Providing an insight into digital drawing technologies

Visualizing the costs and benefits using dashboards

Bachelor Thesis

Industrial Engineering and Management

UNIVERSITY
OF TWENTE.

T.G.J. (Thijmen) Meijer

s1859374

University of Twente

Providing an insight into digital drawing technologies

Visualizing the costs and benefits using dashboards

<u>Personalia</u>	
Name:	T.G.J. (Thijmen) Meijer
Student number:	s1859374
<u>Study:</u>	
Study:	Industrial Engineering and Management
Faculty:	Behavioural, Management and Social sciences
University:	University of Twente
Address:	Drienerlolaan 5 7522 NB Enschede The Netherlands
Phone:	(+31) 053 489 9111
<u>Supervisors:</u>	
First supervisor:	I. Seyran Topan (Ipek) Faculty of Behavioural Management and Social sciences
Second supervisor:	Dr. E. Topan (Engin) Faculty of Behavioural Management and Social sciences
Date:	July 2019

Preface

This report is the result of the bachelor thesis that I have conducted for my bachelor Industrial Engineering and Management at the University of Twente. This research project is executed in collaboration with Company X. The main goal of this thesis is to advise Company X on when to use which digital drawing technology and provide the company a better insight into the costs and benefits of digital drawing technologies.

I would first like to thank my supervisor, the deputy director of Company X, for giving me this opportunity to conduct my bachelor thesis in this company. I also want to thank my supervisor for his pleasant guidance and useful feedback. In addition, I want to thank all employees at Company X for the great time and their useful input and advice for my bachelor thesis.

Second, I want to thank my supervisor at the University of Twente, Ipek Seyran Topan, for all her help and feedback. All my questions were answered incredibly quickly, which I greatly appreciate. I also want to thank Engin Topan for being my second supervisor for this bachelor thesis.

Lastly, I want to thank all my friends and others involved in this research project for their support and help. I also want to thank them for the feedback and creative ideas to improve my bachelor thesis.

Thijmen Meijer, July 2019

Management Summary

This report is written as bachelor thesis to complete my bachelor Industrial Engineering and Management at the University of Twente. This report describes my research project for Company X. Company X is a company specialized in engineering, installing and maintaining systems.

This report mainly focusses on the process of engineering the systems. The designs of the systems can be engineered in AutoCAD (2D-models) and Revit (3D-models). Both drawing programs have advantages and disadvantages, but it is not clear for the management when it is more advantageous to choose one program over the other. Therefore, the main goal of this report is to give the management of Company X an advice on when to choose which program. In order to compose this advice, the following research question has been drawn:

"When should Company X use which digital drawing technology, so that these technologies have an added value for the company?"

This research question is answered in five phases. Every phase has its own research question and sub-questions, together answering the aforementioned main research question. These research questions and sub-questions are answered by interviewing employees of different departments and the management, literature studies, creating a number of dashboards, and analysing the data as output of these dashboards. The current calculation method for the engineering of the project is analysed as well.

Since a couple of years, the demand for 3D-modelled designs has increased enormously. Therefore, Company X changed their engineering process. Some projects are now modelled in 3D using Revit instead of in 2D using AutoCAD. The main difference between these two drawing technologies is that 3D-models have an extra dimension compared to the 2D-models. Therefore, it takes more time for an engineer to master Revit (3D-modelling) than AutoCAD (2D-modelling). However, 3D-models engineered in Revit consist of real-time information of the project, while 2D-models cannot be updated, but must be shared again when changes are made. In addition, changes in a 3D-model will immediately be implemented in all other parts in the model while this is not the case with 2D-models.

In the future, it is expected that most of the projects will be engineered in 3D, since more and more clients expect Company X to model their designs in 3D. However, for some projects it is still more advantageous for Company X to draw them in 2D. Therefore, Company X needs directives for the determination of the choice of the drawing technology.

The large companies in the construction sector use Revit more and more as standard drawing technology. They argue that Revit adds a lot of value to their business processes, costs less time, shares information more easily, and saves money. Since Company X is a subcontractor, their client can set requirements regarding the digital drawing technology used by the company. The legislation regarding (the application for) construction activities, and therefore the drawing technologies used, is currently changing. The changes will make it easier to submit applications for projects in which new digital drawing technologies are used.

Consequently, the measurements (KPIs) that could be used to measure the performance of the digital drawing technologies used by Company X were investigated. After a literature study and some meetings with different employees of the company, I came up with a list of KPIs that are useful for Company X when examining the performance of the digital drawing technology for a project.

Using these variables, five dashboards were made using Excel to give Company X an advice on which digital drawing technology they should use for a project. Using these dashboards, the current projects are compared according to three methods, which are executed for both the costs and the time of the projects engineered with the different drawing technologies.

The results show that the total costs are decreased by 4,5%, the material costs are decreased by 2,2%, and the profit margin is increased. From these results can be concluded that 3D drawing technology causes cost savings compared to 2D drawing technology.

The results of the research on the time needed for a project show that the engineering time is increased by 20,7% (after deleting the outliers it decreased by 0,8%), the installing time is increased by 1,2%, and the construction time is decreased by 16,2%. These results indicate that 3D drawing technology causes an increase in the engineering time needed but on the other hand leads to a decrease in the total construction time for the projects. However, this decrease in construction time for the projects is questionable.

My recommendations for Company X are:

- Focus on engineering projects using 3D drawing technology;
- Engineer only simple projects (based on the type of building, size of the project, and difficulty level of engineering) using 2D drawing technology;
- Use the analyses presented on Dashboard 1 and Dashboard 3 to estimate the costs for a specific project, even better by using the filter options on the dashboards;
- Use the analyses presented on Dashboard 2 and Dashboard 4 to estimate the time needed for a specific project, even better by using the filter options on the dashboards;
- Use Dashboard 5 to determine which type of digital drawing technology to use and to determine the engineering time;
- Keep the database up to date, meaning that the database should be complemented with new data.

Table of content

List of Tables

List of Figures

Reader’s guide

This reader’s guide will give the reader an overview of the structure of my research project. I will shortly explain each chapter of my bachelor thesis below.

Chapter 1 introduces my bachelor thesis. This chapter contains, among others, an introduction to Company X, states a description of my assignment, and presents my problem approach.

Chapter 2 covers information about the current workflow of Company X, the current use of digital drawing technologies and the pros and cons of these technologies, and the current determination of digital drawing technology.

Chapter 3 outlines a literature study about the market development of digital drawing technologies and the development of the law. It also includes other requirements for Company X regarding digital drawing technologies.

Chapter 4 elaborates on the performance of digital drawing technologies. KPIs are selected to express the performance. Consequently, the chapter looks for the data needed for this expression.

Chapter 5 includes the measurement of the performance of digital drawing technologies. It covers a data analysis about the costs and benefits of digital drawing technologies, which is performed using dashboards, and an analysis of the calculation method for the engineering time of projects.

Chapter 6 summarizes the conclusions and gives recommendations to Company X in terms of digital drawing technologies and engineering time. I will also discuss the limitations of my bachelor thesis.

The chapters in this thesis are structured in the same way. The chapters have a short introduction. Thereafter, the chapter’s structure is presented using a bullet list. This improves the clarity of my bachelor thesis and the readability of my bachelor thesis.

I hope you enjoy reading my bachelor thesis.

Thijmen Meijer

Enschede, July 2019

Definitions

In my research project, I used some terms which have different definitions. To avoid misunderstandings of the reader and to ensure that every reader understands this research project, I have created a list of definitions.

KPI	A Key Performance Indicator (KPI) is a type of performance measurement. KPIs indicate the success of an organisation.
BIM	Building Information Modelling (BIM) is a 3D-modelling process that enables document management, coordination and simulation during the entire lifecycle of a project.
AEC	Architecture, Engineering, and Construction. By having these players work together, they can work more efficiently to bring a project to fruition.
CAD	Computer-Aided Design is a computer technology that supports the design process. CAD is used by engineers and designers to create, modify, and analyse technical drawings.
Wabo	General Provisions on Environmental Law Act. It is the basis for many of the permits relating to the physical living environment.
MOR	Ministerial Regulation on Environmental Law. The MOR is based on the Wabo.
BOR	Environmental Law Decree. The BOR is a general administrative measure based on the Wabo.
IFC	Industry Foundation Classes is a data model for exchanging and sharing specific BIM information between different software applications of parties in the construction process.

1 Introduction

In this chapter, I will present my bachelor thesis by introducing Company X, stating my assignment, and presenting my problem approach. In my research design, the research questions which will help me to answer the main research question are described. This chapter is structured as follows:

- Section 1.1 introduces Company X.
- Section 1.2 describes the motivation for the research project.
- Section 1.3 gives the assignment description.
- Section 1.4 presents the problem statement.
- Section 1.5 describes my problem approach and research design.

1.1 Introduction to Company X

Because of confidentiality agreements, any information that could be linked to the company is not presented. Sensitive business information will also not be presented.

Company X (hereinafter referred to Company X) is a specialised installation company. Company X engineers, installs and maintains systems. Company X is always looking for new solutions, customers and of course techniques.

By closely monitoring the technical developments, Company X continues to develop. Also, corporate responsibility is one of the supporting principles of Company X. The certifications of Company X give this responsibility more value. In addition to guarantees for quality, Company X also takes responsibility for the consequences of its business operations for people and the environment.

1.2 Motivation for the research project

For a few years, Company X changed the engineering process of the systems from only engineering 2D-models in AutoCAD to engineering 2D-models in AutoCAD and 3D-models in Revit. Company X has changed the engineering process, as the demand for 3D-modelled projects increased rapidly. Company X does not want to have to reject these projects, because in this way revenue is missed and the competitive position will deteriorate. 3D-modelling also has major advantages in comparison to 2D-modelling. However, it is still unclear to Company X what the costs and benefits of 2D- and 3D-modelling are. That is why I am asked to advise Company X on when to use which digital drawing technology and provide the company a better insight into the costs and benefits of digital drawing technologies, which is the goal of my research project. A more detailed explanation of my assignment can be found in section 1.3.

1.3 Assignment description

Engineering, installing and all other activities that are involved in the projects take a lot of time. Many people are involved in a project. For example, engineering systems costs a lot of time. The systems are engineered by engineers of Company X. The engineering process is a difficult task, as the engineers of Company X have to take many variables into account. For example, in the design phase, they must consider other installations such as ventilation ducts, electricity, lighting, and rainwater drainage. The engineers should also consider the type of building and system in the design phase.

The designs of the systems are engineered in AutoCAD and Revit. In AutoCAD, the systems are engineered in 2D. For a few years, Company X has started using Revit to engineer systems in 3D.

Company X is in doubt for which projects it would be necessary to use which drawing technology. Both drawing programs have their advantages and disadvantages. At the moment, the engineers of Company X have to engineer more and more projects in Revit. However, engineering 3D-models in Revit takes more time than engineering 2D-models in AutoCAD. On the other hand, engineering 3D-models in Revit should cause that mechanics encounter fewer problems when installing the system. At the moment, Company X has not a clear idea how much time it costs to engineer 3D-models in Revit instead of engineering 2D-models in AutoCAD and how much time is saved in the installing process because of engineering 3D-models in Revit. That is why Company X wants to know when it should use which drawing technology.

The assignment Company X gave me, and thus will be my research question for this research project, is described as follows:

"When should Company X use which digital drawing technology, so that these technologies have an added value for the company?"

My assignment has been performed in several departments of Company X. I have been in contact with the IT, Engineering, and Commercial department.

1.4 Problem statement

To determine the core problem, the Management Problem Solving Method is followed. The MPSM is a systematic approach to solve a business problem (Heerkens & Van Winden, 2012, p. 13). This will be done in several phases. In the first phase, I will determine the core problem.

As mentioned in section 1.2, Company X has to deal with some problems. Once I had a clear idea of the company, I discovered these problems. In the meetings with the deputy director, a couple of problems were addressed. I used these problems as a starting point. These were the following problems:

- Less and less practically educated employees
- Training mechanics takes a lot of time (which the few experienced mechanics do not have)
- There is a lack of well-educated mechanics
- Company X has to outsource parts of the work process
- Planning of maintenance work is not properly arranged
- In the future, the legislation will require 3D-modelling
- For a few years, the market requires 3D-modelled projects
- Projects have to be rejected
- There is a lack of information about the costs and benefits of 2D- and 3D-modelling

By visiting the company several times in the preparation phase of this research project, I was able to connect these problems. I made a problem cluster in which all problems are mapped. In the problem cluster, the causes and effects of the problems are identified. By doing this, I determined the core problem. The problem cluster can be found below in Figure 1.

