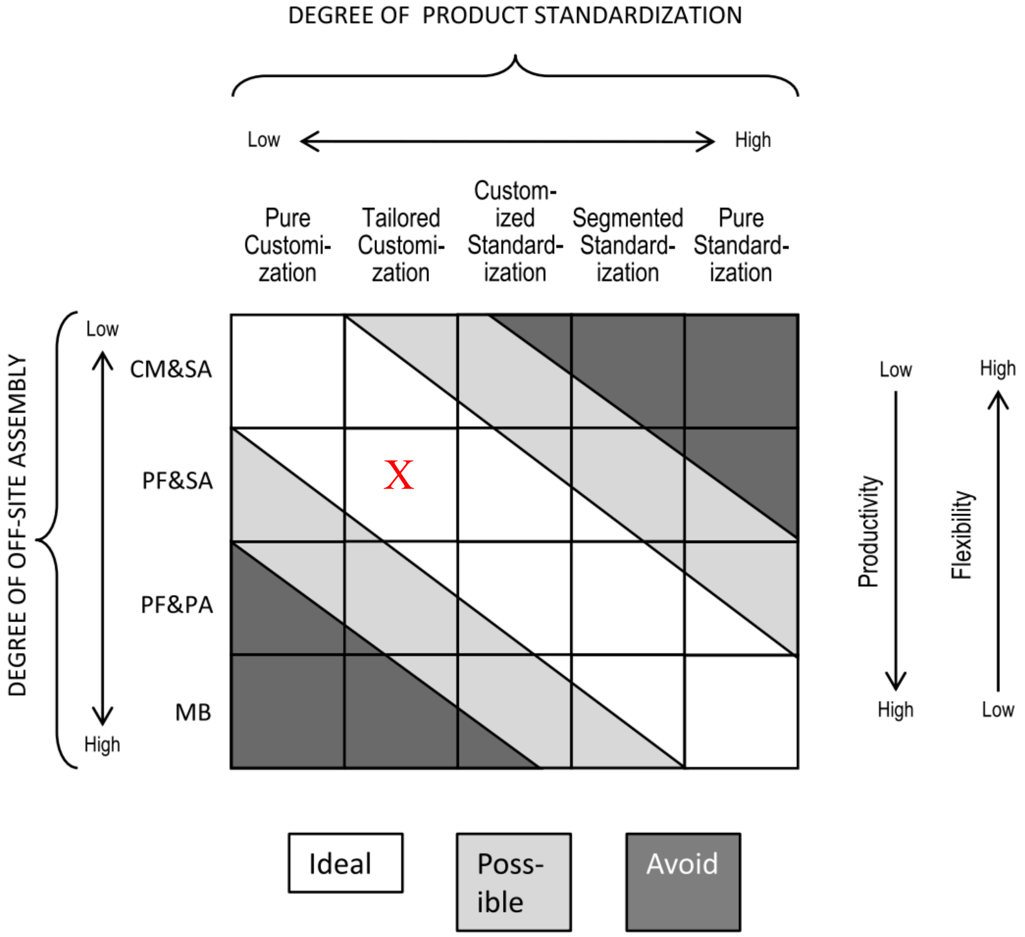


Figure 14: Classification of the case contractors' production system ("X") according to production system classification framework by Jonsson and Rudberg (2015)

Cabins built by the case contractor is best described as *tailored customization* because they offer a basic product (i.e., standard designs such as Aurora, Smart, etc.) that the customer can customize before the fabrication stage (i.e., changes to the standard design is specified before the prefabrication begins). Although *customized standardization* also sounds like an accurate description, cabins built by the case contractor are not purely built from standardized components and therefore this classification less accurate.

The construction process is best characterized as *prefabrication & sub-assembly (PF&SA)* because a high degree of prefabrication is utilized, in which wall elements and load bearing structures are produced off-site, while most sub-assemblies are delivered on-site. The only exception to this is that windows are installed in the prefabricated wall elements, but besides this, doors, isolation, electrical outlets, interior cladding and so on is installed on-site.

Recent changes at the case contractor

At the beginning of 2021, the case contractor changed from a centralized to decentralized management structure for many areas of their organization. Namely, project scheduling and the responsibility for project profitability were moved from a small group of people to three regional teams. The three teams are referred to as teams A, B, and C. Now that project scheduling is done at the team level, the project manager and construction manager are much more involved in the scheduling process. In addition, project profitability is the project managers' responsibility. These changes also enabled each team to become more independent and to develop their own solutions as they see fit. For example, one team can have a role dedicated to handling claims, while the other team does not. Each team is therefore not necessarily organized in the same way. Still, for the most part each team has a team leader, several project managers, and several construction managers, in which each construction manager has several crews of carpenters. A team leader may have 20 to 30 projects in progress at any time.

Data from the case contractor

To perform the data analysis part of this case study, a dataset of projects completed by the case contractor was created. The dataset consisted of all projects they had completed in 2020, 2021, and 2022, so far. For each project, there was descriptive information about the project itself, the cabin built and those involved. This data was used to create the variables which were analyzed in the data analysis (subchapter 3.4).

Several actions were taken to create homogenous and appropriate dataset. That is, projects that were not relevant to the scope of this thesis or not suitable for comparison to each other, were excluded. These actions include:

- Only cabins that were built to absolute completion were included in the dataset. Naturally, a cabin that is not built to absolute completion cannot be compared to a cabin that only required half the work.

- Projects where subcontractors did most, or all of the work, were removed from the dataset. These projects were identified quickly as they typically had very few manhours registered. When all on-site activities were performed by someone else than the case contractor it was clearly specified and so removing these projects were easily done.

- For the most part, the case contractor builds cabins, however, they occasionally build houses, garages, and annexes. These types of projects were removed from the dataset. Although some of their houses are similar to the cabins included in this case study, including other types of buildings would result in unfair comparisons. The only types of cabins include in the dataset were Aurora, Smart, and Jubileum (Figure 12).

The initial dataset consisted of 453 construction projects, but after irrelevant projects and outliers had been excluded, 208 projects remained. The research technique used to analyze this data is described in the next subchapter.

3.4. Data analysis

Multiple regression analysis (MRA) was adopted as the research method of choice to investigate the relationship between several factors and construction performance. In doing so, two regression models were created, one for each research objective. In these models, the factors of interest are expressed as independent variables and performance is expressed as the dependent variable. In Model 1 the dependent model was the number of manhours performed by carpenters on-site (research objective 1), and in Model 2 it was the number of construction days with activities performed on-site (research objective 2).

All variables included in the analysis are briefly presented in Table 5. A more detailed description of each variable and why they were selected is presented later in this subchapter.

Since there are five independent variables with scales and two categorical variables, with three categories each, the analysis should have at least 45 samples, according to the 5:1 ratio proposed by to Hair (2010). The data which was analyzed consisted of 208 samples and thus we are well within the recommended sample size.

Table 5: Variable description. Dependent variables denoted as y and independent variables denoted as x

Notation	Name	Description	Measure
y_1	MANHOURS	Total manhours performed on-site by carpenters Measured in hours	Scale
y_2	CDAYS	Construction days Measured in number of days	Scale
x_1	CONTRACT	Total contract sum Measured in MNOK	Scale
x_2	REVISIONS	Number changes made to the standard cabin design Measured in number of revisions	Scale
x_3	CARPENTERS	Number of carpenters who have worked on-site Measured in number of carpenters	Scale
x_4	WRATIO	Ratio of construction days during winter to total days Measured as a ratio between 0 and 1	Scale
x_5	START	Construction start date Measured as *sequential series numbers**	Scale
x_6	TEAM	The team who owns and is responsible for the project Measured as a categorical value	Nominal
x_7	STYLE	Standardized cabin model Measured as a categorical value	Nominal

* Sequential series numbers are the standard Excel format for storing dates as numerical values. These values represent the number of days since January 1, 1900.

3.4.1. Objectives of the analysis

Hair (2010) highlight three issues the researcher must consider before multiple regression can be applied to a research problem: the research problem must be appropriate for multiple regression, specification of a statistical relationship, and selection of dependent and independent variables. These issues and relevance to this thesis are described below.

First, considering the research objectives in this thesis, multiple regression was applied for explanation purposes. That is, the sign, magnitude, and significance of the independent variables were interpreted as a means of investigating the relationship between construction attributes and construction project outcome.

Second, multiple regression is a relevant research technique for the research problem at hand, as the construction project outcomes have a statistical relationship with construction factors, rather than a functional relationship. That is, based solely on the construction factors, one cannot accurately predict project outcome.

Third (and final), selection of dependent and independent variables was based on strong theory, while also considering measurement error and specification error. That is, the variables were derived from literature. The dependent variables were designed so they reflect important measures of construction performance. The independent variables were based on literature describing factors affecting construction project outcome and performance. The dependent and independent variables, as well as their ties to literature, are presented in the next two sections.

3.4.2. Dependent variables

It is evident that construction performance is a multifaceted concept, in which organizations must succeed in both financial and non-financial areas, while simultaneously having a long and short-term perspective (Pinto and Pinto, 2020, Parmenter, 2015, Toor and Ogunlana, 2010, Tripathi and Jha, 2018). Although different aspects of performance exist, time and cost are frequently highlighted as essential to overall construction performance and project success (Yang et al., 2010, Pollack et al., 2018). Two dependent variables were developed to measure time and cost performance of construction projects.

Number of manhours (MANHOURS) measures the number of hours that carpenters at the case contractor have spent on on-site construction activities. In terms of cost performance, the number of manhours is directly linked to labor costs, which is especially important in countries such as Norway where labor costs are particularly high (Barbosa et al., 2017, Eurostat, 2020). Although the number of manhours is estimated in advance, it is never known for certain and this manhours acts as a variable and to some extent unpredictable cost that can cause cost overruns (Larsen et al., 2016).

Number of construction days (CDAYS) measures the number of days where on-site construction activities were performed by carpenters at the case contractor. This means that days where no work was performed are excluded (e.g., weekends or breaks from construction due to various reasons). This is an important measure of project time performance because the time spent on construction plays a vital role in ensuring that the original schedule is not exceeded (Larsen et al., 2016). Even if the original schedule is met, being able to deliver projects faster than the competition will yield a competitive advantage (Zidane and Andersen, 2018). It is therefore of interest to investigate various factors that affect the number of construction days.

The dependent variables above are not performance indicators by themselves, as comparing values of several projects would give very little insight to actual performance of any sort. However, they are still useful performance measures. For example, if these measures were divided by project scope (e.g., gross floor area), then they would become measures of productivity (Tangen, 2005). They can also be used to calculate time and cost overrun, or at least some variation of it (Chan and Chan, 2004).

In addition, in a regression model one is able to observe the relationship between a given independent variable and the dependent variable, while other independent variables in the model are held constant. The regression models presented later use the contract sum as a measure of project scope and complexity, and therefore one could argue that both dependent variables become measures of productivity. That is, when interpreting the relationship between a construction factor and manhours, for example, the project scope and complexity is held constant. Therefore, one can argue that the dependent variables are measures of productivity when viewed in a regression model that controls from project scope and complexity.

3.4.3. Independent variables

A total of seven independent variables were included in the analysis. The variables were derived from literature describing factors affecting construction performance. As described previously, many of the factors in the literature are described at the very detailed level, which we were not able to reproduce accurately for reasons related to data availability. Instead, the seven independent variables were selected because they are similar to or capture the effects of the performance affecting factors. This becomes clearer as each independent variable is presented in more detail and their ties to performance affecting factors are established.

CONTRACT is the contract sum measured in MNOKs. That is, the purchase price which customers pay. The case contractor takes several factors into account when calculating the contract sum, including project scope and complexity. For instance, they consider cabin features such as gross floor area, number of floors, types of rooms, sizes of room with high complexity, and so on. They also consider resource requirements (human and material) of the project. That is, the cost of construction materials and the estimated labor required to build the cabin. In addition, if the construction site is inaccessible for delivery of prefabricated elements, the cost of a more labor-intensive construction process is factored in.

The CONTRACT variable was chosen because it was able to capture project scope and complexity much better than a single project feature (e.g., gross floor area, total wall length, number of bedrooms, etc.). In addition, initial examination of the data showed that there was a stronger considerably stronger correlation between the contract sum and the dependent variables, compared to other single project features. Note that using multiple variables for project features to describe project scope and complexity was not an option as these were correlated with each other (e.g., when the number of floors increase, the gross floor area also increases in a correlated fashion), which would cause multicollinearity in the regression models.