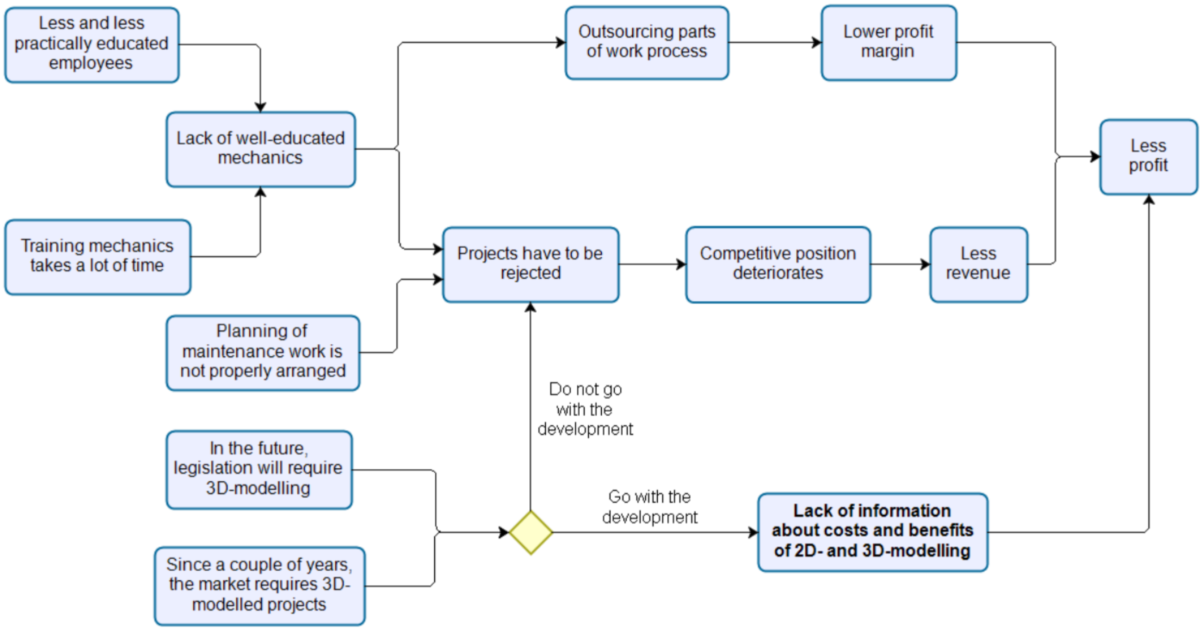

Figure 1: Problem cluster

From the problem cluster and the assignment Company X gave me, I have deduced the main problem of Company X. The construction sector has to deal more and more with this development. For a few years, Company X is required by several building contractors to model in 3D. Besides, the government is developing a law that stimulates construction and installation companies to work together with 3D-models.

Because of this, Company X has to choose if and how it wants to develop regarding their strategy for taking projects. As can be seen in the problem cluster above, Company X has to reject projects, if it does not go along with the development. This will lead to a deteriorated competitive position and less revenue. As a result, less profit will be made by Company X. This is of course not what Company X wants, which is why the company has chosen to go along with the development of digital drawing technologies. However, currently, Company X does not have a clear overview of the costs and benefits of 2D- and 3D-modelling. This causes that Company X does not know when to use which drawing technology. The management thinks that this results in less profit for Company X.

As can be seen in the problem cluster above, there are several causes that lead to less profit for Company X. I did not focus on these other causes (than the above-mentioned) of less profit for Company X, as these problems are difficult to solve in 10 weeks of time. In addition, I believe that solving one of these problems does not have much effect on the work process. Therefore, I have the following problem, the most important problem selected together with the deputy director of the company, defined as my core problem:

"There is a lack of information about the costs and benefits of 2D- and 3D-modelling"

The action problem (Heerkens & Van Winden, 2012, p. 22) regarding this research project is that Company X has a lack of information about the costs and benefits of 2D- and 3D-modelling. As a result, the management thinks Company X makes less profit. Therefore, I investigated whether this hypothesis of the management is correct or not. By investigating the hypothesis of the management, it gets more clarity about the costs and benefits of these digital drawing technologies. So, in terms of a reality and a norm (Heerkens & Van Winden, 2012, p. 23), the reality is that Company X does not know when and which digital drawing technology to select and the norm is that based on knowledge a digital drawing technology should be selected.

1.5 Problem approach and research design

The action problem is clear now. To solve this problem, I have created a problem approach. The problem approach is the second phase of the Management Problem Solving Method (Heerkens & Van Winden, 2012, p. 60). This phase describes in detail how I have approached my research project. It serves as a structure for my research methodology. To solve the action problem in a structured way, the solution process is divided into 5 different phases. To be able to give Company X advice, I followed the problem approach below. For each phase, I present a research question that can be answered using the sub-questions. The first four phases will help me to answer the last research question, which is the main research question of this research project:

"When should Company X use which digital drawing technology, so that these technologies have an added value for the company?"

By answering this research question, the action problem will be solved:

"There is a lack of information about the costs and benefits of 2D- and 3D-modelling"

In each phase, I will explain the research design after presenting the research question. I use the following phases to come up with an advice:

Phase 1: Analyse the current workflow

In the first phase, I will analyse the current workflow of Company X. In this analysis, I will focus on the calculation, engineering, and installation phase, as my assignment is focused on improving these phases of the workflow. After that, I will find out which digital drawing technologies are used in Company X now. Next, I want to figure out what the pros and cons of both digital drawing technology are. I will also find out how currently it is determined which projects are engineered in 2D or 3D. This will be done by answering the following research question and sub-questions:

1. **What does the current workflow of Company X look like concerning new projects?**
    a. What does the current work process of Company X look like, focused on the calculation, engineering, and installation phase?
    b. Which digital drawing technologies are used in Company X at the moment?
    c. What are the pros and cons of the digital drawing technologies used?
    d. How is currently determined which project will be engineered in 2D or 3D?

It is important to understand the current workflow of the calculation, engineering, and installation phase of Company X. By conducting an interview with the deputy director, the first sub-question will be answered. I will conduct an interview with the IT-manager to find out which digital drawing technologies are used in Company X. Also, I want to perform a literature study (Egan, 2008; Storms, 2017) to obtain information about the digital drawing technologies Company X uses. This information will be used to give a general description of these technologies. It is also important to know what the pros and cons of the digital drawing technologies used are. I will conduct interviews with the deputy director, BIM-coordinator, engineers, and the operational manager to get their opinion about the use of the different digital drawing technologies. I will also perform a literature study (Demchak, Dzambazova, & Krygiel, 2009) to answer this sub-question. Next, I will conduct an interview with the deputy director about the current determination of the digital drawing technology used in a project.

Phase 2: Investigate market developments concerning drawing technologies
In the second phase, I will first collect information about the developing of drawing technologies in general. After that, I want to investigate why Company X is required to work in 2D or 3D in a project. Then, I will find out what the law says regarding digital drawing technologies. I also want to find out if there are any plans for future laws on digital drawing technologies. This will be done by answering the following research question and sub-questions:

2. **How is the market developing with respect to digital drawing technologies?**
    a. How are drawing technologies developing?
    b. Why is Company X required to engineer projects in 2D or 3D by other companies?
    c. How is legislation developing regarding digital drawing technologies?

In this phase, it is important to find information about the development of digital drawing technologies. This information will be obtained by performing a literature study (Weisberg, 2008). Also, I will conduct an interview with the BIM-coordinator. After that, it is important to know why Company X is required to engineer projects in 2D or 3D by other companies. This sub-question will be answered by performing an interview with the deputy director. Then, it is also important to have knowledge about the legislation regarding digital drawing technologies. I will obtain this information by performing a literature study (Duivenvoorden & Alwicher, 2018).

Phase 3: Collect information and create KPIs
In the third phase, I will first perform a literature review about existing KPIs. Next, it is important to know which KPIs can express the performance of digital drawing technologies for the installation branch. After that, I will investigate which data I need to create the KPIs. Next, it is important to find out if and how I can obtain this data from the company. Then, it is necessary to identify the preferences of the management regarding the assessment of the performance of digital drawing technologies. This will give an indication of what the management wants to have investigated, making it easier to select the most suitable KPIs. This will be done by answering the following research question and sub-questions:

3. **How can the performance of digital drawing technologies of Company X be measured in terms of costs and benefits?**
    a. Which KPIs exist that can express the performance of projects in general according to the literature?
    b. Which KPIs exist that can express the performance of digital drawing technologies from the company?
    c. What data is needed to create the KPIs so that they are reliable and valid?
    d. Which KPIs does the management of Company X wants to have investigated?

In this phase, it is important to find information about KPIs which can express the performance of projects in general. This information, which will be used to answer the first sub-question, will be obtained by conducting a systematic literature review. It is also important to know which KPIs can express the digital drawing technologies from the company. I will obtain this knowledge by arranging a conversation with the deputy director, operational manager, and project manager to discuss all possible KPIs which I could investigate. I will make a list of all the KPIs I will find in the systematic literature review. Thereafter I will make another list with KPIs which can express specifically the performance of digital drawing technologies used for projects in Company X. Next, I will select (and create) data that I need to show the performance of the digital drawing technologies using KPIs. I will talk with some employees of Company X to find out where I can find the data needed and which data is available. In this way, the third sub-question will be answered. After a discussion with the deputy director, I will select some KPIs from the two lists which I will investigate. Finding the right KPIs is crucial in order to be able to monitor the performance and recognize potential improvements.

Phase 4: Measure performance digital drawing technologies
In the fourth phase, I will measure and analyse the performance of the digital drawing technologies of Company X using some dashboards. First, I will create a manual for these dashboards. Then, I will perform an analysis of the costs of the projects engineered with the different drawing technologies. In this analysis, I will concentrate on some specific costs, which will be selected as KPI in chapter 4. In addition, it is important not only to focus on costs but also on the time needed for the projects. Next, I will find out if the calculation method for the engineering of projects of Company X is aligned with the various drawing technologies. I will also find out how this method can be improved. This will be done by answering the following research question and sub-questions:

4. **How do the digital drawing technologies of Company X perform?**
    a. How should the user use the dashboards?
    b. How is the relation between the costs of projects engineered with the different drawing technologies?
    c. How is the relation between the time needed for projects engineered with the different drawing technologies?
    d. How can the calculation method for the engineering of projects be improved concerning the various drawing technologies?

In this phase, it is important to analyse the data about the costs of and time needed for projects engineered in 2D and 3D. I will first explain the design phase of the dashboards. Thereafter, the purpose of the dashboards and the way the KPIs are visualized will be determined. To finally answer the first sub-question, I will create a clear and simple manual for the users of the dashboards. To answer the second and third sub-question, I will analyse the data. I will also perform an analysis of the current calculation method for the engineering of projects. From the answers of the second and third sub-question, I will conclude if and how the calculation method should be changed. In this way, the pre-calculation of projects will be more accurate, and more profit could be made.

Phase 5: Advice Company X regarding digital drawing technologies
In the fifth phase, I will first describe shortly the conclusions from the market research performed in chapter 3. Then, I will describe the conclusions from the results of the data analysis of the performance of digital drawing technologies performed in section 5.2 and section 5.3. Next, I will present recommendations to Company X in terms of digital drawing technologies and engineering time. This will be done by answering the following research question and sub-questions:

5. **When should Company X use which digital drawing technology, so that these technologies have an added value for the company?**
    a. What conclusions can be drawn from the market research?
    b. What conclusions can be drawn from the data analysis of the performance of digital drawing technologies?
    c. When should Company X use 2D or 3D drawing technology?
    d. How can Company X calculate the engineering time for the different drawing technologies?
    e. What limitations might have influenced my research project?

In this phase, conclusions have to be drawn from the market research and the results of the performance of digital drawing technologies. It is important to describe market developments and to provide advice to Company X regarding these developments. Analyses about the performance of the digital drawing technologies will be presented. Besides, I will provide a well-founded recommendation when Company X should use a type of digital drawing technology. Then, advice on the calculation of the engineering time for the various drawing technologies is provided. Finally, the limitations of this research are discussed, as these limitations might have influenced my research project.

2 Information about the current workflow

In this chapter, I will present information about the current workflow of Company X. The following research question will be answered in this chapter: "*What does the current workflow of Company X look like concerning new projects?"*. I have structured this chapter as follows:

- Section 2.1 describes general information about the workflow of Company X.
- Section 2.2 describes the digital drawing technologies in Company X.
- Section 2.3 describes the pros and cons of the digital drawing technologies used.
- Section 2.4 describes the current determination of 2D- and 3D-projects.
- Section 2.5 summarizes the chapter.

2.1 General information about the workflow of Company X

In this section, the following question is answered: "*What does the current work process of Company X look like, focused on the calculation, engineering, and installation phase?*". I will give a short description of the workflow of Company X.

As mentioned in section 1.1, Company X is a specialised installation company. Company X engineers, installs and maintains systems. These systems are installed in all kinds of buildings. In this way, Company X has to deal with many different types of projects. These projects are accepted by the account manager of Company X. The account manager determines whether Company X conducts a project or not. Before this decision is made, an estimate of the costs of the project is made. From this estimation, a price for which Company X would conduct the project is determined. This price is calculated by the sales engineers of Company X. If the client and Company X agree on all conditions and prices, it will be a project of Company X and so the system will be engineered and installed by Company X. The engineers will start engineering the system. In the engineering department, the system is designed. A system can be designed in different ways. The design process of Company X has changed for a few years, as can be read in section 1.2. In section 2.2 more information about the different digital drawing technologies that are used to design systems, is given.

The materials needed for a project are established after the design has been made. Based on the design of the system, a bill of material is created. The materials from this bill of material are purchased by the operational manager of Company X. Also, parts of the project are prefabricated in the workplace. That is why Company X must have materials in stock which the welders can use to prefabricate parts of the project. These materials are stored in the warehouse of Company X. The inventory manager handles the bills of material of the parts of the project which need to be prefabricated. He checks if there are enough materials in stock in the warehouse, transfers the materials needed, and orders new materials if necessary. The tailor-made prefabrications of a project will be delivered at the construction site. In this way, the mechanics of Company X only have to install the system (and so do not have to edit the components).
Installing the system is not a very complicated process. However, this process is hindered by legislation. The mechanics must take into account many safety standards during the installation process. Also, the system is not the only installation in the building. The mechanics must, therefore, take the other installations into

account when installing the system. This makes it difficult to install a system. The engineering process is therefore very important for Company X since the quality of the drawings determines how well the installation goes.

Once the system is installed in the right way, which is controlled by an independent authority, the delivery of the project will take place.

2.2 Digital drawing technologies in Company X

In this section, the following question is answered: “*Which digital drawing technologies are used in Company X at the moment?*”. There are two types of digital drawing technologies that Company X uses: AutoCAD and Revit. These are described below. Before I am going to describe the drawing technologies, I will first elaborate on the work method of Company X.

Like more and more companies in the AEC-industry, Company X increasingly develops projects using Building Information Modelling (BIM). According to the National BIM Standard (NBIMS) is BIM a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onwards (2015). The Construction Management Association of America (CMAA) defines BIM as: “… production and coordinated use of a collection of digital information about a building project (Egan, 2008)”. So, BIM simplifies the collaboration (providing, retrieving, and adjusting of information) between different parties in a project. To use BIM, Company X must be able to share a digital representation of the system, to publish the information in the model interoperable, and to exchange information open and in the same language for all project parties. To develop systems, Company X makes use of four products of the American multinational Autodesk: BIM 360, AutoCAD, Revit, and Navisworks.

BIM 360

BIM 360 is one of the products of Autodesk that Company X uses. The BIM 360 platform is a cloud-based common data environment in which Company X can exchange project data without cumbersome exports or time-consuming steps. The data can be shared instantly across the team via a web browser or on a mobile device in the field (Storms, 2017). The platform consists of seven products. Company X uses four of these products since some products are irrelevant to the company. The four products are the Design, Docs, Glue, and Build packages of the BIM 360 family. Each product has its place within the AEC-project lifecycle, as depicted in Figure 2.

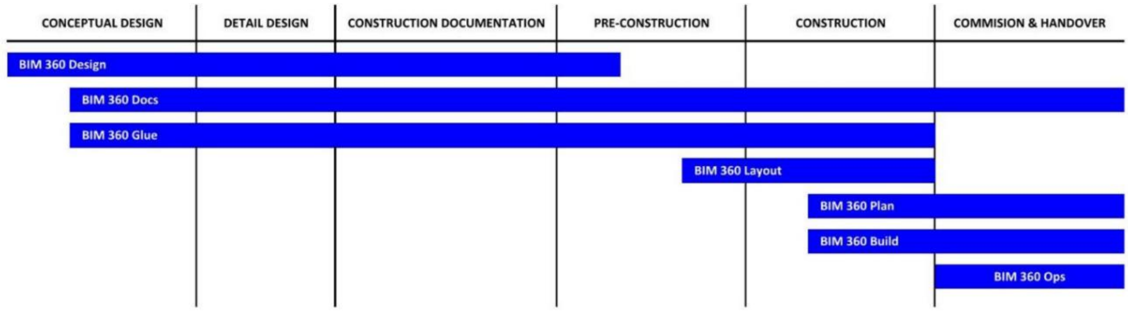

Figure 2: BIM products in AEC-project lifecycle

AutoCAD

Company X uses two different digital drawing programs to engineer systems. One of those digital drawing programs is AutoCAD. AutoCAD is a computer-aided design (CAD) program with which technical drawings can be made. In Company X, AutoCAD is used to create 2D-models of systems. The drawing program was mainly used in the past. Nowadays only the simple projects (based on the type of building among others) are engineered in AutoCAD.

Revit

Nowadays, most of the projects are engineered using Revit. Revit is a BIM software that allows users to design a building and structure its components in 3D. It is a single file database that can be shared among multiple users. The drawings and schedules in Revit are always fully coordinated in terms of the building objects shown in drawings. Company X mainly uses this digital drawing program.

Navisworks

Company X also uses the 3D design review product Navisworks from Autodesk. By using Navisworks, it is possible to combine design and construction data into a model, navigate around in the model, and identify and resolve clash and interference problems before construction starts. The program should make sure that the problems (or 'clashes' in Navisworks) mechanics normally encounter on the construction site already are encountered and solved by the engineers. Navisworks is used in combination with Revit.

2.3 Pros and cons of the digital drawing technologies used

In this section, the following question is answered: "*What are the pros and cons of the digital drawing technologies used?*". I will elaborate on the pros and cons of Revit compared to AutoCAD.

According to Autodesk is the main difference between AutoCAD and Revit that "AutoCAD a general CAD and drafting software used to create precise 2D and 3D drawings is, and Revit software is for BIM with tools to create intelligent 3D models of buildings, which can then be used to produce construction documentation". From this definition, the first and biggest advantage of Revit over AutoCAD can be deduced; by using BIM, Revit can publish 3D-models with real-life information at any time, while AutoCAD's 2D-models were shared once in a certain time (for example, every two weeks). Because of this, it could be that if the building construction changed, the design of the system had to be adjusted completely and so a lot of time was wasted. Thanks to Revit and the additional new working method BIM, this time is no longer wasted.

Besides, in Revit all points in a model are connected. When one part of the model is changed, the rest of the model will also change. Nothing in the model can change without the consequences being implemented immediately, such as a change in the bill of material. This was not the case in AutoCAD. Also, the multiple views in Revit give considerably more control than is possible in AutoCAD. The engineer can immediately see what he is doing and check whether something makes sense or not. This avoids the dreaded fear of last-minute discrepancies (Demchak, Dzambazova, & Krygiel, 2009, pp. 6-9).

On the other hand, Revit also has disadvantages compared to AutoCAD. The main disadvantage of Revit compared to AutoCAD has to do with the learning curve. The learning curve for 2D-modelling in AutoCAD is shorter than the learning curve for 3D-modelling in Revit. This difference is mainly caused by the extra dimension Revit has. Because of the extra dimension that Revit has, an engineer must assign more values to the design than was necessary in AutoCAD. To master Revit, more insight (which takes time) is needed in comparison with AutoCAD.

Starting engineering 3D-models in Revit and using BIM has also caused that the starting point for Company X in the project takes place earlier. Because a project is often adjusted in the beginning, this is mainly a disadvantage for Company X since it needs much more time in the engineering phase. The engineer has to adjust his design more often, which takes time. The engineer will also have to be present at more meetings about the construction, which takes a lot of time. More about the change of the starting point can be read in section 4.2.

2.4 Current determination of 2D- and 3D-projects

In this section, the following question is answered: "*How is currently determined which project will be engineered in 2D or 3D?*". I will elaborate on Company X's strategy and what consideration Company X should make.

More and more clients are obligating Company X to engineer the design of the system in 3D. Especially the large contractors of construction projects already work almost completely in 3D with BIM. This is due to the rapid development of this technology. As a result, Company X will increasingly have to engineer projects in 3D.

Because of confidentiality agreements, sensitive business information will not be presented.

2.5 Conclusion

This chapter was about the current workflow of the projects of Company X. After a new project is accepted by both parties, the engineer starts engineering the system. This can be done by using different drawing technologies. Company X increasingly uses programs on the basis of Building Information Modelling (BIM). For this, the company uses different products of Autodesk: BIM 360, Revit, and Navisworks. The digital drawing technology Revit allows Company X to model designs in 3D. Another drawing technology that Company X uses is AutoCAD, which is a computer-aided design (CAD) program that creates designs in 2D. There are multiple advantages and disadvantages of these two drawing technologies. Since an increased number of clients require Company X to engineer the models in 3D, the company uses this technology more often. However, for some projects, it is still more advantageous to engineer them in 2D.

3 Market developments concerning drawing technologies

In this chapter, I will present information about the market developments of drawing technologies. The following research question will be answered in this chapter: "*How is the market developing with respect to digital drawing technologies?*". I have structured this chapter as follows:

1. Section 3.1 describes the development of drawing technologies.
2. Section 3.2 describes the requirements of contractors regarding drawing technologies.
3. Section 3.3 describes the development of legislation regarding drawing technologies.
4. Section 3.4 summarizes the chapter.

3.1 Development of drawing technologies

In this section, the following question is answered: "*How are drawing technologies developing?*". I will elaborate on the development of AutoCAD and Revit and the development of the market regarding the choice for the drawing technology.

AutoCAD has been available on the market since 1982, making it the first CAD system developed for PCs. Over the years, a few dozen versions have been released. In AutoCAD, only 2D-drawings could be produced in the first versions. Later, a 3D-version of the drawing technology was created (Weisberg, 2008, pp. 140-145).

Revit has entered the market later. The first version was released in 2000. After Autodesk purchased the Revit Technology Corporation in 2002, more research, development, and improvement to the software were done. In 2003 became Revit the basis for future developments. Several new versions of Revit were introduced in the following years. The different versions have been enrolled into one product in 2013. Nowadays a new improved version is released every year. In recent years, Revit has become the standard drawing technology for an increasing number of companies in the construction sector. Because of this rapid development of Revit, BIM is also developing more and more. (Weisberg, 2008, p. 183)

In addition, the construction sector is developing more and more towards the use of 3D drawing technologies and the use of BIM. In a conversation with the Program Manager Digital Construction of BAM Infra Nederland at the seminar "BIM als Businesscase", I was told that BAM gets a lot of added value from the BIM models. BAM is building faster thanks to the use of BIM (Moons, personal communication, June 6, 2019). Moons also claimed that the projects of BAM would be more expensive if BAM had to return to 2D-designs. That is why BAM has plenty of employees prepared internally for BIM and is now cautiously asking her suppliers to work also with BIM. BAM also shows its suppliers that they have to work towards BIM, otherwise it will cost BAM and its suppliers too much money in the future.

Also for Dura Vermeer, another large Dutch contractor, BIM is indispensable. Dura Vermeer was the first large contractor that introduced one BIM standard. All projects that Dura Vermeer takes are processed in the same way in BIM. Thanks to the use of BIM-models, Dura Vermeer is able to share information centrally and clearly. The ultimate goal of the company is to achieve a better (technical) quality of buildings ("BIM | Dura Vermeer," n.d.).

Lastly, for the installer Bosman Bedrijven, is BIM also indispensable. This BIM method has been implemented in the way Bosman Bedrijven works. Hamster, general manager at Bosman Bedrijven, also recognizes the development of the market (Bosman Bedrijven, n.d.):

> "We have been seeing a growing demand for BIM from clients for some time. In recent years, we have already taken the necessary steps to meet this demand. From this centralized approach, we as an organisation hope to connect better with the current market." (para. 2).

The three examples above show, just like the rapid development of Revit (and BIM), that the choice for the digital drawing technology will increasingly be 3D. "Of course, there are costs at the front-side, but those companies which do not participate will experience the disadvantages at the back (Klören, personal communication, June 6, 2019)."

3.2 Requirements of contractors

In this section, the following question is answered: "*Why is Company X required to draw projects in 2D or 3D by other companies?*". I will elaborate on the requirements of the clients of Company X.

Company X is a subcontractor. This means that Company X is hired by a company to perform a part of the project, in this case, the installation of a system. As a result, Company X can make few demands on the client, since the client can choose from several subcontractors. Because of this, in most cases, the client determines the working method (and therefore the drawing technology) of Company X. The client determines the working method of Company X because the work performed by the client and the subcontractor are in this way in line with each other.

As described above in section 2.4 and section 3.1, large construction companies and installers are increasingly inclined to 3D-modelling. Since these companies are often the client of Company X, Company X will more and more have to use 3D drawing technology.

3.3 Development of legislation

In this section, the following question is answered: "*How is legislation developing regarding digital drawing technologies?*". I will elaborate on two future changes to the law and describe the findings from my literature study (Duivenvoorden & Alwicher, 2018).

Currently, citizens of and companies located in the Netherlands are obligated to follow the rules of the Wabo when they want to ask permission for activities that influence the physical living environment (Duivenvoorden & Alwicher, 2018). When this application relates to construction activities, the regulations defined in the MOR and the BOR are also applicable. The MOR states, among others, what information the applicant for an environmental permit must add to his application, in what form, and how the applicant must supply his data. The BOR states for which activities a

Wabo request is mandatory and which authority is competent for an environmental permit, among others. This Wabo system is very complicated because it contains an enormous amount of laws and regulations. That is why the government of the Netherlands wants to change this system.

The Environmental and Planning Act (Omgevingswet) will enter into force in 2021. This Act will combine and simplify the regulations for spatial projects. The aim is to make it easier to start up projects (Government of the Netherlands, 2017). This change in the law has some consequences. The following consequence is the most important for Company X:

- Nowadays, the MOR bothers the use of BIM in the application for an all-in-one permit for physical aspects. BIM-files are often exchanged via IFC. This type of BIM-files is currently not allowed as an attachment to the application for an all-in-one permit for physical aspects, because the MOR uses format restrictions. Therefore Duivenvoorden & Alwicher (2018) advise that the MOR should make it possible to supply BIM files in IFC with the requested information in the new Act.

Also, the Digital Government Act will be introduced soon ("Voortgang Wet digitale overheid," 2018). The Digital Government Act aims to make it possible for Dutch citizens and companies to log in securely and reliably at the platform of the (semi) government. The law also obligates open standards. By indicating IFC as an open standard for BIM-files, digital access to government services becomes simple and connects with the operations of many companies. By standardizing the digital access of building data for both private parties and the government, the adoption of BIM as a standard (uniform) working method will accelerate as well as the process of chain computerization of building data. As a result, companies in the construction sector will be more willing to work with BIM (and therefore 3D drawing technologies) than with 2D drawing technologies.