It is evident that project scope and complexity are factors that influence labor productivity and increase the chances for delays and/or time overruns in construction (Durdyev et al., 2017, Hasan et al., 2018, Böhme et al., 2018, Zhu and Mostafavi, 2017). For these reasons, the CONTRACT variable is included in the analysis.

REVISIONS is the number of changes that the customer made to the standard cabin design. As described previously, the customer chooses a standard cabin design which they can make changes to before prefabrication begins. The REVISIONS variable is simply a measure of the number of changes made, in which each change is registered as a revisions. We know the number of revisions because every revision results in a new architectural drawing being registered to the project. Common modifications are layout changes to make rooms or the entire cabin a different size and resizing windows.

The REVISIONS variable can be interpreted as a measure of increase in complexity or at least an increase in deviation from the standard designs which the contractor and carpenters are familiar with. Based on this, the variable was included in the analysis because several studies find that change orders and increasing the complexity greatly influence productivity and can cause delays or time overruns (Zidane and Andersen, 2018, Durdyev et al., 2017, Hasan et al., 2018, Zhu and Mostafavi, 2017, Böhme et al., 2018). However, in some of these studies, they specify that change orders have the most impact when they are submitted during construction. This is not the case for the REVISIONS variable, as changes are always submitted before prefabrication begins.

CARPENTERS is the total number of carpenters that have worked on a given project, at any point in time during the projects' lifespan. Typically, carpenters work in pairs of two, although in most cases, one pair does the external work (assembly of wall elements and building the exterior) while another pair performs all indoor activities. The number of carpenters on a project was selected as an independent variable because the underlying causes and effects of having many carpenters on the same project can be tied to poor productivity and possibly delays or time overruns. For example, having many carpenters on a project simultaneously can decrease the utilization of each carpenter if there is not enough work to be done (Sanni-Anibire et al., 2020, Zidane and Andersen, 2018). It can increase the chances of disputes occuring (Sanni-Anibire et al., 2020). It can pose as a challenge for the construction manager and potentially lead to poor site management, coordination, and control, which can cause delays and changes to the project schedule (Sanni-Anibire et al., 2020, Durdyev et al., 2017, Böhme et al., 2018, Olawale and Sun, 2010). It can require better and more efficient communication internally at the case contractor, which if they fail at can cause delays and poor productivity (Sanni-Anibire et al., 2020, Durdyev et al., 2017, Hasan et al., 2018, Böhme et al., 2018). A change in the number of carpenters can also be a consequence of poor scheduling and insufficient planning, as the management must move carpenters around due to excess capacity or assist on projects with lagging capacity or behind schedule. Moving carpenters around can also be caused by labor absenteeism (Zidane and Andersen, 2018, Hasan et al., 2018).

WRATIO is the ratio of construction days during the winter to the total number of construction days, in which January, February, March, October, November, and December are considered winter months. The ratio varies between 0 and 1, in which 1 means that all of the construction took place during the winter, 0 means that none of the construction took place during the winter, 0.5 means that half of the construction took place during the winter, and so on. The WRATIO variable was selected because several studies reference unpredictable and inclement weather conditions as factors affecting productivity and causes for delay (Olawale and Sun, 2010, Sanni-Anibire et al., 2020, Hasan et al., 2018). The cold temperatures that comes with the winter can also create issues related to unexpected or difficult soil conditions as the ground freezes, which in turn can delay the project (Durdyev et al., 2017). In addition, the darkness of winter in Norway is also a possible cause for carpenters to be less efficient.

START is the date on which on-site construction activities commenced, measured in the number of days since 1 Jan. 1990. Although existing research on the learning curve in a construction context is somewhat conflicting, some have observed that productivity increase as the number of repetition increases (Panas and Pantouvakis, 2018, Jarkas, 2010). If the effects of the learning curve are present and significant at the larger scale (i.e., improvements are continuously made for every project so that on average, each project is built more efficient than the last), then the START variable is capable of reflecting these improvements. In addition, as described previously, the case contractor changed from decentralized to centralized management in many areas of its organization (Subchapter 3.3), which they believe to have influenced project outcome. If this is the case, then the START variable can reflect potential improvements.

TEAM specify the construction team who performed the project. As described previously, there are three regional team – teams A, B, and C. The TEAM variable was chosen because each team operates relatively independent of each other, with their respective construction managers, carpenters, equipment, routines and so on. In the literature, there exists evidence that the attributes of a given construction team or department (i.e., skill of the construction manager or other supervisors, worker skill, and contractor experience) can greatly influence the chances for delay and influence productivity levels (Zidane and Andersen, 2018, Durdyev et al., 2017, Hasan et al., 2018). Especially differences in communication skills and channels of each team can cause delays and influence productivity (Hasan et al., 2018, Nicholas, 2018). In addition, there are possible regional differences that influence how each team perform (e.g., subcontractor availability, distance from factory and suppliers to construction site, etc.).

STYLE is the standard cabin design which the customer chose. As described previously, there are three standard designs included in the analysis - Aurora, Smart, and Jubileum. Each design has some distinct feature that requires a unique activity to be built. The STYLE variable was chosen for similar reasons as the CONTRACT and REVISIONS variables. That is, project scope and complexity can influence productivity and can cause delays and time overruns (Durdyev et al., 2017, Hasan et al., 2018, Böhme et al., 2018, Zhu and Mostafavi, 2017).

Table 6 shows a summary of the independent variables and the associated factors affecting construction performance.

Table 6: Link between independent variables and performance affecting factors in literature

Independent variable	**Factors**	**References**
CONTRACT	Project scope Project complexity	(Durdyev et al., 2017, Hasan et al., 2018, Böhme et al., 2018, Zhu and Mostafavi, 2017)
REVISIONS	Change orders Increased complexity	(Zidane and Andersen, 2018, Durdyev et al., 2017, Hasan et al., 2018, Zhu and Mostafavi, 2017, Böhme et al., 2018)
CARPENTERS	Poor labor productivity Labor disputes Poor site management and control Poor scheduling Communication Shortage of skill Labor absenteeism Productivity variability	(Zidane and Andersen, 2018, Sanni-Anibire et al., 2020, Durdyev et al., 2017, Böhme et al., 2018, Hasan et al., 2018)
WRATIO	Unpredictable weather Inclement weather Rain effect Unexpected soil conditions	(Olawale and Sun, 2010, Sanni-Anibire et al., 2020, Hasan et al., 2018, Durdyev et al., 2017)
START	Learning curve Organizational structure (decentralized vs. centralized)	(Panas and Pantouvakis, 2018, Jarkas, 2010)
TEAM	Management and coordination Experience Skills of the construction manager	(Zidane and Andersen, 2018, Durdyev et al., 2017, Hasan et al., 2018, Nicholas, 2018)
STYLE	Project scope Project complexity	(Durdyev et al., 2017, Hasan et al., 2018, Böhme et al., 2018, Zhu and Mostafavi, 2017)

3.4.4. Hypotheses

As described in previous sections, the dependent and independent variables were derived from a theoretical background. Since there exists evidence in support of a relationship between the dependent and independent variables, one can assume that a multiple regression analysis of these variables will reveal relationships like those described in the literature. To test whether this is the case or not, the null hypothesis was utilized.

A null and alternative hypothesis was created for each pair of dependent and independent variables. Let y denote a given dependent variable and x denote a given independent variable (values for x and y is the same as described in Table 5). Formulation of the null and alternative hypotheses can then be generalized as such:

Null hypothesis (H_{0-xy}): x has no relationship with y.

Alternative hypothesis ($H_{\alpha-xy}$): x has a statistically significant relationship with y.

For example, H_{0-11} is the null hypothesis for dependent variable MANHOURS and independent variable CONTRACT, H_{0-21} is the null hypothesis for dependent variable MANHOUS and independent variable REVISIONS.

The α value used to calculate power and performing tests for the null hypotheses was set to 0.05.

4. Data analysis and results

The chapter describes the application of multiple regression analysis to investigate the relationship between construction factors and construction project outcome. This chapter provides an objective description of the analysis and its results. A more detailed discussion is presented in Chapter 0.

4.1. Preliminary examination

In this subchapter, the dependent and independent variables are examined.

4.1.1. Univariate examination

The variables are examined individually. Appendix

Appendix 1 shows histograms for the continuous variables and bar charts for the categorical variables.

Table 7 shows descriptive statistics for the continuous variables. Note that Skewness (S_{KP}) is a measure of distribution symmetry, in which a normal distribution has $S_{KP} = 0$. When $S_{KP} < 0$ the peak of the distribution is skewed to the left and when $S_{KP} > 0$ the peak of the distribution is skewed to the right. Kurtosis (K) is a measure of the distribution shape, in which a normal distribution has $K = 0$. When $K < 0$ the peak of the distribution has a sharp form and when $K > 0$ the peak of the distribution is flattened.

Based on values for Skewness and Kurtosis, in combination with histograms, it is evident that variables MANHOURS, CDAYS, and CONTRACT are approximately normally distributed. Variables REVISIONS, CARPENTERS, WRATIO, and START have a non-normal distribution, however, this is not necessary when using OLS and the least-squares procedure as it is an unbiased estimator regardless of distributions.

Table 8 shows frequencies for the categorical variables. For the TEAM variable, there is an overrepresentation of team B and a lack of representation of team C. The same applies to the

STYLE variable, in which there is an overrepresentation of Smart and a lack of representation of Jubileum. Ideally, for both the TEAM and STYLE variables, there would be an equal representation of each categorical variable.

Table 7: Descriptive statistics for continuous variables

	N	Std. Deviation	Mean	Minimum	Maximum	Skewness	Kurtosis
MANHOURS	204	477,959	1318,44	392	4030	1,525	5,595
CDAYS	181	26,179	73,28	18	205	1,326	4,269
CONTRACT	208	0,785637	2,97335	1,081	6,523	0,980	2,822
REVISIONS	208	2,261	3,25	1	14	1,441	2,842
CARPENTERS	208	4,484	7,83	2	18	0,464	-0,902
WRATIO	181	0,310775	0,49227	0,000	0,989	0,050	-1,160
START	207	278,637	43901,18	43340	44445	-0,202	-1,131

Table 8: Frequency table for categorical variables (N = 208)

	Frequency	Percent
TEAM		
A	40	19.2
B	158	76.0
C	10	4.8
STYLE		
Aurora	50	25.5
Jubileum	35	16.8
Smart	120	57.7

4.1.2. Bivariate examination

The variables are examined in pairs of two. Table 9 shows the correlations between the continuous variables using Pearson’s correlation coefficient. Several of the independent is significantly correlated with the dependent variables. Some of the independent variables are also significantly correlated with each other, which can cause multicollinearity issues when implemented in a regression model. However, as will be described later, the variance inflation factor (VIF) for all independent variables had values less than 5, which is a common cutoff point used to detect multicollinearity (Craney and Surles, 2002).

Table 9: Bivariate analysis with Pearson's correlation coefficient (r)

	MANHOURS	CDAYS	CONTRACT	REVISIONS	CARPENTERS	WRATIO	START
MANOURS	1	.916**	.430**	.349**	0,040	.234**	-.341**
CDAYS	.916**	1	.380**	.322**	0,057	.151*	-.406**
CONTRACT	.430**	.380**	1	0,076	.249**	0,021	.296**
REVISIONS	.349**	.322**	0,076	1	-0,124	0,052	-.348**
CARPENTERS	0,040	0,057	.249**	-0,124	1	0,054	0,078
WRATIO	.234**	.151*	0,021	0,052	0,054	1	-.239**
START	-.341**	-.406**	.296**	-.348**	0,078	-.239**	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

4.2. Regression calculations

In this subchapter, the regression results are presented, and the quality of the analysis is assessed.

4.2.1. Model summary

Two multiple regression models were developed, one for each of the dependent variables. Model 1 estimates the MANHOURS variable and Model 2 estimates the CDAYS variable. The models can be summarized as:

- Model 1: The overall model was significant at the 0.001 level, F(13, 166) = 17.713, $p < 0.001$, with $R^2 = 0.581$ and adjusted $R^2 = 0.548$.

- Model 2: The overall model was significant at the 0.001 level, F(13, 166) = 14.652, $p < 0.001$, with $R^2 = 0.534$ and adjusted $R^2 = 0.498$.

In both models, the coefficient of determination (R^2) is relatively high. Hence, both models can explain a relatively large proportion of variance in the dependent variables using the selected independent variables.

Parameter estimates for Model 1 and Model 2 are presented in

Table **10** and Table 11, respectively. Note that *partial eta squared* is a measure of the proportion of total variation in the dependent variable that is attributable to the independent variable, when excluding the effects from other independent variables (Pierce et al., 2004). For example, in Model 1, the partial eta squared value of CONTRACT is 0.345, meaning that this variable explains 34.5% of the variation in MANHOURS, given that the effects of other variables are excluded.

Table 10: Model 1 parameter estimates. Dependent variable = MANHOURS. B = unstandardized regression coefficient and Sig. = Significance level (p-value)

	B	**Sig.**	**Partial Eta Squared**	**Power**[b]
CONTRACT	345,572	0,000	0,336	1,000
REVISIONS	33,699	0,006	0,044	0,787
CARPENTERS	7,470	0,246	0,008	0,212
WRATIO	232,600	0,006	0,045	0,796
START	-0,645	0,000	0,178	1,000
TEAM		0,001	0,079	0,926
TEAM=B	-104,728	-392,021		
TEAM=A	247,772	-47,015		
TEAM=C	0[a]			
STYLE		0,235	0,017	0,309
STYLE=Aurora	201,463	-271,837		
STYLE=Jubileum	-17,684	-484,218		
STYLE=Smart	0[a]			

a: the parameter is set to zero because it is redundant

b: Computed using $\alpha = 0.05$

Table 11: Model 2 parameter estimates. Dependent variable = CDAYS. B = unstandardized regression coefficient and Sig. = Significance level (p-value)

	B	Sig.	Partial Eta Squared	Power[b]
CONTRACT	19,101	0,000	0,320	1,000
REVISIONS	0,856	0,220	0,009	0,231
CARPENTERS	0,417	0,258	0,008	0,204
WRATIO	4,505	0,345	0,005	0,156
START	-0,042	0,000	0,217	1,000
TEAM		0,006	0,059	0,827
TEAM=B	-1,440	0,885		
TEAM=A	15,445	0,132		
TEAM=C	0[a]			
STYLE		0,164	0,022	0,378
STYLE=Aurora	11,145	0,498		
STYLE=Jubileum	13,695	0,398		
STYLE=Smart	0[a]			

a: the parameter is set to zero because it is redundant

b: Computed using $\alpha = 0.05$

4.2.2. Quality of the analysis

The assumptions for multiple regression and linear regression techniques are tested.

Linearity of the phenomenon measured

Partial residuals plots were used to evaluate the linearity of the relationship between a given dependent and independent variable. A LOESS curve was added to highlight trends in the plots. Partial residual plots for Model 1 and Model 2 are presented in

Appendix 2 and Appendix 3, respectively.

For both models, variables CONTRACT and START have a clearly defined linear trend. A trend also exists for variables CARPENTERS and WRATIO, but it is not as linear compared to the two previous variables. A trend exists for the REVISIONS variable, as suggested by the LOESS curve, but many of the residuals deviate from the LOESS curve. It would be reasonable to conclude that the REVISIONS variable has a linear relationship, but there is a great amount of deviation from the linear trend.

Constant variance of the error terms (homoscedasticity)

Residual plots were used to evaluate the variance of the error terms. Residual plots for both models are presented in Appendix 4. We recall that heteroscedasticity is present when there is some pattern in the residuals' deviation from the null plot. Interpreting the residual plots reveals that little or no heteroscedasticity exists. However, at very high values of the dependent variables, residuals deviate more. In this range of values there are very few samples and thus this is possible the result of randomness.

Lavene's test of equality of error variance and Breusch-Pragan test for heteroscedasticity were used to further investigate the variance of the error terms. Both tests concluded that heteroscedasticity is present in both models.

As per recommendation by Hair (2010) and Matejka and Fitzmaurice (2017), one should evaluate both statistics and visualization of the data. Despite Lavene's test and Breusch-Pragan test concluding that heteroscedasticity is present, the residual plots show that there is very little heteroscedasticity. Still, note that heteroscedasticity can cause biased p-values, in which p-values become artificially low when the degree of heteroscedasticity increase. In this analysis, we conduce that the effects of heteroscedasticity on p-values are small and most likely negligible.

Independence of the error terms

Variables START and WRATIO are the only sequencing variables included in the analysis. To determine whether the sequencing order of samples in these two variables influence the independence of error terms, the variables were plotted against the residuals of both models (Appendix 5). The plots show no apparent time-based dependency for the START variable and no apparent event-based dependency for the WRATIO variable. The error terms are therefore independent from one another. This means that the model is equally accurate (or inaccurate) and does not produce biased estimations at all values of START and WRATIO.

Normality of the error terms distribution

The distribution of residuals was plotted to evaluate the normality of the error terms (Appendix 6). Skewness for Model 1 and Model 2 are 0.344 and 0.096, respectively. Kurtosis for Model 1 and Model 2 are 2.283 and 2.244 respectively. Based on visualization of the distributions and normality statistics (Skewness and Kurtosis), the error terms are approximately normally distributed for both models.

Normal Q-Q plots were used to highlight non-linearity at the tails of the error terms distributions (Appendix 7). The plots show that some deviation from the normal distribution is present at the tails. That is, errors are greater at very low and high values of the dependent variables.

Kolmogorov-Smirnova and Shapiro-Wilks tests of normality were used to further investigate whether the error terms are normally distributed. Kolmogorov-Smirnova test concluded that the error terms for Model 1 are non-normally distributed and for Model 2 are normally distributed. Shapiro-Wilks test concluded that both models are non-normally distributed.

To determine whether the error terms are normally distributed, Hair (2010) recommends the use of both statistical tests and visualizations of the data. Statistical tests of normality find that the error terms for Model 1 and Model 2 are non-normally distributed. However, by looking at the distributions as histograms and normal Q-Q plots, it seems reasonable to conclude that the error terms are approximately normally distributed as there is very little deviation from the normal distribution. In addition, it should be noted that statistical tests such as Kolmogorov-Smirnova and Shapiro-Wilks are increasingly sensitive for larger sample sizes, which can also explain why non-normal distribution of residuals were detected. Yet, if the case was that the error terms of both models were non-normally distributed, this would not have biased the regression coefficients, only skewed the p-values (Hair, 2010).

No correlation between independent variables (no autocorrelation)

The variance inflation factor (VIF) was used to detect correlations among the independent variables. Table 12 shows the VIF values for independent variables included in the analysis. Note that the VIF values are the same regardless of dependent variable and thus these values apply to both Model 1 and Model 2. All continuous variables are below or equal to 1.532. The STYLE variable is also relatively low, with values at or below 1.196. On the other hand, the TEAM variable has much more multicollinearity. This is somewhat expected since they are categorical variables. In addition, the frequency of each team is heavily skewed in favor for team B, as they make up a large portion of the samples. This creates a situation where if it is not team A or C, then there is a high probability of being team B. Hence, multicollinearity occurs. Still, the VIF values re below the common cutoff point of 5 (Craney and Surles, 2002).

Table 12: Variance inflation factor (VIF) values for independent variables in models 1 and 2

	Variance inflation factor (VIF)
CONTRACT	1.271
REVISIONS	1.286
CARPENTERS	1.358
WRATIO	1.107
START	1.532
TEAM	
TEAM=B	4.584
TEAM=A	4.387
TEAM=C	.
STYLE	
STYLE=Aurora	1.196
STYLE=Jubileum	1.130
STYLE=Smart	.

4.3. Hypothesis tests

In this subchapter, the null and alternative hypotheses are tested. We recall that our generalized null hypothesis states that no relationship exists between a given pair of dependent and independent variables, while the alternative hypothesis states a significant relationship exists. Two possible outcomes are considered for the alternative hypothesis:

- *Supported*: The relationship between the dependent and independent variable is significant at the 0.05 level ($p < 0.05$).

- *Not supported*: The relationship between the dependent and independent variable is not significant at the 0.05 level ($p > 0.05$).

Table 13 presents a summary of the tests. In these results, power refers to the probability of detecting a relationship that really exists. That is, the probability of correctly supporting the alternative hypothesis. In all cases where the alternative hypothesis is supported, the power values is greater than or approximately 80%, as recommended by Hair (2010).

Table 13: Summary of alternative hypotheses

Hypothesis	Dependent variable	Independent variable	Result
$H_{\alpha-11}$	MANHOURS	CONTRACT	Supported (p = 0.000, power = 1.000)
$H_{\alpha-21}$	MANHOURS	REVISIONS	Supported (p = 0.006, power = 0.787)
$H_{\alpha-31}$	MANHOURS	CARPENTERS	Not supported (p = 0.246, power = 0.212)
$H_{\alpha-41}$	MANHOURS	WRATIO	Supported (p = 0.006, power = 0.796)
$H_{\alpha-51}$	MANHOURS	START	Supported (p = 0.000, power = 1.000)
$H_{\alpha-61}$	MANHOURS	TEAM	Supported (p = 0.001, power = 0.926)
$H_{\alpha-71}$	MANHOURS	STYLE	Not supported (p = 0.235, power = 0.309)
$H_{\alpha-12}$	CDAYS	CONTRACT	Supported (p = 0.000, power = 1.000)
$H_{\alpha-22}$	CDAYS	REVISIONS	Not supported (p = 0.220, power = 0.231)
$H_{\alpha-32}$	CDAYS	CARPENTERS	Not supported (p = 0.258, power = 0.204)
$H_{\alpha-42}$	CDAYS	WRATIO	Not supported (p = 0.345, power = 0.156)
$H_{\alpha-52}$	CDAYS	START	Supported (p = 0.000, power = 1.000)
$H_{\alpha-62}$	CDAYS	TEAM	Supported (p = 0.006, power = 0.827)
$H_{\alpha-72}$	CDAYS	STYLE	Not supported (p = 0.164, power = 0.378)

5. Discussion

In this chapter the regression results are interpreted and discussed in more detail.

5.1. Interpretation of the regression results

In this subchapter, each pair of dependent and independent variable are examined and interpreted.

5.1.1. Contract sum

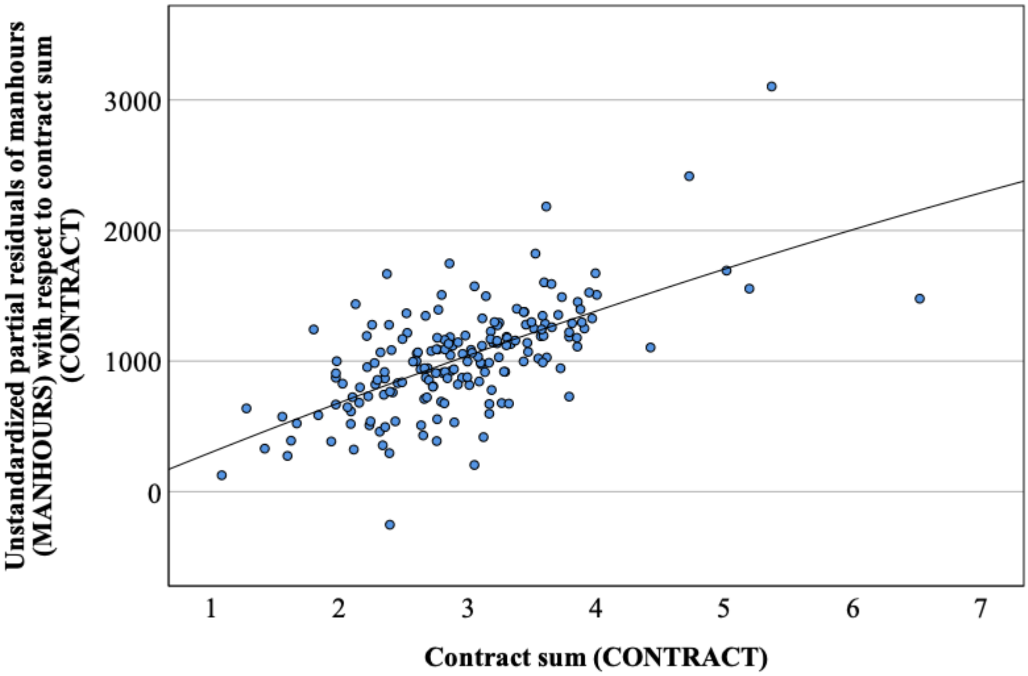
A significant relationship was identified between the CONTRACT variable and on-site manhours performed by carpenters (Model 1: p-value <.001 power = 1.000). When the contract sum increases by 1 MNOK, on-site manhours increase on average by 345 hours. We recall that contract sum is calculated from project scope, complexity, and resource requirements (human and materials). This can therefore be rephrased as: an increase in project scope, complexity, and resource requirements, equivalent to 1 MNOK, results in 345 additional manhours. For reference, projects included in the analysis had on average of 1318 manhours, which makes an increase of 345 hours a considerable amount.