3.4 Conclusion

In this chapter, the market developments concerning digital drawing technologies were central. As stated before, Revit is used more and more in the construction sector, although AutoCAD entered the market earlier. Different large construction companies argue that BIM (and therefore Revit) have a big positive impact on their workflows and revenues. Since Company X is a subcontractor, the client can determine the drawing technology that the company has to use. Currently, the legislation on the digital drawing technologies for construction activities is regulated in the Wabo system. However, since this system is quite difficult, new legislation for this topic is being made at this moment. In the new legislation, bundled in the Environmental and Planning Act, the use of IFC BIM-files are possible, if the advice of Duivenvoorden and Alwhicher (2018) is being followed. Moreover, the new Digital Government Act will provide bigger support for BIM as a working method by companies in the construction sector.

4 Literature review on performance drawing technologies

In this chapter, I will present information about the performance of drawing technologies in Company X. The following research question will be answered in this chapter: "*How can the performance of digital drawing technologies of Company X be measured in terms of costs and benefits?*". I have structured this chapter as follows:

5. Section 4.1 describes performance indicators for projects.
6. Section 4.2 describes performance indicators for digital drawing technologies.
7. Section 4.3 describes the data needed to measure the KPIs.
8. Section 4.4 describes the preferences of the management.
9. Section 4.5 summarizes the chapter.

4.1 Project performance indicators

In this section, I give a brief summary of my systematic literature review. An extensive version of my systematic literature review can be found in Appendix A. This systematic literature review is used to find information about and create a list of KPIs which can express the performance of projects in general.

It is important for Company X to be able to assess the projects properly because this determines the performance of the company. Therefore, KPIs that can indicate the performance of the projects well, should be found. This is done by answering the following knowledge problem in this systematic literature review:

"Which KPIs exist that can express the performance of projects in general according to the literature?"

The taken steps in this review to select literature systematically and the list with final selected articles are in Appendix A.2, Appendix A.3, and Appendix A.4.

<u>Theoretical perspective</u>

There are many KPIs available in the literature to express the performance of projects. Only a few of them are relevant for Company X. To be able to select the right KPIs, I first made a list of all important frequent KPIs found in the literature, which is the goal of this systematic literature review. For this, it is first necessary to determine the theoretical perspective to be able to classify the KPIs. The articles read, consider a total of four different perspectives, namely: cost management, time management, quality management, and stakeholders. Table 1 below shows the framework including perspectives to cluster KPIs which indicate the performance of projects. In Table A.5 a conceptual matrix of the perspectives viewed per articles can be found.

The created framework including perspectives is based on the Project Management Triangle or also called the Iron Triangle (Atkinson, R., 1999). Atkinson mentions that cost, time, and quality are linked with measuring the success of project management. These three perspectives together form the Iron Triangle. I added the perspective 'stakeholders' to these perspectives, as the stakeholders are an important group to consider in measuring the performance of projects.

Table 1: Framework including perspectives

Perspective			
Cost management	**Time management**	**Quality management**	**Stakeholders**

Clustering concepts

The articles that were selected describe many concepts to categorize KPIs. In Table A.6 these concepts are categorized in the framework I created. In this conceptual matrix, the different KPI concepts per article are presented.

Selecting KPIs from the literature

In this step, the relevant KPIs mentioned by the authors of the articles are selected and clustered in the framework presented above in Table 1. The relevant KPIs can be used to indicate the performance of a (construction) project in general. Some KPIs from the articles were, in my opinion, irrelevant, since they do not apply to the performance of a project or these KPIs cannot be measured. Table A.7 gives an overview of the available KPIs per article in the framework.

Framework including KPIs

In this section, I removed the duplicate KPIs from Table A.7 to create my final framework with KPIs from literature which can measure the performance of a project in general. This list depicted in my final framework is presented in Table 2 below. In this list, there are 41 KPIs shown.

The list is used, together with another list made to answer the question "*Which KPIs exist that can express the performance of digital drawing technologies from the company?*", to select KPIs which I have investigated. The second list has been made in section 4.2. The selection of the KPIs has been done after a discussion with the deputy director.

Table 2: Final framework with KPIs from literature

Cost management	Time management	Quality management	Stakeholders
Unit cost	Construction time	Accident rate	Satisfaction of participants
% net variation over final cost	Speed of construction	Meeting technical specification	Customer satisfaction on services
Net present value	Time variation	QMS Performance	Customer satisfaction on products
% of construction cost variance	% of construction time variance	Project team performance	Feedback from client
Profitability	Time predictability	Labour safety performance	Working atmosphere at the company
Productivity	# time extra needed in addition to the project pre-calculation	Quality assurance	
Cost predictability	% activities completed without schedule delay	Safety	
Project costs	# times a mechanic needs to revise work	Quality	
Profit margin	# times a mechanic asks for information about the project		
Project pre-calculation costs variance	Average response time to RFIs		
Ratio project costs to BIM costs	Ratio engineering hours first and last 3D-project		
BIM ROI			
# risks prevented by BIM			
# errors and omissions on construction site			
Revenue per employee			
Ratio project costs to IT investments			
Travel, printing, document shipping costs			

4.2 Digital drawing technologies performance indicators

In this section, the following question is answered: "*Which KPIs exist that can express the performance of digital drawing technologies from the company?*". This expression of the performance of digital drawing technologies is split into two parts. I will first elaborate on KPIs that can express specifically the performance of digital drawing technologies used for projects of Company X. These KPIs complement the list created in my systematic literature review. I will make four dashboards on which most of the KPIs selected in section 4.4 will be displayed. Next, I describe some variables which influence the engineering method. I will make another dashboard that presents my advice concerning the type of digital drawing technology and the percentage of engineering time based on these variables. More about this percentage can be found in section 5.4.

Performance indicators of installation projects

The product Company X delivers is not a standard. There are not many companies that engineer, install, and maintain this type of systems. This in combination with the specific scope of this part of my assignment, the focus on the performance of digital drawing technologies which are used to engineer systems, makes it hard to find relevant literature. That is why I arranged some meetings with the deputy director, operational manager, and some project managers to create a list of KPIs which are related to this specific topic. In this way, the KPIs are more in line with my assignment and the initial preferences of the deputy director are covered. So, the list of indicators for the performance of projects in general, described in section 4.1, will be complemented by the more specific indicators for installation projects described below in Table 3. This list shows 12 KPIs.

Table 3: KPIs of installation projects

Cost management	Time management	Quality management	Stakeholders
Expected project costs	Expected construction time	Difficulty level engineering	Work pace of engineer
Material costs	Total meetings about construction	Difficulty level installing	Work pace of mechanic
Failure costs	Engineering time		
IT costs	Installing time		

After I discussed with the deputy director, operational manager, and project managers about possible KPIs that I could investigate and the second list was drawn up, I merged the two lists. In this way, I created the final framework with KPIs based on the literature and some discussions. This framework is presented in Table B.1. This list shows a total of 53 KPIs.

The framework depicted in Table B.1 will be used to select several KPIs which I will investigate. This selection will be made together with the deputy director. More about the selection of KPIs can be found in section 4.4.

Variables engineering method

I will use some variables to determine the engineering method Company X should use for a project. These variables are all related to the engineering process in Company X. They determine the way of engineering and the time needed to engineer the project. Some variables influence just one of the above-mentioned topics. Table 4 below shows the variables with a brief explanation.

Table 4: Variables engineering method

Variable	Explanation
Variables that determine the way of engineering and the time needed to engineer the project	
Type of building	Each type of building must be engineered differently. Company X installs systems in among others the following buildings: distribution centres, factories, hotels, offices, parking garages, and shopping centres. The building largely determines the difficulty level of engineering and installing.
Size of a project	The size of a project crucially determines the time needed for engineering. This variable is measured by the selling price. Labour time and materials are the highest costs for projects.
Difficulty level engineering	In general, the following rule applies: The more difficult the project is, the more efficient it is to engineer a 3D-model. The difficulty level is of course also a large factor in the number of hours required for engineering.
Variables that determine the way of engineering	
Total lead time of projects	The number of weeks Company X gets to engineer and install the system is important for the engineering method. The workload influences the engineering method because a high workload means that a design must be completed quickly, which can lead to a quick general engineered 2D-model instead of a more specific 3D-model.
Legal form of a project	The legal position of Company X in the project is also a variable for the engineering process. The legal structure determines which responsibilities Company X has and which Company X can pass on. A number of possible clients of Company X are the owner of a building, a contractor or an installer.
Variable that determine the time needed to engineer the project	
Starting point for Company X in the project	- If the engineer could start engineering the system at the start of the construction project (when almost no decisions about the building have been made), the engineer will most likely have to adjust his model often. - If the engineer could start engineering the system when, for example, the final design of the building is made (changes in the design of the building are still possible), the engineer will have to adjust his model sometimes. - If the engineer could start engineering the system when the implementation design of the building is made (there will only be changes if mechanics experience problems), the engineer will most likely hardly have to adjust his model.
Number of mechanics working on a project	The number of mechanics that has to install the system determines the engineering time. The mechanics must continue to work, which means that the engineering process must proceed specific and well. The more mechanics work on a project, the faster the project needs to be engineered.
Difficulty level installing	In general, the following rule applies: The more difficult the installation of the system is, the more time an engineer needs to engineer the system.
Number of meetings about construction	The more often an engineer has a meeting about the construction, the more time is spent on engineering. In these meetings, crucial changes for Company X in the construction can be discussed. The travel times for the engineers to these meetings are often long.

I have included most of these variables in my considerations for drafting my opinion on the engineering method. The variables ‘type of building’, ‘size of a project’, and ‘difficulty level engineering’ are used to come up with my advice about the type of digital drawing technology. The variables ‘starting point for Company X in the project’, ‘number of mechanics working on a project’, and ‘difficulty level installing’ are subsequently added to these variables to draft my opinion about the time needed to engineer the project. I decided not to use the variables ‘total lead time of projects’, ‘legal form of a project’, and ‘number of meetings about the construction’, although the fact that these variables are important for the choice in the type of digital drawing technology, because the total lead time of the project often changes as the project progresses, the legal form of a project is difficult to quantify (each client has its way of working for example), and the number of meetings about construction is too different for the projects.

Some variables were difficult to quantify. One of these variables is the ‘starting point for Company X in the project’. Because Company X has started with engineering 3D-models of systems in Revit and the use of BIM for a few years, the starting point for Company X in the project takes place earlier. As a result, the engineer has to adjust his model more often, which takes time. Figure 3 below shows a timeline of a project generally.

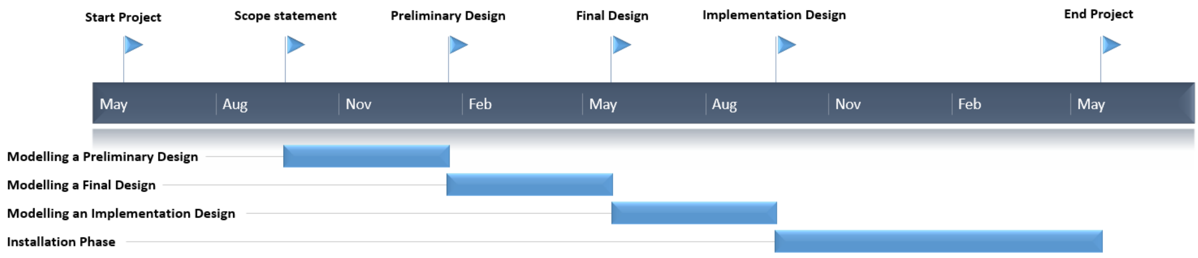

Figure 3: Timeline of a project

Before 3D-models were made, Company X was often involved in the project at the beginning of the Implementation Design phase. Because 3D-models of buildings are being made and information about the models is shared using BIM, Company X is involved earlier in the project by the client. Nowadays Company X is often involved in the project at the start of the Final Design phase or even at the end of the Preliminary Design phase. This earlier starting point for Company X in the project has advantages and disadvantages. The main advantage is that Company X can now present its opinion and ideas earlier. The main disadvantage is that the number of engineering hours increase. I have quantified this variable by giving various options as a starting point, such as the start of the Preliminary Design phase, end of the Final Design phase, or middle of the Implementation Design phase.

The variable ‘difficulty level engineering’ was also difficult to quantify. I have quantified this variable by looking at the type of building and the number of pre-calculated engineering hours. The variable is used in this way to determine the digital drawing technology. For the variable ‘difficulty level installing’ I will use the same method, but then I will, logically, look at the installing hours pre-calculated instead of the pre-calculated engineering hours. More about these difficulty levels can be found in section 5.1.

4.3 Data management

In this section, the following question is answered: "*What data is needed to create the KPIs so that they are reliable and valid?*". I will first elaborate on the data needed for calculating the KPIs and figure out if this data is available or not. Then I will discuss which data is used and which data not.

Data needed

I need data to calculate the KPIs. I have collected this data from various departments in Company X. For some KPIs, I needed more than just one data item. In contrast, I have used some data items for the calculation of multiple KPIs. For example, I used the data items 'total hours spent on a project', 'project costs', and 'estimated project costs' to calculate multiple KPIs. Also, some data I wanted to use was not available. Because of this, I could not calculate the related KPIs. All data I needed to calculate the KPIs are mentioned in Table 5 and Table 6 below.