A significant relationship was identified between the CONTRACT variable and number construction days (Model 2: p-value <.001 and power = 1.000). When the contract sum increases by 1 MNOK, the number of construction days increased by 19 days. This can be rephrased as: an increase in project scope, complexity, and resource requirements, equivalent to 1 MNOK, results in 19 additional construction days. For reference, projects included in the analysis lasted on average 73 days (only counting days where on-site activities were performed).

Given that carpenters work in pairs of two and they work eight hours per day, the relationship between contract sum and number of construction days (Model 2) can be interpreted as: an increase in contract sum equivalent to 1 MNOK will on average results in $2 * 8 * 19 = 304$ additional manhours. Which is quite close what was observed in Model 1 (345 manhours per 1 MNOK increase in contract sum). A better estimation of the average number of additional manhours per 1 MNOK increase in contract sum is most likely somewhere between 304 and 345 manhours.

Figure 15 shows partial residual plots for Model 1 and Model 2 with respect to the contract sum (CONTRACT). That is, they show the relationship between contract sum and manhours or number of construction days when the effects of other variables are removed. Indeed, a linear relationship is clearly defined for both models, in which manhours and number of construction days increase when the contract sum increases.

Although a significant relationship with contract sum was identified in both models, it does not mean that all the underlying factors of contract sum contribute equally (or at all) to changes in manhours and number of construction days. For example, if the customer wants a more expensive tile in the kitchen, then the contract sum goes up, but the labor required to install it does not necessarily change. Similarly, if the customer increases the size of windows, then the contract sum goes up, but since windows are installed during prefabrication the labor that is required on-site is unaffected. It would therefore be unreasonable to assume that all the underlying factors of contract sum have the same effect on manhours and number of construction days. On the other hand, some underlying factors of contract sum that can be expensive while also affecting on-site labor include total cabin size (gross floor area), adding a fireplace, adding or moving electrical outlets, if prefabricated elements cannot be delivered on-site, and adding a charging port for electric cars.



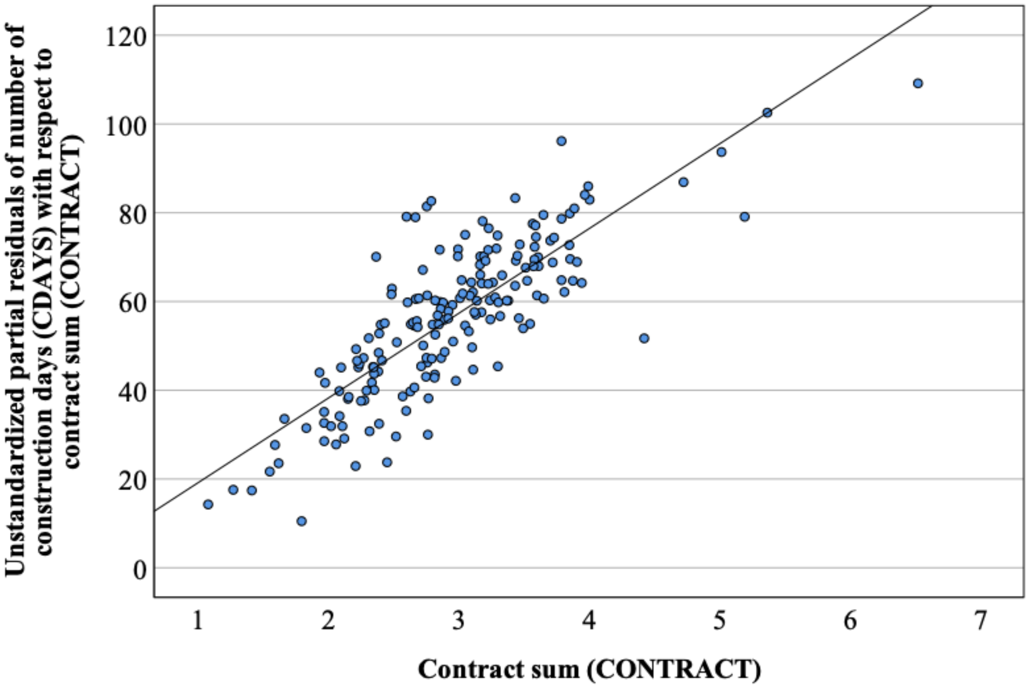


Figure 15: Unstandardized partial residuals plot for Model 1 (top) and Model 2 (bottom) with respect to contract sum (CONTRACT)

5.1.2. Changes to the standard design

A significant relationship was identified between the REVISIONS variable and on-site manhours performed by carpenters (Model 1: p = 0.006, Power = 0.787). The relationship reveals that for every change made to the standard cabin design, the carpenters must on average perform 34 additional hours of work. On the other hand, a significant relationship was not identified between the REVISIONS variable and the number of construction days (Model 2: p = 0.220, power = 0.231).

Figure 16 shows the relationship between the REVISIONS variable and manhours when the effects of other variables are removed. Although a positive relationship exists, it is not clearly defined. In some cases where many changes had been made, the manhours were equal to those of projects with no changes. Indeed, not all changes to the standard cabin design have the same effect on the manhours.

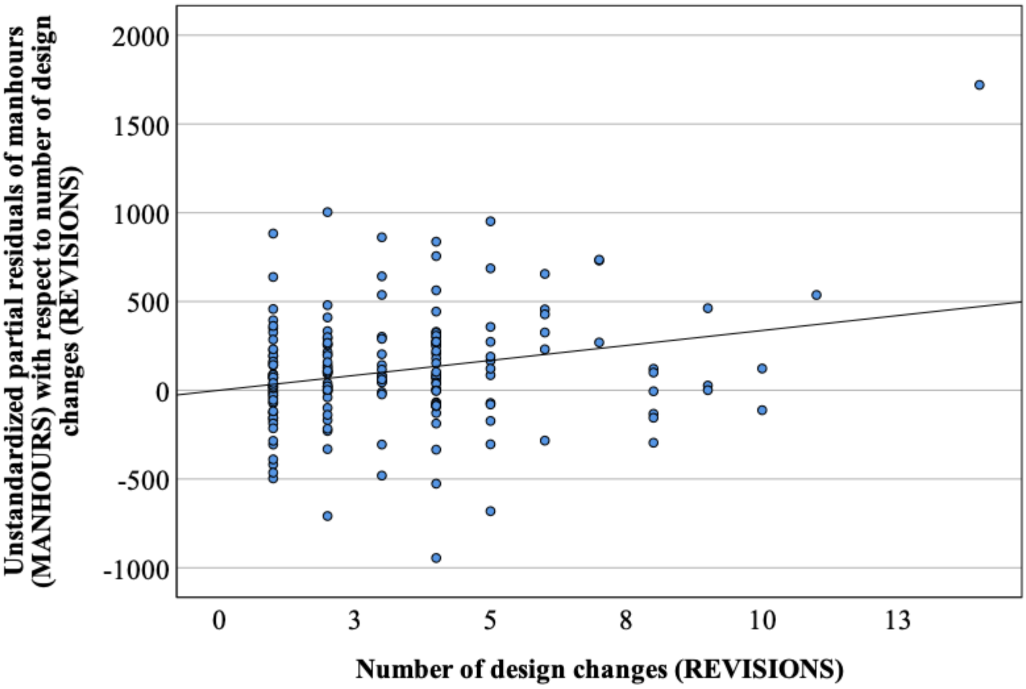


Figure 16: Unstandardized partial residuals plot for Model 1 with respect to number of changes made to the standard cabin design (REVISIONS)

One of the issues with the REVISIONS variable and interpretation of it is that not all changes to the standard design have the same effect on manhours. For example, layout changes that increase the total cabin size will probably increase the work that is required of the carpenters.

One the other hand, changing the types of tiles in in the kitchen will probably have no effect on the number of manhours. In the REVISIONS variable however, all changes are seen as equal. It would be much more insightful if one could pinpoint the most common changes and estimate their effects on manhours.

We recall that for each change made to the standard design, the cost of additional materials and labor is factored into the contract sum. It is then interesting that the REVISIONS variable was found to be statistically significant, which suggests that the case contractor is not accurately estimating the additional manhours required for at least some types of design changes. Because of this, the case contractor can maybe justify increasing the price of design changes, as design changes require on average 34 manhours more than what they are currently estimating and adding to the contract sum.

In the literature, there is a considerable amount of evidence for change orders influencing productivity and increase chances of delays, although some emphasize that change orders during construction are the most influential kind (Olawale and Sun, 2010, Zidane and Andersen, 2018, Hasan et al., 2018). Note that these studies are concerned with segments of the construction industry where the issue of change orders after construction start is more prevalent compared to that of house construction. For the case contractor, we recall that customers must submit all changes before construction start. Change orders that are submitted after construction start are therefore not present in the projects which were analyzed. The regression results can therefore not be used to determine whether change orders during construction have the same effect in house construction as in other types of construction.

5.1.3. Number of carpenters involved

A significant relationship was not identified for the CARPENTERS variable with on-site manhours performed by carpenters (Model 1: $p = 0.246$, power = 0.212) or number of construction days (Model 2: $p = 0.258$, power = 0.204).

The fact that no significant relationship was identified suggests that involvement of more carpenters does not necessarily reduce the utilization of each carpenter. It also suggests that involvement of more carpenters does not reduce the crew's ability to efficiently communicate with each other or for the construction manager to effectively control many carpenters (Sanni-

Anibire et al., 2020, Hasan et al., 2018). These results suggests that project and construction managers should not be afraid to move carpenters around, from project to project, given that there is enough work to go around.

5.1.4. Construction during winter

A significant relationship was identified for the WRATIO variable and on-site manhours performed by carpenters (Model 1: p-value 0.006 and power 0.796). On the other hand, a significant relationship was not identified for the WRATIO variable and number of construction days (Model 2: p = 0.345, power = 0.156).

We recall that the WRATIO variable is the ratio of construction days during winter. The regression results show that a cabin that was only built during winter had on average 232 manhours more than a cabin that was built completely outside of the winter period. In other words, for every percent the WRATIO variable increases, the number of manhours increase on average by 2.32 hours.

Figure 17 shows the relationship between the WRATIO variable and manhours when the effects of other variables are removed. Clearly, cabins built during the winter require on average more manhours than those built completely outside the winter period. However, in some cases where the cabin was completely built during winter, the number of manhours were the same as some cabins built completely outside the winter period. Indeed, just because a cabin is built during the winter does not necessarily mean that more manhours are required, however, there seems to be a trend where this is the case. From the partial residual plot, there appears to be a jump in the number of manhours when WRATIO is at 40% or above.

In the literature, several studies reference rain as a cause of delay in project activities and something that can reduce labor productivity (Olawale and Sun, 2010, Sanni-Anibire et al., 2020, Hasan et al., 2018, Durdyev et al., 2017). Findings presented in the data analysis of this thesis suggest that these effects also apply to snow and winter conditions. Observations made in the preliminary study suggests possible root causes for the observed relationship between winter and manhours. For example, snow on scaffolding had to be shoveled before activities could start or continue, deliveries of prefabricated elements and construction materials were delayed (possibly due to snowy and icy roads), and equipment breakdowns (possibly due to cold temperatures) (Christensen, 2021).

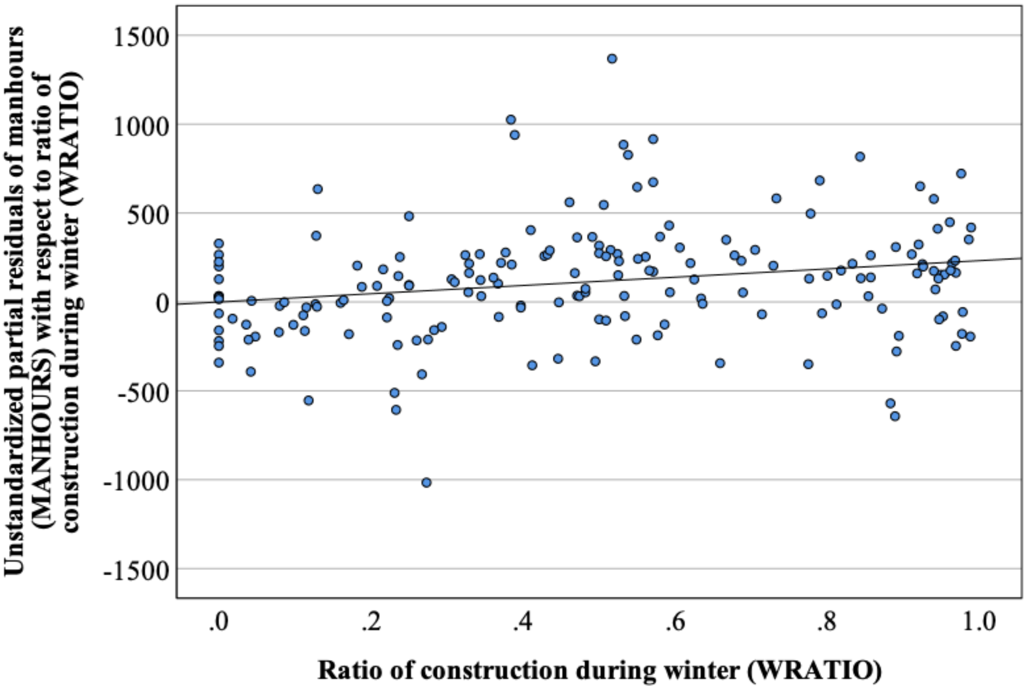


Figure 17: Unstandardized partial residuals plot for Model 1 with respect to the ratio of construction days during winter to total construction days (WRATIO)

5.1.5. Construction start

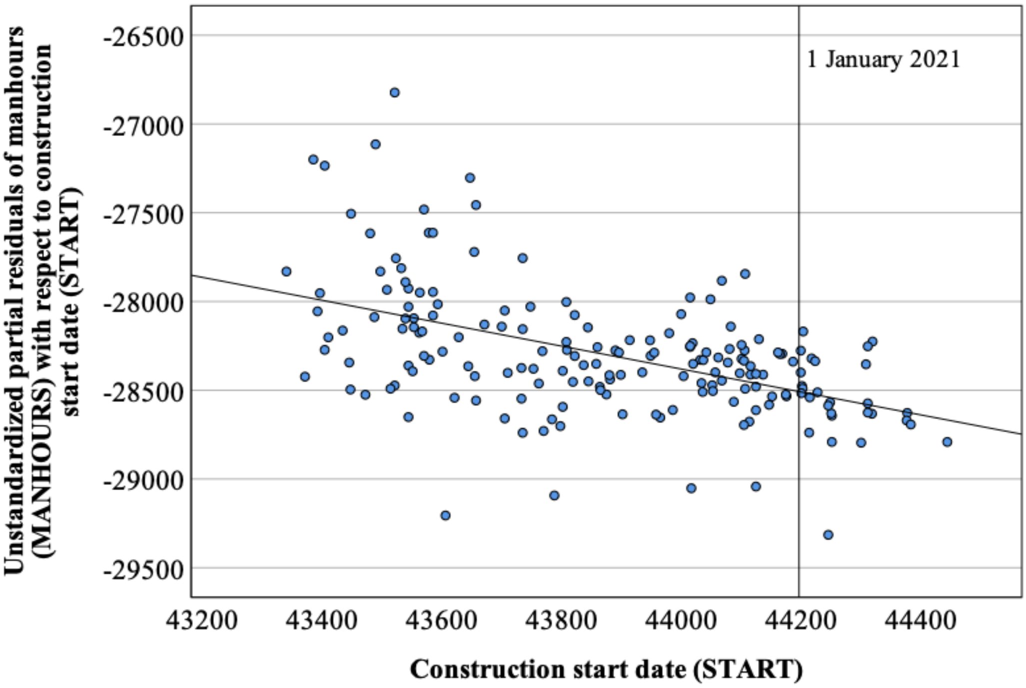
A significant relationship was identified between the START variable and on-site manhours by carpenters (Model 1: p = 0.000, power = 1.000). A significant relationship was also identified between the START variable and number of construction days (Model 2: p = 0.000, power = 1.000).

Figure 18 shows partial residuals plots from Model 1 and Model 2, with respect to construction start. The charts show the effects of the START variable on manhours and the number of construction days when the effects of other variables were removed. It shows that a negative trend exists, in which manhours and number of construction days decrease when the start date increases. The relationship is also approximately linear. In addition, the relationship with number of construction days is steeper compared to the one with manhours.

We recall that the START variable is the date which on-site construction activities commenced, measured as the number of days since 1 Jan 1990. Project included in the analysis started between 2019 and 2022. Within this timeframe, the case contractor has on average reduced the number of manhours per project by 0.645 hours and the number of construction days by 0.042 days, per day. Consequently, in a yearly perspective, the regression results suggests that the case contractor has on average improved by reducing the number of manhours by 235 hours and the number of construction days by 15 days. Put in perspective, projects have on average 1318 manhours and 73 construction days, which makes the observed improvements a considerable amount.

We recall that the case contractor made some changes at the beginning of 2021, in which several responsibilities were decentralized and moved to three regional teams (subchapter 3.3). 1 January 2021 is roughly when these changes were implemented and is marked in Figure 18 as a vertical line. Indeed, manhours and the number of construction days have decreased since the changes were made. This suggests that the changes that were made at the beginning of 2021 have had an impact on reducing manhours. However, in both cases a downwards slope/trend already existed, either when the changes were made or sometime before that. We can therefore not say for certain that the recent changes at the case contractor is the driving force behind the observed improvements or whether it is just a continuation of the existing downwards trend. In addition, only a small portion of the projects included in the analysis started after 1 January 2021. It is possible that these changes have influenced manhours and the number of construction days but does not appear until more time has passed and more projects have been completed.

In the literature there exists some evidence suggesting that construction labor productivity improve over time, as more repetitions are performed (Panas and Pantouvakis, 2018). Some specify that the effects of repetition is only visible at the project level or even negligible (Jarkas, 2010, Pellegrino et al., 2012). Given these findings, it is possible that the effects of repetition can explain some of the improvements observed in Figure 18, however, it is unlikely that repetition is the only factor responsible for the observed improvements. Especially considering that the improvements are quite large. In addition, other important events have taken place during the observed timeframe. For instance, the COVID-19 pandemic has affected labor availability and increased the cost of common construction materials (Statistics Norway, 2022a). These factors have potentially influenced the case contractor to reduce costs and utilize worker better than before, which in turn has reduced manhours and number of construction days. To summarize, as several important events and changes have taken place over the observe timeframe, we cannot highlight one specific underlying factor or root cause for the observed changes in relation to the START variable in this analysis.



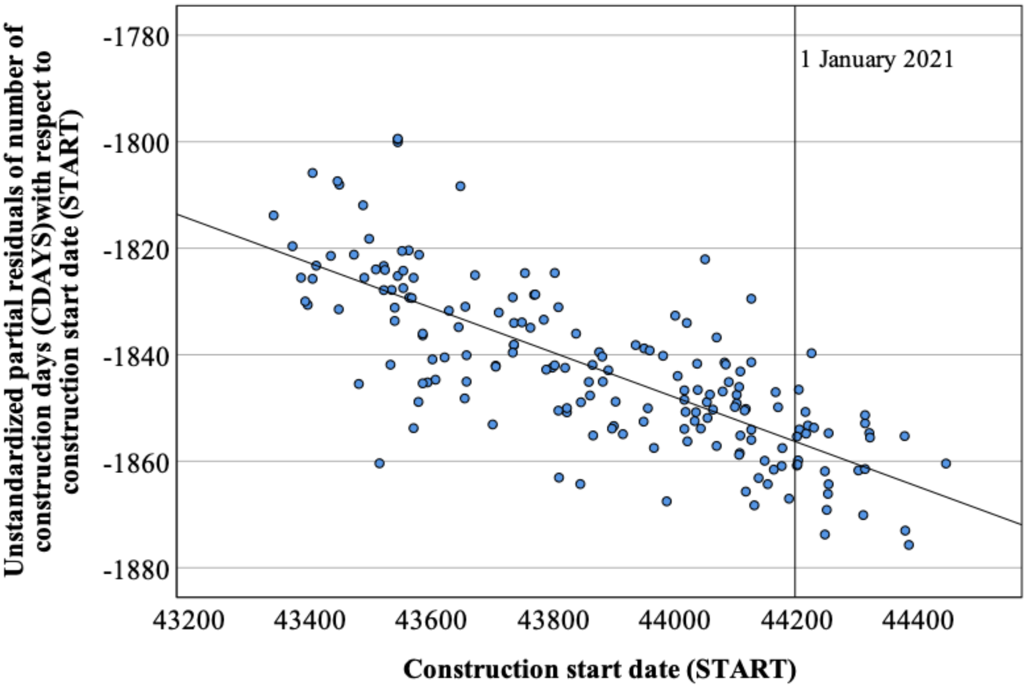


Figure 18: Unstandardized partial residuals plot for Model 1 (top) and Model 2 (bottom) with respect to construction start (START)

5.1.6. Construction team

A significant relationship was identified between the TEAM variable and on-site manhours performed by carpenters (Model 1: p = 0.001, power = 0.926). A significant relationship was also identified between the TEAM variable and the number of construction days (Model 2: p = 0.006, power = 0.827). Based on the unstandardized regression coefficients in Table **10** and Table 11, we can deduce that the difference between the "worst" and "best" performing teams, there is a difference of 352.5 manhours and 16.9 days of on-site construction.

We recall that the case contractor has with three regional teams, who operates relatively independent of each other, and considering the recent changes at the case contractor, project scheduling is now performed at the team level. The scheduling process involves the project manager and construction manager. Given this information, it is possible that differences in the scheduling process, or even the skill of the management, can influence project performance (Zidane and Andersen, 2018, Durdyev et al., 2017, Hasan et al., 2018, Nicholas, 2018). However, the differences between each team are not clearly defined and we can therefore not highlight these factors as more than possible explanations for the observed differences in performance.

On the other hand, the observed difference in performance can be attributed to varying use of subcontractors. For instance, team A typically pour and build the concrete foundation themselves (part of step 2.4 in Figure 13) while other teams more frequently outsource this work to subcontractors. The same applies to work associated with building interior features (part of step 2.6 in Figure 13). These differences make themselves present in the data which was used in the analysis. On average, team A spends 30 hours on building the foundation, team B spends 13 and team C spends zero. However, considering the fact that projects on average takes 1318 manhours, these differences are quite small and are therefore most likely not the main or largest factor causing the observed differences in performance.

The representation of each team in the analysis is quite uneven. Among the 208 projects that were analyzed, team A, B, and C make up 19.2%, 76%, and 4.8%, respectively (Table 8). It is possible that the lack of representation can for certain teams have biased the results. In addition, we recall that multicollinearity is higher among dummy variables of the TEAM variable. This can also cause biased results. By results we refer to the unstandardized regression coefficients.

In summary, there are many potential factors influencing the observed relationship between the TEAM variable and performance, as discussed in the sections above. It is therefore not possible to highlight one specific factor as the most likely cause.

5.1.7. Standard cabin design

A significant relationship was not identified for the STYLE variable with manhours (Model 1: $p = 0.235$, power 0.309) or construction days (Model 2: $p = 0.164$, power = 0.378). However, it is interesting that the CONTRACT variable, which reflects project scope, complexity, and resources requirements, was found to have a significant relationship in both models, yet the STYLE variable did not. Arguably, selection of a standard cabin design does not affect manhours or the number of construction days because each design comes in many different sizes. Perhaps there is not enough of a distinction between each cabin design for significant relationship to appear. That is, although each design varies in style and look, they all come in relatively similar sizes and thus require roughly the same workload. If there was a unique characteristic for size or complexity for each design, then the outcome would most likely have been different.