Table 5: Data for KPIs section 4.1

Data needed	**Available**
Total hours spent on a project	V
Planned completion date projects	V
Activities on time finished (finished before planned completion date)	V
Extension of time granted by the client	XXX
# hours spent on a project after completion date	V
Project costs	V
Estimated project costs	V
Selling price of a project	V
# mechanics & engineers worked on a project	V
m^2 of projects	V
IT investment of a project	XXX
Total costs of IT (BIM)	XXX
Planned costs of IT (BIM)	XXX
# errors and omissions on construction site	XXX
# risk factors detected using BIM	XXX
# times a mechanic asks for information about the project	V
# reworks	XXX
Feedback from customers about materials	XXX
Feedback from customers about service	V
Total	**19**

Table 6: Data for KPIs section 4.2

Data needed	**Available**
Pre-calculation: Duration project	V
Pre-calculation: Material costs	V
Material costs calculated afterwards	V
# engineering hours per project pre-calculated	V
# engineering hours per project calculated afterwards	V
# installing hours per project pre-calculated	V
# installing hours per project calculated afterwards	V
# projects	V
Failure costs of a project	XXX
Work pace of engineer	XXX
Work pace of mechanic	XXX
Pre-calculation: Prefabrication hours	V
Prefabrication hours calculated afterwards	V
Total	**13**

Data selected

As mentioned above, some data was not available so I could not analyse the related KPIs. However, a number of these KPIs are important to investigate. That is why I will briefly mention how the KPIs '# errors and omissions on construction site', '# times a mechanic asks for information about the project', '# times a mechanic needs to revise work', and 'failure costs' could demonstrate a difference by the use of the new digital drawing technologies and engineering method:

- **# errors and omissions on construction site**
  By using 3D-modelling, the number of errors on the construction site should decrease. The problems that mechanics normally encounter on the construction site are already encountered by the engineers in so-called 'clashes' due to 3D-modelling. However, there is no exact data available about the number of errors and that is why I cannot visualize this KPI.
- **# times a mechanic asks for information about the project**
  The clash detection in Navisworks causes fewer problems on the construction site. The mechanics also got a tablet on which they can see the 3D-drawings of the system. This clarifies the installation method. As a result, the mechanics have fewer questions for the engineers.
- **# times a mechanic needs to revise work**
  As mentioned above, 3D-modelling should cause the number of errors on the construction site reduces. As a result, the number of times a mechanic needs to revise his work should also decrease.
- **Failure costs**
  The biggest cost saving of 3D-modelling will be the failure costs. Since the management of Company X thinks the failure costs are one of the biggest costs that could be saved, the management is pleased with this development. However, the exact failure costs of projects are unknown.

In addition to the data that is not available, I have excluded some data for my research. This data was available, but I did not use it because the related KPIs did not have priority according to the management, were irrelevant to compare, or were not investigated due to the time limit. Some examples are: 'feedback from customers about service', '# hours spent on a project after completion date', and 'activities on time finished'. In the end, I used the data shown in Table 7 to calculate the KPIs.

Table 7: Selected data

Total hours spent on a project	Project costs
Estimated project costs	Selling price of a project
m^2 of projects	Pre-calculation: Duration project
Pre-calculation: Material costs	Material costs calculated afterwards
# engineering hours per project pre-calculated	# engineering hours per project calculated afterwards
# installing hours per project pre-calculated	# installing hours per project calculated afterwards
Pre-calculation: Prefabrication hours	Prefabrication hours calculated afterwards

I have also excluded some projects for my research. I did not include the first projects that were engineered in 3D because these projects were used as a pilot. They will give a distorted picture concerning the results. That is why I did not analyse these projects.

4.4 Selecting KPIs

In this section, the following question is answered: "*Which KPIs does the management of Company X wants to have investigated?*".

As described in section 4.1 and section 4.2, the KPIs found are general project performance indicators and more specific indicators that express the performance of digital drawing technologies used to engineer systems. After a discussion with the deputy director, I selected several KPIs from the lists created. I will investigate these KPIs in chapter 5 of this report.

To select the most suitable KPIs, I classified the KPIs into 5 categories, namely:

1. Preferred KPIs to show on the dashboard
   These KPIs are the ones I will investigate in the continuation of this report. By calculating, analysing, and drawing conclusions from these KPIs, I get a clear insight into the performance of the projects. By displaying the results of these KPIs on the dashboards, the company also gets an overview of the performance of the projects.
2. Not investigated KPIs due to time limit
   I chose not to investigate these KPIs, as this would take me too much time in the limited number of weeks I have.
3. Irrelevant KPIs for comparison between the project
   I will not investigate these KPIs since the comparison between these KPIs has no added value. They are too specifically focused on a project and therefore comparison with another project will not make sense.
4. No priority
   I will not investigate these KPIs either, because these KPIs do not have priority according to the management.
5. Data not available
   Lastly, I will not investigate these KPIs, as there is no data available in the company about these KPIs.

The list with KPIs after this classification into 5 categories can be found in Table 8 below. The classification has been clarified using colours as shown above.

Table 8: KPI selection

Cost management	Time management	Quality management	Stakeholders
% of construction cost variance	# time extra needed in addition to the project pre-calculation	Difficulty level engineering	Feedback from client
Profit margin	Construction time	Difficulty level installing	Customer satisfaction on services
Project pre-calculation costs variance	Speed of construction	Quality	Satisfaction of participants
Project costs	Expected construction time	Accident rate	Working atmosphere at the company
Unit cost	Engineering time	Labour safety performance	Customer satisfaction on products
Expected project costs	Installing time	Meeting technical specification	Work pace of engineer
Material costs	Time predictability	Project team performance	Work pace of mechanic
Cost predictability	Ratio engineering hours first and last 3D-project	QMS Performance	
Productivity	% activities completed without schedule delay	Quality assurance	
Profitability	# times a mechanic asks for information about the project	Safety	
% net variation over final cost	Total meetings about construction		
Travel, printing, document shipping costs	Average response time to RFIs		
Revenue per employee	% of construction time variance		
Failure costs	Time variation		
IT costs	# times a mechanic needs to revise work		
BIM ROI			
Net present value			
Ratio project costs to BIM costs			
# risks prevented by BIM			
# errors and omissions on construction site			
Ratio project costs to IT investments			

4.5 Conclusion

This chapter gave more information about KPIs that can express the performance of projects in general and digital drawing technologies specific. The main goal of this chapter was to come up with indicators that can measure the performance of the digital drawing technologies used by Company X. The literature about this topic considers four perspectives to be important for the classification of the KPIs that measure the performance of the digital drawing technologies, namely: cost management, time management, quality management, and stakeholders. Based on these literature sources, I made a list of KPIs that are relevant for projects in general. After some meetings with the deputy director, operational manager and some project managers I created a list of KPIs that are relevant for this specific topic.

Next to that, I made a list of all variables that are related to the engineering process in Company X. After this list was complete, I examined which variables could be used in this research project to come up with advice about the type of digital drawing technology and the time that is needed to engineer the project. Furthermore, this section was about the data needed for the measurement of the KPIs. Since not all data needed for measuring the KPIs were available, I explained why these KPIs would change due to the usage of the new digital drawing technology and the engineering method.

The final list of KPIs that are used in this research project to come up with my advice for Company X on how to decide which digital drawing technology could be used best for a project and how much time is needed for a project is:

- ‘% of construction cost variance’
- ‘profit margin’
- ‘project pre-calculation costs variance’
- ‘project costs’
- ‘unit cost’
- ‘expected project costs’
- ‘material costs’
- ‘# time extra needed in addition to the project pre-calculation’
- ‘construction time’
- ‘speed of construction’
- ‘expected construction time’
- ‘engineering time’
- ‘installing time’
- ‘difficulty level engineering’
- ‘difficulty level installing’

5 Measurement performance of drawing technologies

In this chapter, I will measure the performance of digital drawing technologies in Company X. The following research question will be answered in this chapter: "*How do the digital drawing technologies of Company X perform?*". I have structured this chapter as follows:

- Section 5.1 describes the dashboards.
- Section 5.2 describes the cost relation of projects considering the different drawing technologies.
- Section 5.3 describes the relation between the time needed for projects considering the different drawing technologies.
- Section 5.4 describes the calculation method for the engineering of projects considering the different drawing technologies.
- Section 5.5 summarizes the chapter.

5.1 Dashboards

In this section, the following question is answered: *"How should the user use the dashboards?"*. This section is split into three sub-sections. I will first elaborate on the design phase of the dashboards. Thereafter, the purpose of the dashboards is described. Finally, a manual of the dashboards is given.

<u>Design phase of the dashboards</u>

Before I started creating the dashboards, I calculated all KPIs. I did this by creating databases that contain all the necessary data to calculate the KPIs, as shown in Table 7. Also, I have set up a measuring method or formula for every KPI. This measuring method or formula can be found in Table 9 below.

Table 9: Measuring method or formula for KPIs

KPIs	Way of measurement (Formula)	Value
# time extra needed in addition to the project pre-calculation	# hours delay	hours
% of construction cost variance	(Project costs - Estimated project cost) / Estimated project cost *100%	% growth (or decline) in construction costs
Construction time	Total hours spent on a project	hours
Profit margin	(Net sales - Expenses) / Net Sales *100%	% profit for every euro worth of sale
Project pre-calculation costs variance	Outturn costs / Pre-calculation (costs) *100%	% growth calculation (before vs. after)
Speed of construction	m2 / construction time	m2 per hour
Project costs	Sum of all costs related to the project	€
Unit cost	Total costs / m2	€ per m2
Expected construction time	# time pre-calculated for a project	hours
Expected project costs	# costs pre-calculated for a project	€
Material costs	Pre-calculated material costs / Expected project costs *100%	%
Material costs	Material costs calculated afterwards / Project costs *100%	%
Engineering time	Engineering hours per project pre-calculated / (Installing hours per project pre-calculated + Pre-calculated prefabrication hours) *100%	%
Engineering time	Engineering hours per project calculated afterwards / (Installing hours per project calculated afterwards + Prefabrication hours calculated afterwards) *100%	%
Installing time	Installing hours per project pre-calculated / Expected construction time *100%	%
Installing time	Installing hours per project calculated afterwards / Construction time *100%	%
Difficulty level engineering	(Value Type Building + Value Engineering time) / 2	1 till 100
Difficulty level installing	(Value Type Building + Value Installing time) / 2	1 till 100

As can be seen in Table 9 above, the formulas for the KPIs 'Difficulty level engineering' and 'Difficulty level installing' contain input variables that have not been discussed before. That is why I will show these formulas below and define their input variables:

$$\text{Difficulty level engineering} = \frac{(\text{Value Type Building} + \text{Value Engineering time})}{2}$$

$$\text{Difficulty level installing} = \frac{(\text{Value Type Building} + \text{Value Installing time})}{2}$$

where

- 'Value Type Building' is the 'value linked to the difficulty level of the building to be engineered'.
- 'Value Engineering time' is the 'value linked to the percentage for the time needed for engineering'.
- 'Value Installing time' is the 'value linked to the percentage for the time needed for installing the system'.

I determined the Value Type Building after a discussion with the operational manager. These values for the difficulty level of the buildings can be found in Table 10 below. I have made a distinction between 'existing' and 'new' buildings since there is a significant difference in these types of buildings in terms of engineering. I have used the following formula to quantify this significant difference:

$$\text{New building} = \text{Existing building} * 0{,}8$$

This formula is, just like the difficulty level of the buildings, established after a discussion with the operational manager. By linking values to every type of building in which Company X installs systems, the difficulty level of engineering (installing) is partially quantified.

In addition to the Value Type Building, I also linked values to the engineering and installing time. I did this in the same way as the values for the difficulty level of the buildings, namely by discussing with the operational manager. For the Value Engineering time, I have proportionally divided the values at an interval of $0{,}1 \leq x \leq 0{,}3$ ($10\% \leq x \leq 30\%$ where x means all possible values for the percentage of engineering time) to be sure all pre-calculated percentages for the engineering time are included. More information about this pre-calculated percentage can be found in section 5.4. All values $x < 0{,}1$ get a value of 4,5 and all values $x > 0{,}3$ get a value of 100. I used a total of 22 different values for the Value Engineering time, as can be seen in Table 10. For the Value Installing time, I have proportionally divided the values at an interval of $0{,}5 \leq x \leq 0{,}75$ ($50\% \leq x \leq 75\%$). All values $x < 0{,}5$ get a value of 3,7 and all values $x > 0{,}75$ get a value of 100. I used 27 values for the Value Installing time. By putting these two values in the formula and dividing the total by two, the Difficulty level engineering (installing) for the project has been determined.

Now that all KPIs have been explained and calculated, I will elaborate on the design of my dashboards. To avoid interpretation mistakes, it is important to visualize the KPIs correctly. By this, I mean that the KPIs have to be visualized clearly and

Table 10: Values used to determine the Difficulty level engineering (installing)

Type Building	Value (1 - 100)	Engineering	Value (1 - 100)	Installing	Value (1 - 100)
Existing Distribution centre	25	10,00%	4,5	50,00%	3,7
New Distribution centre	20	11,00%	9,1	51,00%	7,4
Existing Food factory	100	12,00%	13,6	52,00%	11,1
New Food factory	80	13,00%	18,2	53,00%	14,8
Existing Hotel	50	14,00%	22,7	54,00%	18,5
New Hotel	40	15,00%	27,3	55,00%	22,2
Existing Laboratory	80	16,00%	31,8	56,00%	25,9
New Laboratory	64	17,00%	36,4	57,00%	29,6
Existing Non-food factory	90	18,00%	40,9	58,00%	33,3
New Non-food factory	72	19,00%	45,5	59,00%	37,0
Existing Office	60	20,00%	50,0	60,00%	40,7
New Office	48	21,00%	54,5	61,00%	44,4
Existing Parking garage	70	22,00%	59,1	62,00%	48,1
New Parking garage	56	23,00%	63,6	63,00%	51,9
Existing School	50	24,00%	68,2	64,00%	55,6
New School	40	25,00%	72,7	65,00%	59,3
Existing Shop	60	26,00%	77,3	66,00%	63,0
New Shop	48	27,00%	81,8	67,00%	66,7
Existing Shopping centre	60	28,00%	86,4	68,00%	70,4
New Shopping centre	48	29,00%	90,9	69,00%	74,1
Existing Showroom	50	30,00%	95,5	70,00%	77,8
New Showroom	40	100,00%	100,0	71,00%	81,5
Existing Storage	25			72,00%	85,2
New Storage	20			73,00%	88,9
Existing Workplace	40			74,00%	92,6
New Workplace	32			75,00%	96,3
				100,00%	100,0

logically in graphs and that these graphs are easy to understand. This is done by implementing the selected KPIs on dashboards. A total of five dashboards are created to visualize the KPIs and present my advice. Screenshots of the five dashboards can be found in Appendix C to G.