The average contract sum for all cabins is 2.97 MNOK (Table 7). For Aurora, Smart, and Jubileum the contract sum is 3.06, 2.93, and 2.99 MNOK, respectively. Because there is so little difference in the contract sum, we can assume that the scope and complexity of each cabin is relatively equal and therefore require relatively the same amount of work.

5.2. Practical implications and external validity

In the previous subchapter, the regression results were discussed explicitly form the perspective of the case contractor. In this subchapter, the regression results are discussed in terms of external validity and its general implications. That is, how other house contractors can make us of the findings presented in this thesis.

Among the variables included in the analysis, the contract sum (CONTRACT), which is a measure of project scope, complexity, and resource requirements (human and materials), is by far the variable with the most influence on manhours (MANHOURS) and project duration

(CDAYS). The partial eta squared values quantify how much more "important" this variable is compared to other variables analyzed. From

Table **10** we see that the contract sum is roughly twice as "important" as any other variable in influencing the number of manhours, and from Table 11 we see that the contract sum is roughly 1/3 more "important" than any other variable in influencing the number of construction days. Although the exact values may not be the same for other house contractors in Norway, it would be reasonable to assume that project scope and complexity are the most influential factor on performance of other house contractors in Norway, the same way it is observed in this analysis. Especially if they too build "kataloghus" like the case contractor in this thesis.

The regression results show that different teams perform considerably different from each other, and as discussed in the previous subchapter, it is possible that these differences are caused by differences in scheduling and skill of the management. Regardless of the underlying causes, the fact that each team performed so different from each other suggests that other house contractors can gain valuable insight to best and worst practices by investigating their own teams and/or departments. In other words, there are potentially "low hanging fruit" for performance improvement which house contractors can obtain without having to participate in a comprehensive and long-lasting benchmarking study of several contractors.

The regression results also show that construction during winter typically requires more manhours and lasts longer. Especially those operating in northern Norway or in areas with especially cold environments should consider optimizing the time of construction so that the majority of construction is performed outside the coldest months. The point is that although it is feasible to build during winter, the regression results suggests that it is less efficient.

6. Conclusions

This chapter presents the main findings in this thesis. The contribution to knowledge, limitations of the thesis, and suggestions for further work is also presented.

6.1. Main findings

The overall objective of this thesis was to contribute to the body of knowledge on construction performance, especially for house construction in Norway. In doing so, two research objectives were fulfilled: (1) investigate factors affecting the number of manhours performed by carpenters on-site, and (2) investigate factors affecting the duration of on-site construction. For simplicity, the number of manhours (research objective 1) and the number of construction days (research objective 2) are referred to as performance, or individually as manhours and duration.

To meet the research objectives, a literature study was conducted to identify construction factors affecting construction productivity. A case study was conducted to investigate some of the previously identified construction factors in a house construction context, using data from 208 house construction projects. Multiple regression was used to analyze the relationships between the factors and performance. The analysis shows that manhours and duration have a statistically significant relationship with project scope and complexity, date of construction start, and construction team (or department). In addition, it shows that manhours have a statically significant relationship with construction during winter and the number of changes to the standard building design.

The analysis presented in this thesis shows that project scope and complexity have by far the greatest potential to influence performance. That is building attributes such as gross floor area, number of floors, room complexities, and so on. Date of construction start had the second most influential variable on performance, however, the underlying factors contributing to this observation have not been settled, as there are many potential factors contributing to the observed relationship. Construction team (or department) was the third most influential factor for performance. Possible team characteristics that differentiate their performance include the skill of team members (management and labor), ability to communicate efficiently, and experience. Construction during winter and the number of changes to the standard building design had roughly the same potential to influence performance and were the least influential factors on performance.

The findings presented in this thesis highlight and quantify potential improvement areas that house contractors can pursue to improve their time and cost performance. In doing so, they will become more resource-efficient (human and material) and they will contribute to some of the current challenges in our society and the construction industry. For instance, by building more efficiently, the high emissions of the construction industry will be reduced (IEA, 2019), and they will contribute to releasing pressure on the housing market by supplying more alternatives for affordable housing (Solheim, 2019). Additionally, being able to build faster and at a lower cost than the competition yields a competitive advantage (Zidane and Andersen, 2018).

6.2. Contribution to knowledge

The work presented in this thesis provides new and useful knowledge on performance in the house construction context, of which there is a lack of existing research. Since construction can be region and industry-segment specific, the findings presented in this thesis are especially relevant to house construction in Norway as this is explicitly the scope of this thesis. For instance, some research on construction in Norway exists, but they are focused on other types of construction or include a broad definition of construction types (Ingvaldsen and Edvardsen, 2007, Zidane and Andersen, 2018).

While many previous studies on construction performance often have relied on survey responses (Dissanayaka and Kumaraswamy, 1999, Walker, 1995), the findings presented in this thesis were derived from real projects and the associated data records. Hence, the general limitations and drawbacks of doing a survey do not apply to the findings shown in this thesis. For example, surveys may be subject to biased answers, unmotivated responders, confusion about the questions, and so on. With that said, measurement error exists in all data, including the one used in this analysis.

This thesis also describes the application of multiple regression as a method for analyzing construction project data. This thesis shows how an easily accessible and well-known technique can be used to extract useful information with relatively little effort.

6.3. Limitations

The limitation of this thesis is addressed in three points.

Since there is a lack of research on performance in Norwegian house construction, the scope of this thesis had to be rather broad. Consequently, the selection of variables included in the analysis remained somewhat broad as well, although this was partly due to limited data availability. Given the variables and findings presented in this thesis, it is not possible to assume any type of causality between any of the factors and performance. To do this, more research is needed, especially using more detailed variables and control groups.

Limitations of multiple regression analysis apply. Namely, multiple regression can only determine average values, which is not an accurate representation of real construction projects (Tangen, 2005). In reality, no single construction project will be perfectly average. Especially considering the categorical variables. That is, a project cannot be half of one design style and half another. This leads to the discussion of the flaw of averages and how one should be cautious when interpreting average values, especially when they measure diverse and complex systems.

The scope of this thesis is house construction in Norway, however, the type of construction project that was analyzed was cabins. These cabins are very similar to typical Norwegian houses in terms of size and design. The case contractor builds houses as well as cabins, using the same production techniques and construction teams as with cabins. Despite these similarities, cabins are strictly speaking not houses. For that reason, one can argue that the findings presented in this thesis are less relevant to its scope and overall objective.

6.4. Further work

Many alternatives can be pursued to build upon the work presented in this thesis. Some of the most useful alternatives are described below.

As described in the previous subchapter, variable selection and specificity were a limitation of this thesis. There are several ways to try and solve this limitation. One alternative would be to investigate the variables that were identified as statistically significant in this thesis in more detail (i.e., the contract sum, number of changes to the standard design, winter conditions, date of construction start, and construction team). Especially the date of construction start was found to be very important, yet no reasonable underlying cause could be identified.

While the variables included in this analysis are mostly focused on factors that reduce performance, it would be equally useful to identify factors that have a positive effect on performance. Arguably, identifying factors that increase performance may result in more actionable measures which can be implemented in practice, compared to identify factors that have a negative effect on performance. For example, the regression results suggests that project scope and complexity is the most important and influential factor affecting performance (manhours and duration), however, it is difficult to a contractor do anything about this. Therefore, some potential research perspectives are:

- How does different production systems (degree of off-site assembly and product standardization) affect construction performance in a house construction context? One could for example sue the classification framework proposed by Jonsson and Rudberg (2015) to define some ideal and non-ideal placement in their framework based on a house construction context. For example, where in their framework are the best performing contractors located? Are all of them clustered in one specific area of the matrix?

- Lean construction is well known within the construction industry, yet there is a lack of quantitative research on how lean construction techniques affects construction performance, especially in the context of house construction (Nicholas, 2018, Singh and Kumar, 2020). By identifying the effects of different lean construction techniques on performance one can suggest which techniques contractors should implement first.

- Digitalization and use of BIM is often highlighted as an important factor to improve construction productivity (Barbosa et al., 2017). By quantifying the effects of different trends related to digitalization, construction organizations can prioritize which to invest in.

In addition to the suggestions above, there is clearly other factors affecting construction performance. The regression models presented in this thesis achieved R^2 values of 0.548 and 0.498 for Model 1 and Model 2, respectively. This means that the selection of variables used in the analysis can explain 54.8% and 49.8% of the variation in manhours and number of construction days, respectively. An alternative for further work is to attempt to identify the remaining variables affecting construction performance. One method of doing this is to explore the utilization of other research techniques. For example Ingvaldsen and Edvardsen (2007) used data envelopment analysis (DEA).

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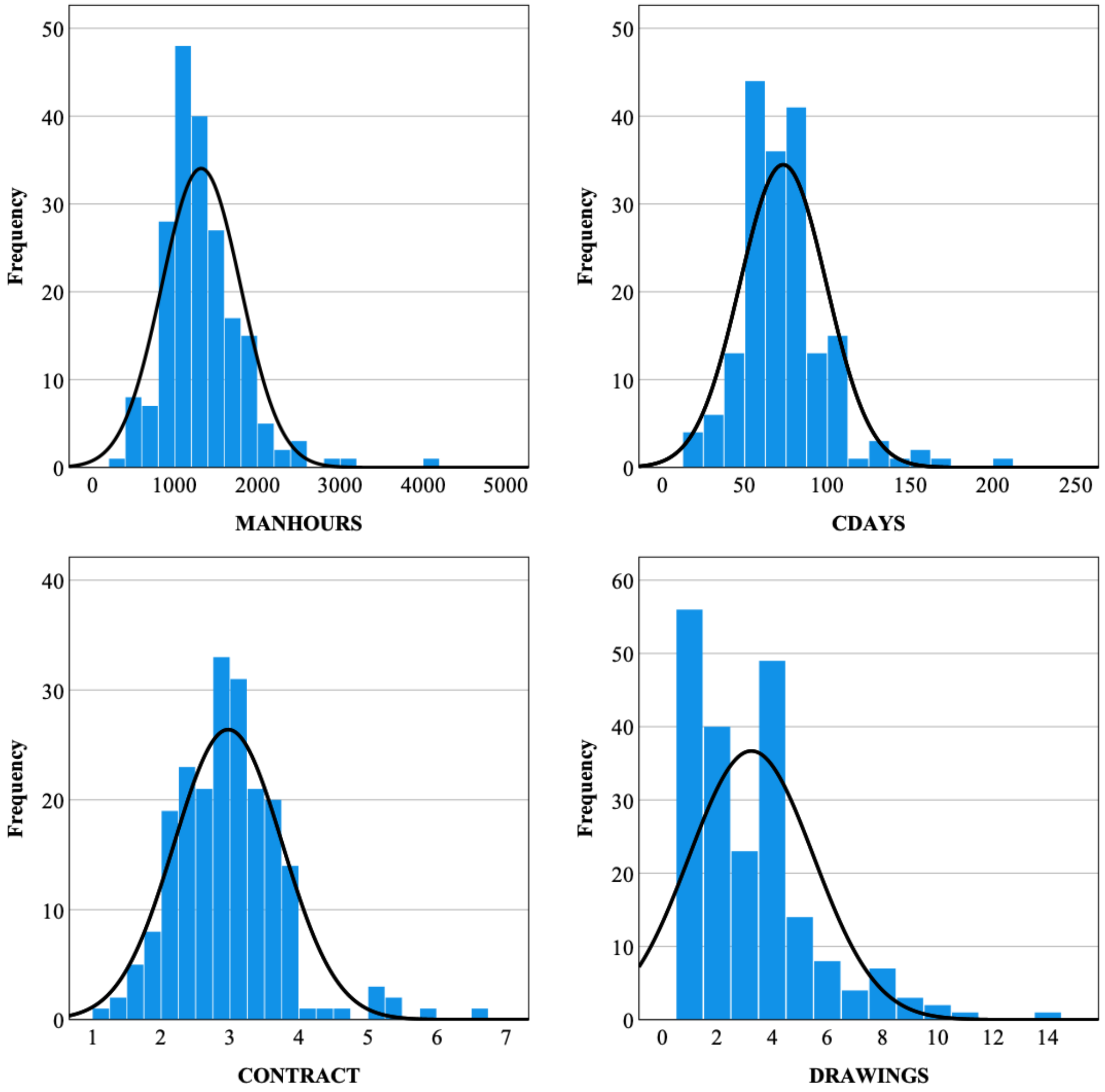
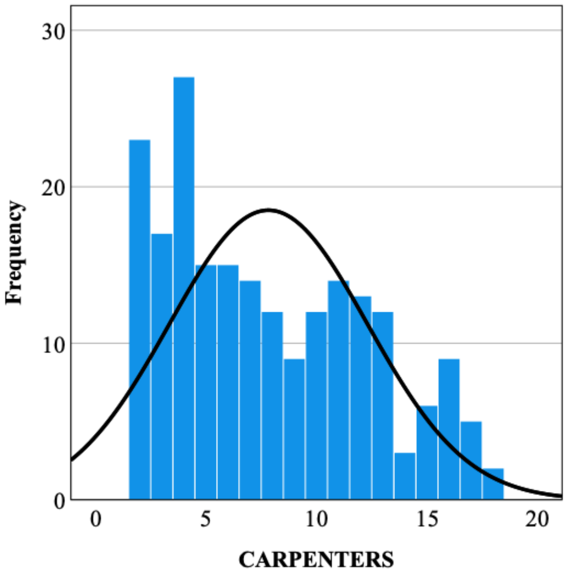
Appendix

Appendix 1: Frequencies for all variables

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0
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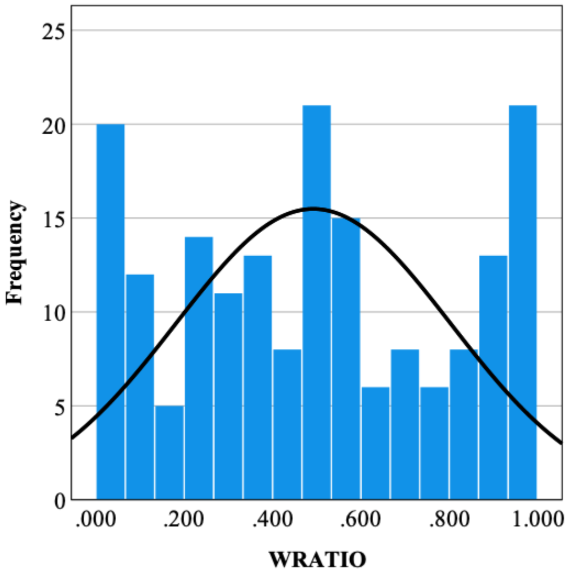
10
15
20
CARPENTERS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15
10
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.200
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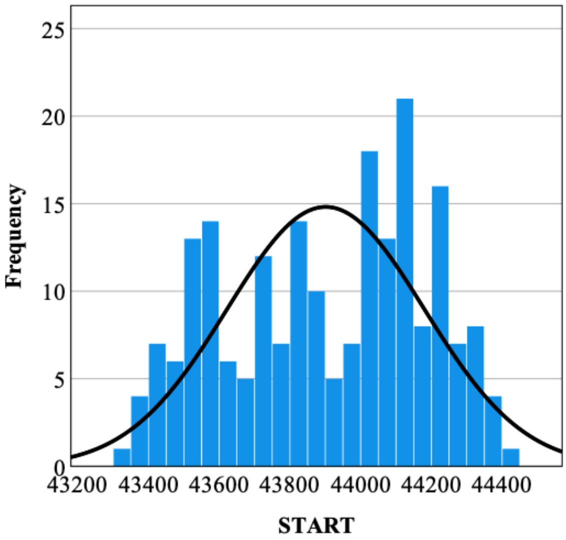
.800
1.000
WRATIO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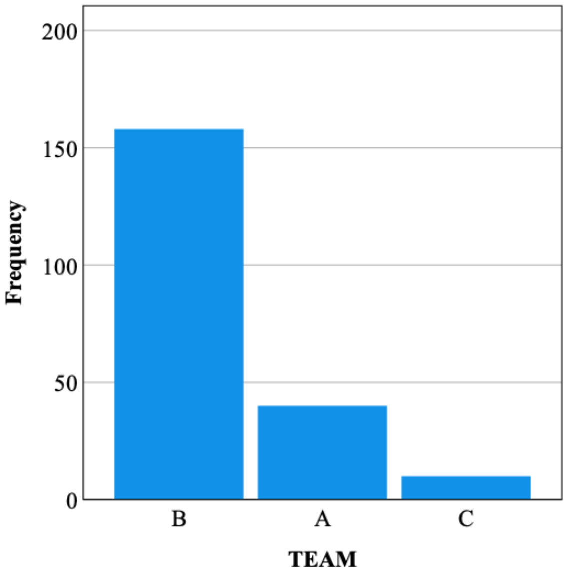
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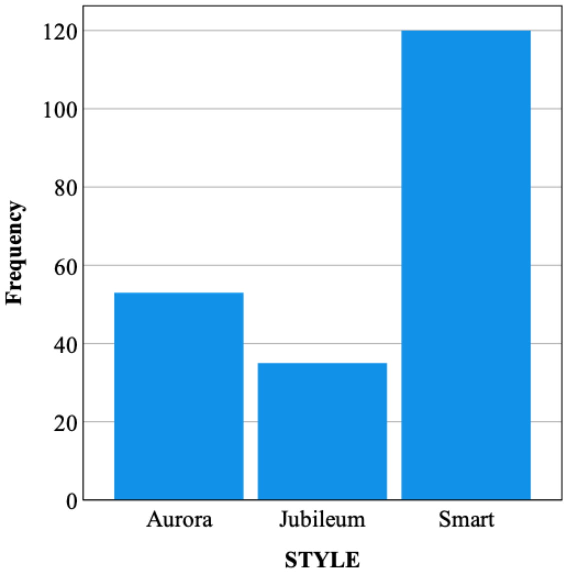
A
C
TEAM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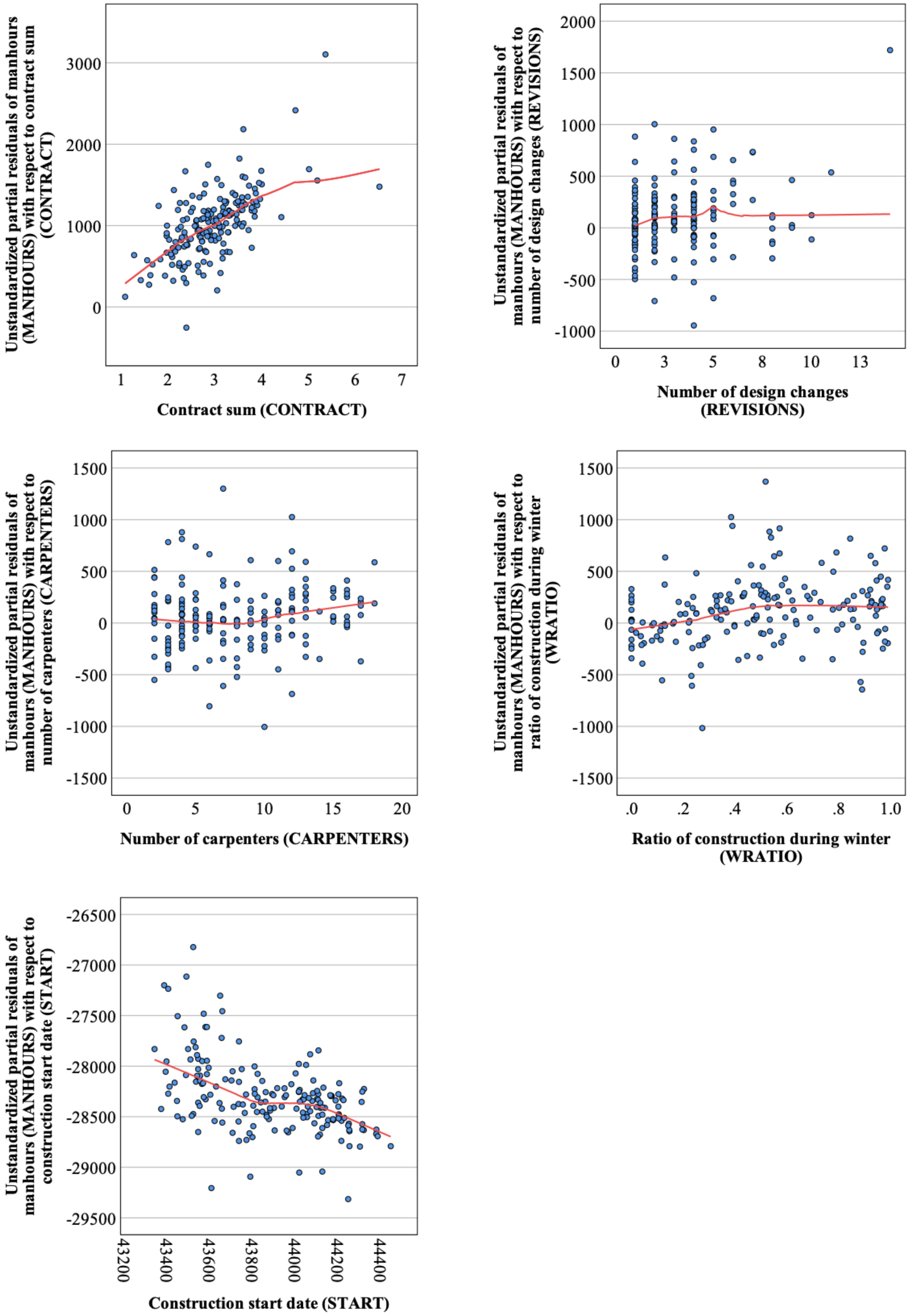
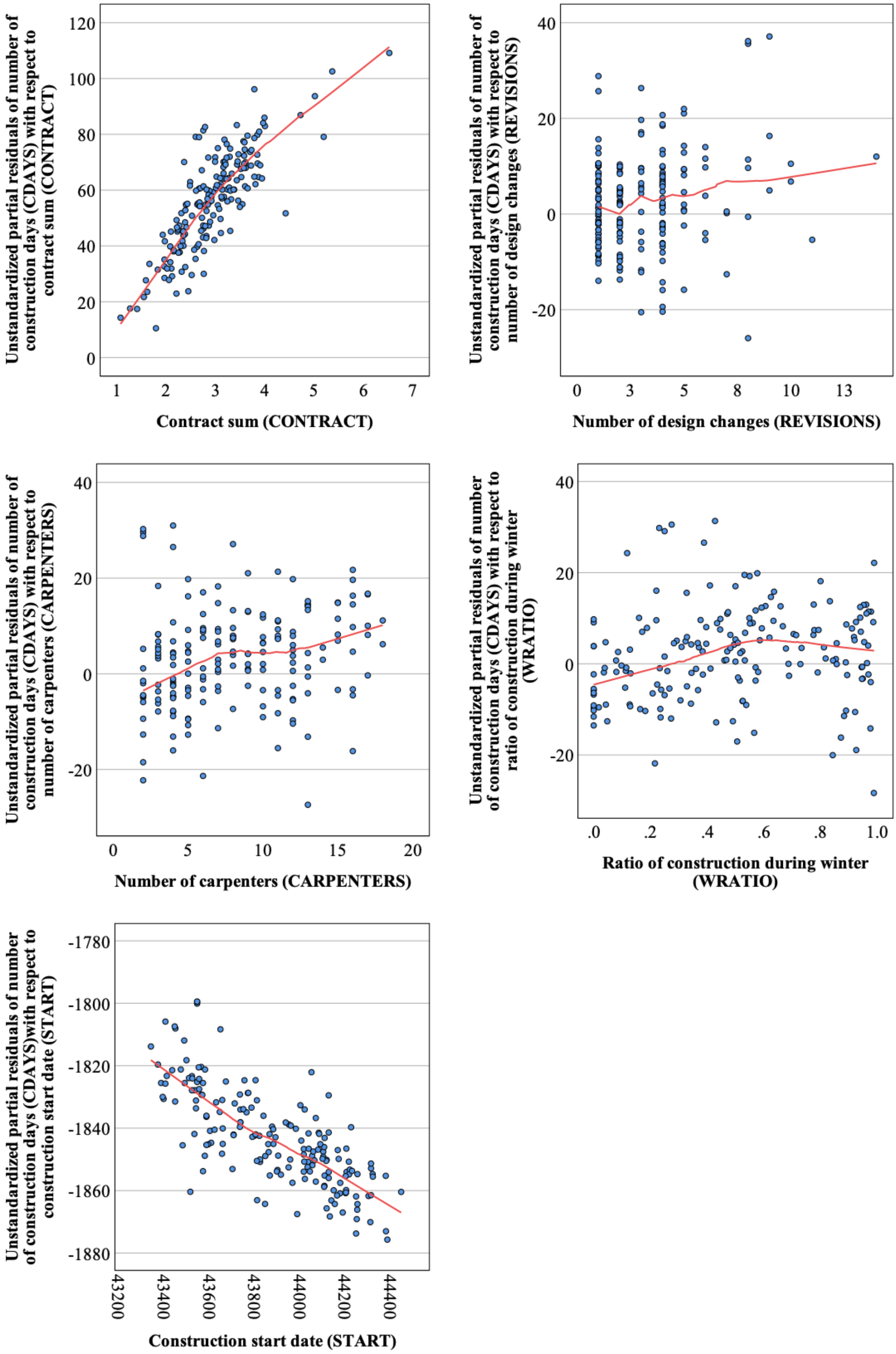
Aurora
Jubileum
Smart
STYLE