For the dashboards I used three different types of charts:

1. **Column chart**
   This chart is used to compare data from different projects with each other. The height of the column indicates the height of the data value.
2. **Line chart**
   This chart is used to compare data from and show trends between different projects.
3. **Bar chart**
   This chart is used to compare data from different projects with each other. This chart is only used if the data contains negative values. If the data only contains positive values, the column chart is used.

All charts have axes, graph titles, and a legend. In some cases, I have also added data labels to the graph. To avoid confusion, I chose not to show the data labels in some cases.

I coloured the background of my dashboard light blue since this colour shows a clear contrast between the charts and the background.

Finally, I chose, together with the management, to be able to filter the dashboards by project, project number, new or existing (building), type of building, date, and project manager, because the various types of projects are easy to show in this way.

Purpose of the dashboards

In addition to clear design, it is also important to think about the purpose of the dashboards. As mentioned above, I have created five dashboards. These dashboards are divided into three different types. Dashboard 1 and Dashboard 3 are basically the same dashboards. The only difference is that Dashboard 1 contains data about 2D-projects and Dashboard 3 contains data about 3D-projects. The same applies to Dashboard 2 and Dashboard 4. Dashboard 5 is used to give advice on which digital drawing technology should be used and to give advice on the percentage for the engineering time. The purpose of the three different types of dashboards is described per dashboard below.

Dashboard 1 and 3: Cost Analysis

The purpose of the first and third dashboard is to show all cost-related KPIs. As shown in Appendix C and Appendix E, these are the following eight KPIs:

1. Material costs (pre-calculated)
2. Material costs (calculated afterwards)
3. Expected project costs
4. Project costs
5. % of construction cost variance
6. Speed of construction
7. Unit cost
8. Profit margin

These KPIs are shown in eight different graphs. I have also added a graph next to these eight graphs. This graph shows a comparison between the material costs (pre-calculation versus calculation afterwards). By selecting a project (or a specific type of project) the user gets a visualization of the costs of that (type of) project. In this way, the pre-calculation of a new project could be improved by comparing the costs of old projects. The KPI ‘speed of construction’ is shown at these dashboards, since this KPI gives, together with the ‘unit cost’, a clear overview of the costs per m^2.

Dashboard 2 and 4: Time Analysis

The purpose of the second and fourth dashboard is to show all time-related KPIs. As shown in Appendix D and Appendix F, these are the following seven KPIs:

1. Engineering time (pre-calculated)
2. Engineering time (calculated afterwards)
3. Installing time (pre-calculated)
4. Installing time (calculated afterwards)
5. Expected construction time
6. Construction time
7. # time extra needed in addition to the project pre-calculation

These KPIs are shown in seven different graphs. I have added two graphs to these seven graphs. These graphs show a comparison between the engineering and installing time (pre-calculation versus calculation afterwards). Just like with

Dashboard 1 and 3, the user can select a (type of) project. By comparing this data, the pre-calculation of a new project could improve.

Dashboard 5: Advice
The purpose of the fifth dashboard is to present my advice, as shown in Appendix G. In this dashboard, it is possible to select a project. The dashboard then automatically looks up all the important data of this project. The first piece of advice that this dashboard displays has to do with the type of digital drawing technology that should be used. It is also possible in this dashboard to select a 'starting point for Company X in the project' and the 'number of mechanics working on a project'. Advice on the percentage for the engineering time based on, among others, these variables (which are explained in section 4.2) is also displayed on this dashboard. The KPIs 'Difficulty level engineering' and 'Difficulty level installing' are also shown and used to come to my advice.

Except for one KPI, all KPIs are displayed on a dashboard. I have decided not to display the KPI 'project pre-calculation cost variance' since this KPI shows the same variance as the KPI '% of construction cost variance'. To avoid misinterpretations, only the KPI '% of construction cost variance' is shown.

<u>Manual of the dashboards</u>
Finally, it is, of course, important that the dashboards function well and are user-friendly. That is why I created a manual for every type of dashboard. By following this manual, the user can use the dashboards correctly. Before I describe the manuals for the dashboards, I will first describe a manual for adding new project data to the database.

Adding new data to the database
Adding new data to the database is very simple. The user just selects the cell at the bottom right of the database and presses the TAB key on his keyboard.

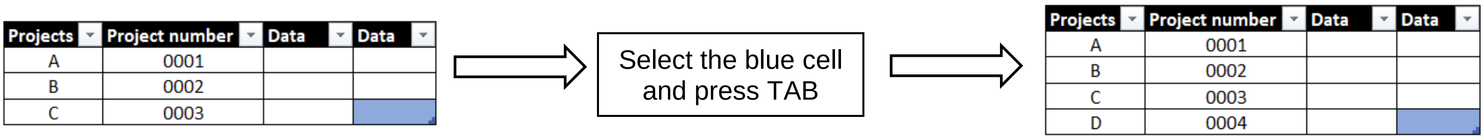

Figure 4: Method to add data

In the yellow cells in the database, the user can select an option. By clicking on the cell, a selection option appears. Figure 5 presents an example of a selection option.

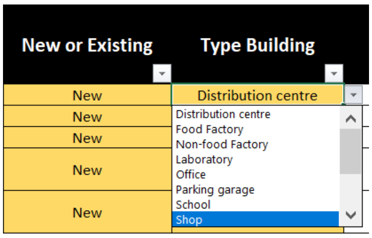

Figure 5: Selection options database

Once the user has added the new data in the database, he must update the table 'KPIs and Variables'. By selecting the cell at the bottom right of the table and pressing the TAB key on your keyboard, as shown in Figure 4, this is done. If the user updated the table 'KPIs and Variables', he has to refresh the whole Excel file to update the dashboards. By clicking on the 'Data' tab and next on the 'Refresh' button (in Dutch; 'Gegevens' and 'Alles vernieuwen', see Figure 6), this is done.

Figure 6: Refreshing the table 'KPIs and Variables'

Dashboard 1 and 3: Cost Analysis

The first and third dashboard should be used in the following way: at the top left of the dashboard, several filter options are shown. By using these filter options, the user can filter projects based on the project name, project number, new or existing building, type of building, date, or project manager. The filter options are shown in Figure 7. By applying these filter options, projects can be compared with each other. The dashboard updates itself when the user selects an option from the filter. If the user wants to select multiple options from a filter, the multiple selection button has to be selected, as shown in Figure 8. The dashboards can be found in Appendix C and Appendix E.

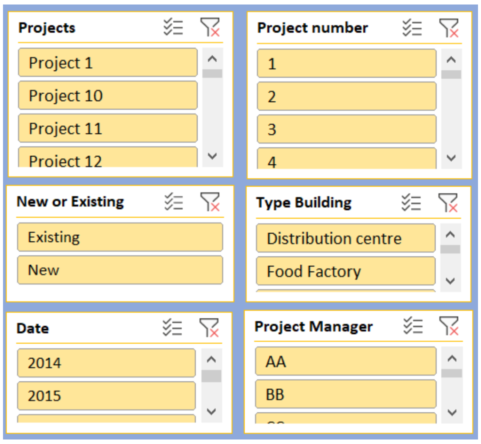

Figure 7: Filter options Dashboard 1 to 4

Dashboard 2 and 4: Time Analysis

The second and fourth dashboard should be used in the same way as Dashboard 1 and 3. The dashboards contain the same filter options which should also be used in the same way. The dashboards can be found in Appendix D and Appendix F.

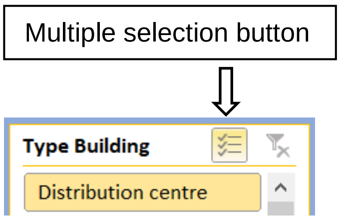

Figure 8: Multiple selection

Dashboard 5: Advice

The fifth dashboard also requires a manual. First, the user can select a project in the yellow cell, as shown in Figure 5. The dashboard then automatically looks up all the important and required data of this project. Figure 9 shows which data exactly is looked up.

Select project	Project number	Building	Selling price	Difficulty level engineering (1 - 100)
A	0001	Shopping centre	XXX	51,3
		New		

Figure 9: Variables for digital drawing technology

Next, the user can click on the 'Advice digital drawing technology' button. My advice regarding the digital drawing technology appears automatically, as shown in Figure 10. This advice is based on the variables shown in Figure 9. As described in section 2.4, most projects will receive a 3D drawing technology advice. Only if the project is simple will my advice be 2D drawing technology. My code for my advice can be found in Appendix H.

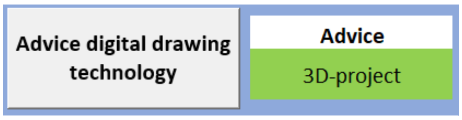

Figure 10: Advice digital drawing technology

Select project	Project number	Starting point	# mechanics for project	Difficulty level installing (1 - 100)
A	0001	end of Final Design phase	2 mechanics	40,7

Figure 11: Variables for percentage of engineering time

Afterwards, the user can change the variables 'starting point of Company X in the project' and 'number of mechanics working on a project' by selecting an option. Figure 11 shows which variables are added to the variables depicted in Figure 9 to determine the percentage of engineering time.

Lastly, the user can click on the 'Advice engineering percentage' button. My advice regarding the percentage of engineering time appears automatically, as shown in Figure 12. More information about the percentage for the engineering time and my code can be found in section 5.4.

Figure 12: Advice engineering percentage

5.2 Relation 2D- and 3D-projects regarding costs

In this section, the following question is answered: "*How is the relation between the costs of projects engineered with the different drawing technologies?*". By assessing the costs of the projects that have been engineered in different ways, the performance of the drawing technologies can be compared with each other. I will perform a data analysis using Dashboard 1 and Dashboard 3 to be able to assess this performance.

My data analysis implies that there are relatively large differences in projects that have been engineered using the 2D drawing technology and projects that have been engineered using the 3D drawing technology in terms of costs. By comparing the average values of the 2D-projects with the average values of the 3D-projects, I can make links between digital drawing technologies and their costs. The average values of these types of projects can be found in Table 11 and Table 12 below.

Table 11: Average values 2D-projects (costs)

Averages 2D-projects	
Project costs	€A1
Expected project costs	€B1
% of construction costs variance	C1%
Unit cost	€D1
Profit margin	E1 %
Material costs (pre)	F1 %
Material costs (after)	G1 %
Speed of construction	H1 m^2 p/h

Table 12: Average values 3D-projects (costs)

Averages 3D-projects	
Project costs	€A2
Expected project costs	€B2
% of construction costs variance	C2 %
Unit cost	€D2
Profit margin	E2 %
Material costs (pre)	F2 %
Material costs (after)	G2 %
Speed of construction	H2 m^2 p/h

To compare the projects in an honest way (for example qua size of the project), I used the formula below. I tried to limit other variables as much as possible with this formula.

$$\text{Relative difference} = \frac{\text{Average 2D}-\text{project}}{\text{Average 3D}-\text{project}} * 100\%$$

The relative difference between the projects can now be determined. Then I thought about which links would be interesting to make in my data analysis. I finally decided to make three links between the projects (in terms of costs). These relations seemed interesting to me since the type of digital drawing technology has a lot of influence on the KPIs in these relations.

First, I made a link between the KPIs 'expected project costs' and the 'project costs', or in other words the pre-calculation and calculation afterwards of the total costs of the projects. To make a link between the pre-calculation and calculation afterwards I have used the formula below.

$$\text{Relation} = \frac{\text{Relative difference pre- calculation}}{\text{Relative difference calculation afterwards}} * 100\%$$

To be able to make the link between the expected project costs and the project costs, I have done the following calculation:

$$\text{Relative difference expected project costs} = \frac{\text{€B1}}{\text{€B2}} * 100\% = \text{BB\%}$$

$$\text{Relative difference project costs} = \frac{\text{€A1}}{\text{€A2}} * 100\% = \text{AA\%}$$

$$\text{Relation} = \frac{\text{BB}}{\text{AA}} * 100\% = 95{,}5\%$$

This relation shows that the pre-calculation compared to the calculation afterwards of the **total costs has decreased by 4,5%**. This is a positive change since the 3D-projects of Company X have thus relatively lower total costs relative to 2D-projects.

The second link I made has to do with the KPI 'material costs'. I used the same calculation method as above. The following relation is derived from this calculation:

$$\text{Relative difference material costs (pre)} = \frac{\text{F1}}{\text{F2}} * 100\% = \text{FF\%}$$

$$\text{Relative difference material costs (after)} = \frac{\text{G1}}{\text{G2}} * 100\% = \text{GG\%}$$

$$\text{Relation} = \frac{\text{FF}}{\text{GG}} * 100\% = 97{,}8\%$$

This relation shows that the pre-calculation compared to the calculation afterwards of the **material costs has decreased by 2,2%**. This is a positive change since the 3D-projects of Company X have thus relatively lower material costs than 2D-projects.