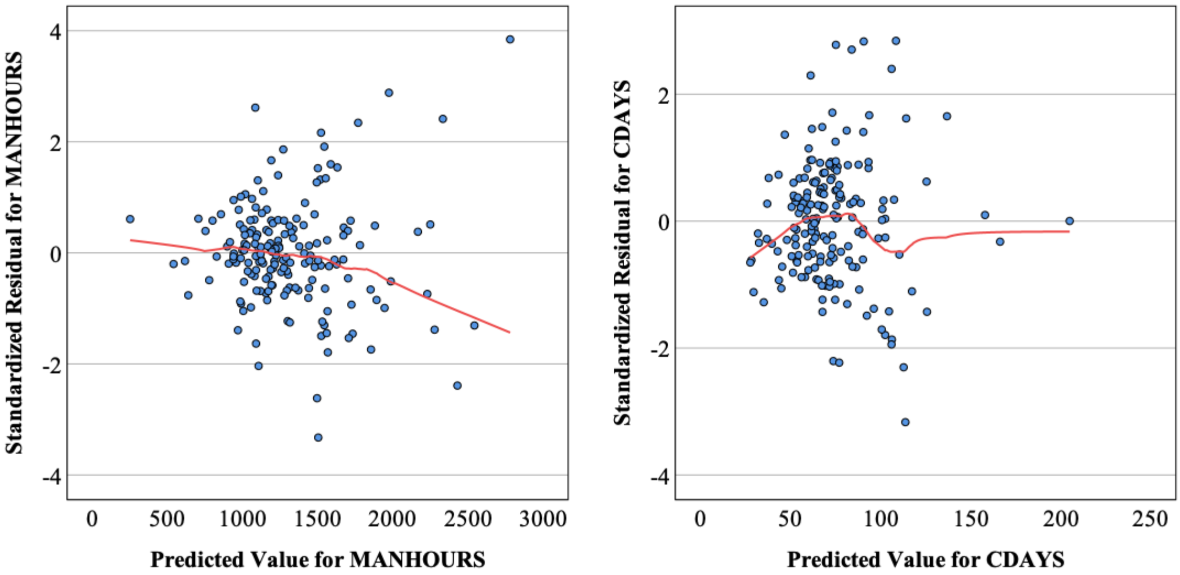
Appendix 2: Partial residual plots for Model 1 with LOESS curve (red)



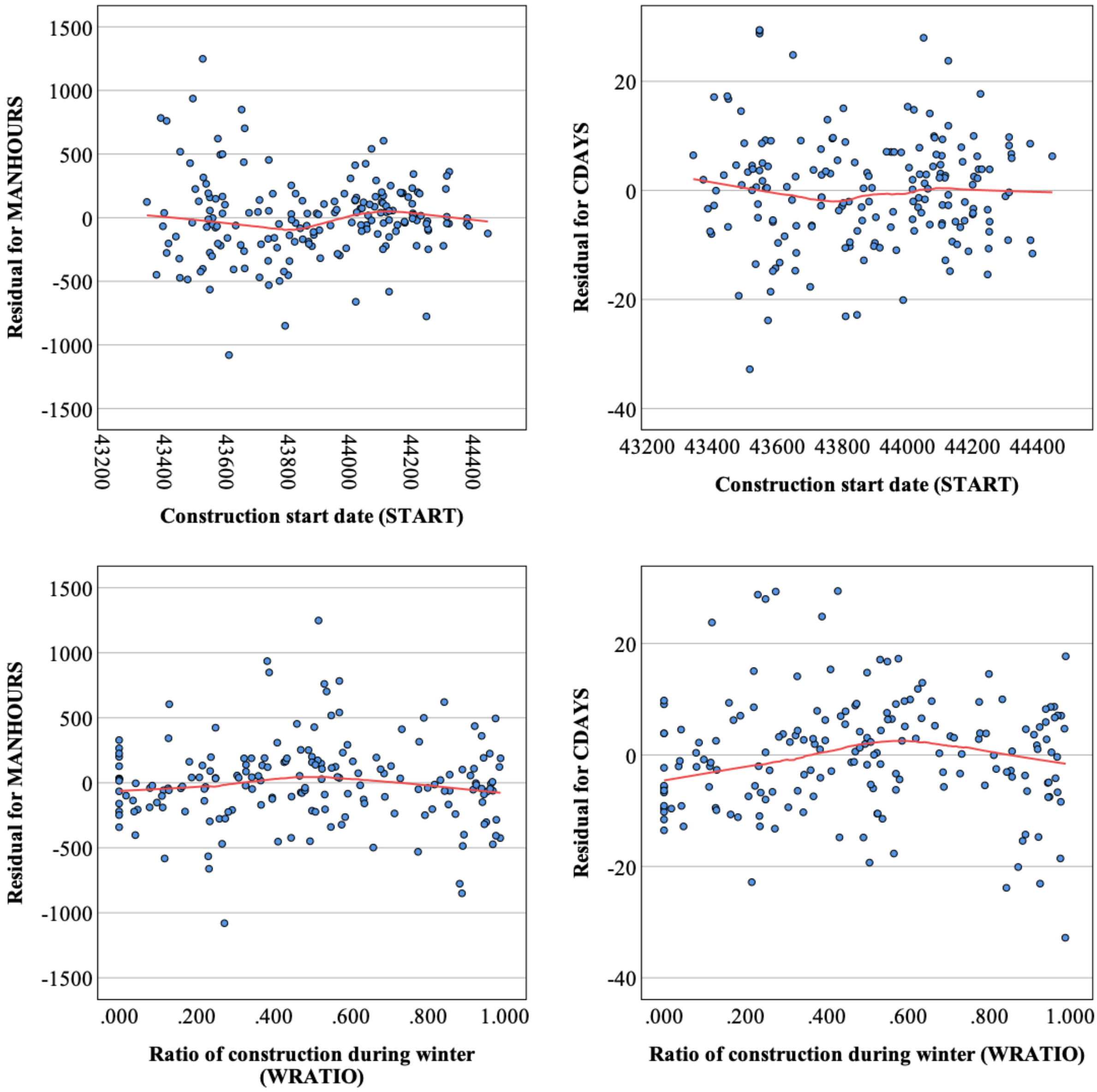
Appendix 3: Partial residual plots for Model 2 with LOESS curve (red)



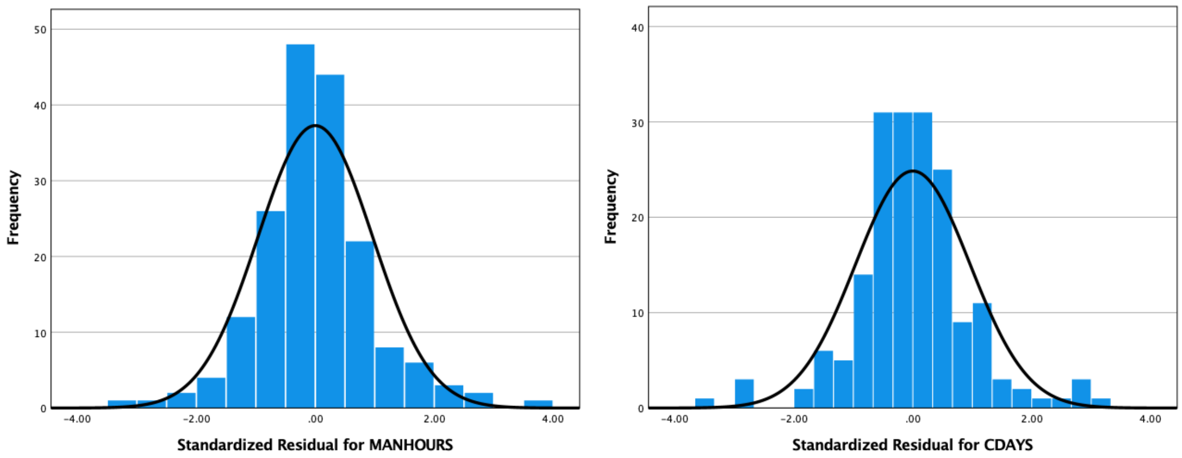
Appendix 4: Predicted values plotted against standardized residuals w/LOESS curve



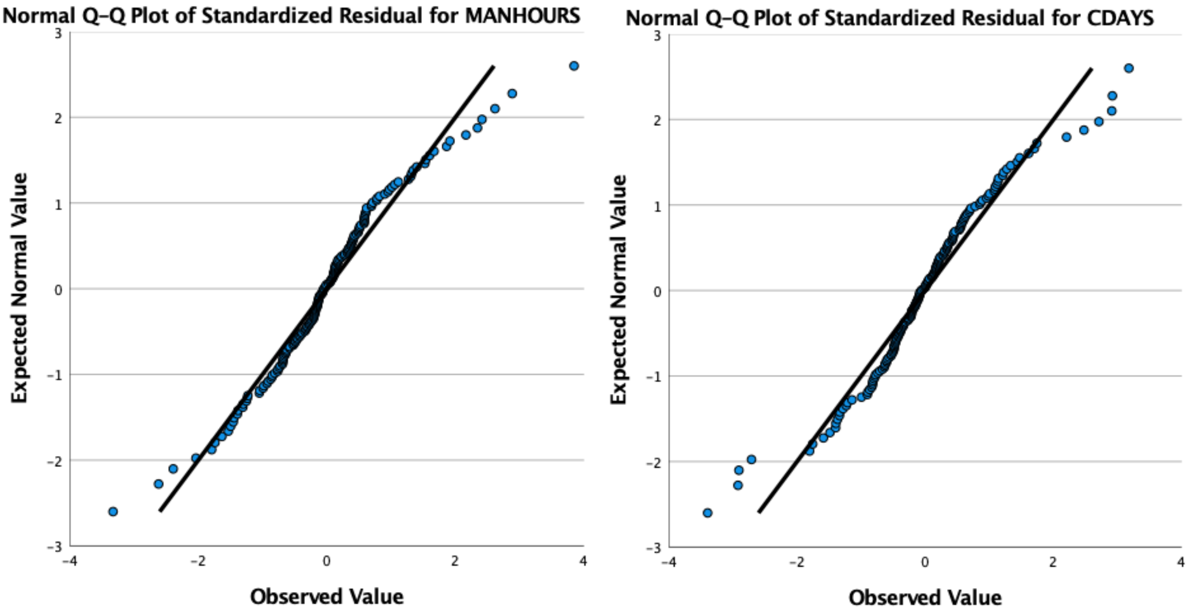
Appendix 5**:** Sequencing variables plotted against residuals w/ LOESS curve



Appendix 6: Distribution of standardized residuals for Model 1 and Model 2



Appendix 7: Normal Q-Q plots for Model 1 and Model 2



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