Lastly, I made a link between the other KPIs by comparing the average values of the KPIs of the different types of projects. The KPI 'profit margin' was particularly interesting to investigate, since the management of Company X thought Company X made less profit through the lack of information about costs and benefits of 2D- and 3D-modelling. This hypothesis is contradicted in my data analysis since the profit margin of the 3D-projects is higher than the profit margin of the 2D-projects. In addition to this increase in the profit margin, the other KPIs also developed positively.

5.3 Relation 2D- and 3D-projects regarding time

In this section, the following question is answered: "*How is the relation between the time needed for projects engineered with the different drawing technologies?*". By assessing the time needed for the projects that have been engineered in different ways, the performance of the drawing technologies can be compared with each other. I will perform a data analysis using Dashboard 2 and Dashboard 4 to be able to assess this performance.

My data analysis implies that there are relatively large differences in projects that have been engineered using the 2D drawing technology and projects that have been engineered using the 3D drawing technology in terms of time. By comparing the average values of the 2D-projects with the average values of the 3D-projects, I can make links between digital drawing technologies and the time needed. The average values of these types of projects can be found in Table 13 and Table 14 below.

Table 13: Average values 2D-projects (time)

Averages 2D-projects	
Engineering time (pre)	I1 %
Engineering time (after)	J1 %
Installing time (pre)	K1 %
Installing time (after)	L1 %
Expected construction time	M1
Construction time	N1
# time extra needed in addition to the project pre-calculation	O1

Table 14: Average values 3D-projects (time)

Averages 3D-projects	
Engineering time (pre)	I2 %
Engineering time (after)	J2 %
Installing time (pre)	K2 %
Installing time (after)	L2 %
Expected construction time	M2
Construction time	N2
# time extra needed in addition to the project pre-calculation	O2

To compare the projects in an honest way, I used the formulas described in section 5.2. I tried to limit other variables as much as possible with these formulas.

The relative difference between the projects can now be determined. I thought about which links would be interesting to make in my data analysis. I finally decided to make three links between the projects (in terms of time). These relations seemed interesting to me since the type of digital drawing technology has a lot of influence on the KPIs in these relations.

First, I made a link between the engineering time pre-calculated and calculated afterwards. To be able to make this link, I have done the following calculation:

$$\text{Relative difference engineering time (pre)} = \frac{\text{I1}}{\text{I2}} * 100\% = \text{II}\%$$

$$\text{Relative difference engineering time (after)} = \frac{\text{J1}}{\text{J2}} * 100\% = \text{JJ}\%$$

$$\text{Relation} = \frac{\text{II}}{\text{JJ}} * 100\% = 120{,}7\%$$

This relation shows that the pre-calculation compared to the calculation afterwards of the **engineering time has increased by 20,7%**. This is a negative change since the 3D-projects of Company X need thus relatively more engineering time than 2D-projects.

However, I have to comment on this calculation. The average engineering time calculated afterwards for 2D-projects is J1% and for 3D-projects J2%. There are one 2D-project and one 3D-project where the percentage for the engineering time (calculation afterwards) is incredibly high. Because these values are almost 4 and almost 6 times bigger than the average value, I considered these values as outliers. These values arise because the numerator in the formula used increases enormously and the denominator decreases enormously (see section 5.4, conversion of the formula ‘Engineering hours’). If I do not include these outliers in my calculation, the average engineering times calculated afterwards are just J3% and J4%, respectively. The relative difference engineering time (after) will then change to JJ2% and the relation will change to 99,2%. In this case, the relation shows that the **engineering time has decreased by 0,8%**!

The second link I made has to do with the KPI installing time. I used the same calculation method as above. The following relation is derived from this calculation:

$$\text{Relative difference installing time (pre)} = \frac{\text{K1}}{\text{K2}} * 100\% = \text{KK}\%$$

$$\text{Relative difference installing time (after)} = \frac{\text{L1}}{\text{L2}} * 100\% = \text{LL}\%$$

$$\text{Relation} = \frac{\text{KK}}{\text{LL}} * 100\% = 101{,}2\%$$

This relation shows that the pre-calculation compared to the calculation afterwards of the **installing time has increased by 1,2%**. This is a negative change since the 3D-projects of Company X need thus relatively more installing time than 2D-projects.

Lastly, I made a link between the KPIs expected construction time and the construction time, or in other words the pre-calculation and calculation afterwards of the total time needed for the projects. To be able to make this link, I have done the following calculation:

$$\text{Relative difference expected construction time} = \frac{\text{M1}}{\text{M2}} * 100\% = \text{MM}\%$$

$$\text{Relative difference construction time} = \frac{\text{N1}}{\text{N2}} * 100\% = \text{NN}\%$$

$$\text{Relation} = \frac{\text{MM}}{\text{NN}} * 100\% = 83{,}8\%$$

This relation shows that the pre-calculation compared to the calculation afterwards of the **construction time has decreased by 16,2%**. This is a positive change since the 3D-projects of Company X need thus relatively less time than 2D-projects. This positive change can also be found in the KPI ‘# of time extra needed in addition to the project pre-calculation’.

However, the KPIs installing time and construction time can give a wrong impression. Company X outsources parts of the installing phase of a project sometimes. This reduces the installing hours of Company X in the financial overviews I used. The costs of outsourcing are processed under the item ‘subcontracting’. This item only contains the costs (so not the time used) for subcontracting. As a result, it looks like construction time decreases. Because some projects require much more installing time than pre-calculated, these outsourced hours cannot be seen in the installing time result.

Because Company X is in the initial phase of the new way of engineering, there will undoubtedly be additional costs that have not been included in these relations. As a result, it could be that using 3D drawing technology, in contrast to the above results, costs more and takes more time than using 2D drawing technology. This statement is partly true. As described in section 3.1, Klören told me that at the front-side 3D-modelling has costs, but the disadvantages in the back will be bigger than these costs. Company X is now in this initial phase, so the use of 3D drawing technology could cost money and time. However, Company X will in the long-term benefit from the choice to use the 3D drawing technology, as can already be seen partially in the data analysis.

5.4 Calculation method for engineering the projects

In this section, the following question is answered: “*How can the calculation method for the engineering of projects be improved concerning the various drawing technologies?”.* I will first elaborate on the current calculation method for the engineering time of projects. Next, I will discuss my improved way to calculate the engineering time.

Because of confidentiality agreements, sensitive business information will not be presented.

Due to the increasing use of 3D-modelling, this calculation method will have to be adjusted, as engineering in 3D will initially take more time. That is why I will come up with an improved way to calculate the engineering hours by basing the calculation of the engineering time on a percentage which is based on some variables. I used the following variables to calculate the percentage for the engineering time:

A. Type of building (2,4)
B. Size of a project (1,9)
C. Difficulty level engineering (1,9)
D. Starting point for Company X in the project (2,9)
E. Number of mechanics working on a project (0,3)
F. Difficulty level installing (0,6)

The one variable influences engineering time more than the other. That is why I have given factors to the variables. I have determined these factors after a discussion with the operational manager. The factors are placed behind the variables. By using the following formula, my variable percentage for the engineering time is calculated:

$$\text{Variable percentage for engineering time (Vpet)} = \frac{\big((2{,}4 * \text{A}) + (1{,}9 * \text{B}) + (1{,}9 * \text{C}) + (2{,}9 * \text{D}) + (0{,}3 * \text{E}) + (0{,}6 * \text{F})\big)}{10}$$

The value of each variable is determined in its way in my code. My code for determining the percentage for the engineering time can be found in Appendix I. I will briefly explain the calculation of one variable below.

For example, variable D, the starting point of Company X in the project, is calculated based on values linked to the starting point. These values are shown in Table 15 on the right. As described in section 4.2, before 3D-models were made, Company X was often involved in

Table 15: Values starting point

Starting point	Value
beginning of Preliminary Design phase	1,8
middle of Preliminary Design phase	1,6
end of Preliminary Design phase	1,5
beginning of Final Design phase	1,3
middle of Final Design phase	1,2
end of Final Design phase	1,1
beginning of Implementation Design phase	1,0
middle of Implementation Design phase	0,9
end of Implementation Design phase	0,8

the project at the beginning of the Implementation Design phase (see Figure 3). That is why I have taken this starting point as the standard and therefore assigned the value 1 to it. For the other starting points, I used the following exponential formula:

$$\text{Value starting point} = 0{,}909 * 1{,}1^{x}$$

in which

- x means the value from the beginning of Implementation Design phase (the earlier the starting point, the higher the value of x). So, for the beginning of Final Design phase, x has a value of 4, for beginning of Preliminary Design phase, x has a value of 7, and for the end of Implementation Design phase, x has a value of -1.
- the factor 1,1 is determined after a discussion with the operational manager.

I then used the formula below to get a value between 1 and 10. I applied this formula to every variable.

$$\text{Value (between 1 and 10)} = \frac{\text{Value variable}}{\text{Maximum value variable}} * 10$$

So, variable D with for example starting point 'end of Preliminary Design phase' has the following value:

D = 0.909 * $1{,}1^4$ = 1,33
(1,33 / 1,77) * 10 = **7,5**

After a value has been assigned to each variable, the formula 'Variable percentage for engineering time (Vpet)' (see above) is applied. A value between 1 and 10 will result. Because I use an interval of $0{,}1 \leq x \leq 0{,}3$ ($10\% \leq x \leq 30\%$ where x means all possible values for the percentage of engineering time), I use the following formula to determine the percentage for engineering time:

$$\text{Percentage for engineering time} = \frac{(10 + (2 * \text{Vpet}))}{100}$$

In this way, I get a value for the percentage of the engineering time between 10% and 30%.

5.5 Conclusion

This chapter was about the measurement of the performance of digital drawing technologies. The first part of this chapter was about the design of the dashboards and the usage of these dashboards by the user. First, the KPIs were calculated using databases that contain all the information about the necessary variables. The formulas for the measurement of the KPIs were also prepared at this point. Next, the dashboards were designed using three types of charts, namely: column charts, line charts, and bar charts.

In addition, the purpose of the dashboards was discussed. I created a total of five dashboards. Dashboard 1 and Dashboard 3 focus on the cost analysis, while

Dashboard 2 and Dashboard 4 focus on the time analysis. Dashboard 5 is about my advice. Furthermore, I created a manual for every type of dashboard to make sure that the user can correctly use the dashboards.

Moreover, the costs of the projects that are engineered in different ways are examined to compare the performance of the different drawing technologies used by Company X. This is also done with the difference in the time needed for engineering the projects. In this analysis, the projects are compared in three ways. The first method compares the difference between the total costs and the expected costs of the project in 2D- and 3D-projects. Secondly, the difference between the pre-calculated material costs and the material costs calculated afterwards in 2D- and 3D-projects are examined. Lastly, I made a link between the other KPIs by comparing the average values of the KPIs of the different types of projects. Overall, there could be stated that Company X will in the long-term benefit from the choice to use the 3D drawing technology, as can already be seen partially in the data analysis.

Lastly, the calculation process of the engineering process is analysed. I adjusted the current calculation method for the engineering time since more and more projects are engineered in 3D. 3D-modelling will take more time in the beginning than 2D-modelling. I have set up a formula that gives a percentage of the expected engineering hours. Therefore, I used six different variables that have different weights in my calculation. After assigning all the different values to the variables, my improved calculation method for the expected engineering time gives a value between 10 and 30 percent.

6 Conclusion, recommendations, and limitations

In this chapter, I will conclude on the market research performed in chapter 3 and on the results of the data analysis of the performance of digital drawing technologies performed in section 5.2 and section 5.3. Next to that, I will present my recommendations to Company X in terms of digital drawing technologies and engineering time. At the end of this chapter, I will discuss the limitations of this research project. To be able to present advice to Company X, the following research question will be answered: "*When should Company X use which digital drawing technology, so that these technologies have an added value for the company?*". I have structured this chapter as follows:

- Section 6.1 describes the conclusions of the market research.
- Section 6.2 describes the conclusions of the data analysis of the performance of digital drawing technologies.
- Section 6.3 describes my recommendations regarding digital drawing technologies.
- Section 6.4 describes my recommendations regarding engineering time.
- Section 6.5 discusses the limitations of this research project.

6.1 Conclusions market research

In this section, the following question is answered: "*What conclusions can be drawn from the market research?*". I will elaborate on the results of my market research performed in chapter 3.

Analysing the results of the market research in chapter 3 shows that the market is developing strongly. There is an increasing demand for the use of 3D drawing technologies. Company X will increasingly have to engineer projects in 3D, as more and more clients are obligating Company X to engineer the design of the system in 3D. Modelling in 3D will Company X cost money and time in the initial phase, but the company will earn even more money and time in the long-term.

In addition to the strong development of the market regarding the use of 3D drawing technologies, the law is also developing in this direction. New laws such as the Environmental and Planning Act and the Digital Government Act simplify the execution of projects by supporting digital techniques.

6.2 Conclusions performance digital drawing technologies

In this section, the following question is answered: "*What conclusions can be drawn from the data analysis of the performance of digital drawing technologies?*". I will elaborate on the results of my data analysis performed in section 5.2 and section 5.3.

When analysing the results from the data analysis regarding the costs of the projects that have been engineered in different ways, the performance of drawing technologies is assessed. The results show that the total costs are decreased by 4,5%, the material costs are decreased by 2,2%, and the profit margin is increased from E1% to E2%. From these results can be concluded that 3D drawing technology causes cost savings compared to 2D drawing technology. A visualization of the data and an overview of my analysis can be seen on Dashboard 1 (Appendix C) and Dashboard 3 (Appendix E).

When analysing the results from the data analysis regarding the time needed for the projects that have been engineered in different ways, the performance of drawing technologies is assessed. The results show that the engineering time is increased by 20,7% (after deleting the outliers it decreased by 0,8%), the installing time is increased by 1,2%, and the construction time is decreased by 16,2%. From these results can be concluded that 3D drawing technology causes an increase in the engineering time needed but on the other hand leads to a decrease in the total construction time for the projects. However, this decrease in construction time for the projects is questionable, as described in section 5.3. A visualization of the data and an overview of my analysis can be seen on Dashboard 2 (Appendix D) and Dashboard 4 (Appendix F).

6.3 Recommendations digital drawing technologies

In this section, the following question is answered: *"When should Company X use 2D or 3D drawing technology?"*. I will present my recommendation to Company X when to use 2D or 3D drawing technology.

As large contractors and installers on the market are increasingly inclined to work with 3D drawing technologies and this technology is developing rapidly, I recommend Company X to focus on engineering projects using 3D drawing technologies. My recommendation is to engineer only the simple projects, based on the type of building (for example a distribution centre or storage), size of the project, and difficulty level of engineering (if this level is less than 45), using 2D drawing technology. For this type of projects, it will be beneficial to use 2D drawing technology instead of 3D drawing technology. My recommendation for each specific project can be found on Dashboard 5 (Appendix G). By using the created database, KPIs, and dashboards, Company X can make a choice in terms of digital drawing technology based on knowledge gained from historical data. This resolves the difference between the reality and the norm, as described in the problem statement in section 1.4.

6.4 Recommendations engineering time

In this section, the following question is answered: *"How can Company X calculate the engineering time for the different drawing technologies?"*. I will present my recommendation to Company X how to calculate the engineering time for each specific project.

As engineering a project using 3D drawing technology is completely different than engineering a project using 2D drawing technology, I recommend Company X to use Dashboard 2, Dashboard 4, and particularly Dashboard 5 to determine the engineering time. On Dashboard 5, my recommendation for each specific project can be found. The calculation for the percentage for the engineering time that was needed to present my recommendation is based on, among others, the type of building, the difficulty level of engineering, and the starting point of Company X in the project. In addition to my recommendation for a specific project presented on Dashboard 5, I recommend Company X to use the analyses presented on Dashboard 2 and Dashboard 4 to estimate the engineering time needed for the specific project, even better by using the filter options on the dashboards.

Finally, I recommend Company X keeping the database up to date, meaning that the database should be complemented with new data. The dashboards should be refreshed as described in section 5.1 so that the dashboards also stay up to date.

6.5 Limitations

Probably the biggest limitation of this research project is that KPIs are used to measure the performance of digital drawing technologies. For this research project, it is presumed that all changes in the results of these KPIs are in direct correlation with the use of the different digital drawing technologies when its actuality is likely other variables also contributed to each project's performance. As no two projects are exactly the same and multiple variables contributed to the changes in the results of the KPIs, it was difficult to quantify which pros and cons were directly associated with the change of digital drawing technologies and which pros and cons were merely the results of different variables.

In addition, as 3D-modelling is still a relatively new technology, little data was available on projects conducted using the 3D drawing technology (Revit and sometimes BIM). Therefore, the results of this research project are quite flexible and should be adjusted over time (when more data is available). It is also difficult to make a link in terms of costs and time between projects that are engineered with the various drawing technologies. This is mainly due to the large differences between projects and the small database.

Besides that, the number of outsourced installing hours processed in the financial overviews I used, is not stated. Because of this, there might be deviations in the results of my data analysis, especially in the result of the KPIs construction time and installing time.

Company X not only accepts new projects. The company also conducts adaptations to old projects, if necessary. In this research project, I only took into account new projects to limit the number of different types of projects I had to investigate. Also, I only investigated the digital drawing technologies AutoCAD and Revit (with BIM), since these drawing technologies are used in Company X. I have not done research into drawing technologies that might be better for Company X. This kept the research project manageable within the given time window.

Another limitation of this research project is that there is a lack of prior knowledge about creating dashboards that visualize the performance of a product or process, in this case, digital drawing technologies. Because of this lack of prior knowledge to start the research project, I had to do a lot of research before I could come to an answer.

Finally, it is difficult to validate the dashboards, since the time window was short. I would have liked to test whether my dashboards and advice are externally valid, but this is currently not possible.

References

Atkinson, R. (1999). Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International Journal of Project Management*, *17*(6), 337–342. https://doi.org/10.1016/S0263-7863(98)00069-6

BIM | Dura Vermeer. (n.d.). Retrieved June 3, 2019, from https://www.duravermeer.nl/expertise/bim

Bosman Bedrijven opent BIM-Office — Bosman. (2017, December 18). Retrieved June 3, 2019, from https://www.bosmanbedrijven.nl/2017/12/18/bosman-bedrijven-opent-bim-office/

Demchak, G., Dzambazova, T., & Krygiel, E. (2009). *Introducing Revit Architecture 2009: BIM for Beginners*. Indianapolis, Indiana: Wiley.

Duivenvoorden, J. J., & Alwicher, K. A. E. (2018). *Ruimte voor BIM in wet- en regelgeving*. Retrieved from https://www.bimloket.nl/upload/documents/downloads/Rapportage%20Ruimte%20voor%20BIM%20in%20wet%20en%20regelgeving%20versie%202018.pdf

Egan, J. (2008, January 23). Builders Cut Expenses with New Technology. Retrieved May 25, 2019, from https://www.nreionline.com/technology/builders-cut-expenses-new-technology

Government of the Netherlands. (2017, October 6). Revision of Environment and Planning Laws. Retrieved June 26, 2019, from https://www.government.nl/topics/spatial-planning-and-infrastructure/revision-of-environment-planning-laws

Heerkens, J. M. G., & Van Winden, A. (2012). Geen probleem: een aanpak voor alle bedrijfskundige vragen en mysteries : met stevige stagnatie in de kunststoffabriek. Nieuwegein, The Netherlands: Van Winden Communicatie.

National BIM Standard. (n.d.). About the National BIM Standard-United States® | National BIM Standard - United States. Retrieved May 20, 2019, from https://www.nationalbimstandard.org/about

Revit vs AutoCAD | Compare Software | Autodesk. (n.d.). Retrieved June 26, 2019, from https://www.autodesk.com/solutions/revit-vs-autocad

Storms, C. (2017, November 8). Connect the Docs with Autodesk's cloud and mobile platform BIM 360. Retrieved June 15, 2019, from https://projectdelivery.autodesk.com/blog/connect-the-docs-bim-360/

Voortgang Wet digitale overheid. (2018, December 20). Retrieved June 26, 2019, from https://www.digitaleoverheid.nl/overzicht-van-alle-onderwerpen/wetgeving/wet-digitale-overheid/voortgang-wet-digitale-overheid/

Weisberg, D. E. (2008). *The Engineering Design Revolution*. Retrieved from http://images.designworldonline.com.s3.amazonaws.com/CADhistory/85739614-The-Engineering-Design-Revolution-CAD-History.pdf

Appendix A Systematic Literature Review

In this appendix, my systematic literature review protocol is presented. The result of this systematic literature review is presented in section 4.1. Based on Noort (2019), I used the following structure for the systematic literature review:

1. Define the key theoretical concepts
2. Define search strings
3. Determine inclusion and exclusion criteria
4. Use a conceptual matrix
5. Describe the method used

A.1 Key theoretical concepts

In order to execute a systematic literature review, I have to identify which theory I need. I will look at KPIs which can express the performance of projects in general.

In the literature, many different KPIs can be found. I will focus on KPIs which can measure the performance of projects in terms of costs and time for example. The measurement will focus on the calculation, engineering, and installation phase of a project.

By using this systematic literature review, I want to find more information about KPIs which can assess the performance of a project in general. I will make a list of all the KPIs I will find in the systematic literature review. Thereafter I will make another list with KPIs which can express specifically the performance of digital drawing technologies used for projects in Company X. After a discussion with the deputy director, I will select several KPIs from these two lists which I will investigate. To be able to make the first list, I will answer the following knowledge problem using this systematic literature review:

Which KPIs exist that can express the performance of projects in general according to the literature?

A.2 Define search strings

To find relevant articles, I have to make use of search strings in a smart way. The search strings I will use will be specific. In this way, irrelevant articles that will not help me to answer my knowledge problem are excluded.

To make the search strings specific, I used two types of search strings: fixed and variable search strings. The fixed search string is, logically, used in every search and the variable search strings are added to the fixed strings.
The fixed search string I used is **"KPI"**. This search string ensures that each selected journal is about performance indicators.
The variable search strings that I used are **"Project performance management"**, **"construction industry"**, **"construction project"**, and **"BIM"**. An explanation is presented below.

1. **Project performance management**: I want to find information about project performance management since the KPIs should measure the performance of

projects in general and performance management an important aspect of this process is.

2. **Construction industry**: I want to find information about the construction industry since Company X a company in the construction sector is and thus KPIs focused on this industry should be selected.
3. **Construction project**: I want to find information about construction projects because the KPIs from the articles should focus on projects from the construction industry.
4. **BIM**: I want to find information about BIM since BIM gives architecture, engineering, and construction professionals the insight and tools to more efficiently plan, design, construct, and manage buildings. Company X uses the BIM process in projects, so KPIs which measure the performance of BIM are needed.

This systematic literature review is executed using two databases: Scopus and Web of Science. Articles from both databases will be checked on overlaps.

A.3 Determine inclusion and exclusion criteria

In this section, I will mention my inclusion and exclusion criteria. I used these criteria to filter the articles that I want to read for my systematic literature review. I will first give my inclusion criteria. Subsequently, I will present my exclusion criteria. These criteria are used to determine my selection for this review. This searching process is given below.

Inclusion Criteria

The inclusion criteria I will use, are presented in Table A.1 below. Also, a motivation for the use of these inclusion criteria can be found in the table.

Table A.1: Inclusion criteria

Number	Inclusion criteria	Reason for inclusion
1	Articles in which KPIs are mentioned for project (success) measurement	I want to make a list of all KPIs found in the literature. That is why each article must contain some KPIs.
2	Case studies in which the KPIs are tested (or their validity is tested)	I want to find applications for the KPIs in terms of case studies. In case studies, advantages and disadvantages of KPIs will be identified. This will help me to make a selection for KPIs I am going to investigate.
3	Keywords: Key performance indicators, construction industry, project performance, performance management, balanced scorecard, benchmarking	These words are keywords found in the articles.

Exclusion criteria

The exclusion criteria I will use, are presented in Table A.2 below. Also, a motivation for the use of these exclusion criteria can be found in the table.

Table A.2: Exclusion criteria

Number	Exclusion criteria	Reason for exclusion
1	Articles that do not focus on measuring the performance of projects	I will exclude articles that do not focus on measuring the performance of projects, as these articles do not fit the context of my assignment.
2	Articles that are not in English	Since I cannot understand Chinese or Spanish articles (I encountered these languages), I will exclude them.
3	Articles that are not accessible	Articles for which I have to pay or articles that only publish a summary, I will have to exclude.
4	Articles released earlier than 2000	I will exclude articles released earlier than 2000 because the approach of projects (and so the measurement) in these articles is outdated.
5	Subjects: Computer Science, Environmental Science, Earth and Planetary Science, Physics, and Astronomy	These subjects do not refer to my assignment or the company.

Searching process

The search strings, inclusion, and exclusion criteria will be used in my searching process. The purpose of my searching process is to find several sources using the search strings. After applying the inclusion and exclusion criteria, the resources I am going to use stayed over. The overview is presented in Table A.3.

Table A.3: Overview searching process

Search string	Scope	Data of search	Number of entries
Search protocol for Scopus			
"KPI" AND "Project performance management" AND "construction industry"	Article title, Abstract, Keywords	9 May 2019	60
"KPI" AND "construction project"	Article title, Abstract, Keywords	9 May 2019	59
"KPI" AND "BIM"	Article title, Abstract, Keywords	10 May 2019	19
Search protocol for Web of Science			
"KPI" AND "Project performance management" AND "construction industry"	Topic	9 May 2019	13
"KPI" AND "construction project"	Topic	9 May 2019	42
"KPI" AND "BIM"	Topic	10 May 2019	7
Total number of articles			**200**
Remove duplicates			-112
Selecting based on exclusion criteria			-77
Removed after reading complete article			-6
Included after reading complete article			+1
Total selected for review			**6**

A.4 Use of conceptual matrix

In this section, I will first present the articles selected from the systematic literature review described above. A list of the articles selected can be found in Table A.4.

Table A.4: Literature list

Nr.	Author (Year)	Title	Citations	Journal
1	Chan, A.P.C & Chan, A.P.L. (2004)	Key performance indicators for measuring construction success	356	Benchmarking
2	Luu, V.T. et al. (2008)	Improving project management performance of large contractors using benchmarking approach	86	International Journal of Project Management
3	Sibiya, M. et al. (2015)	Construction Projects' Key Performance Indicators: A Case of the South African Construction Industry	2	ICCREM – Environment and the Sustainable Building
4	Radujković, M. et al. (2010)	Application of key performance indicators in South-Eastern European construction	21	Journal of Civil Engineering and Management
5	Won, J. & Lee, G. (2016)	How to tell if a BIM project is successful: A goal-driven approach	13	Automation in Construction
6	Coates, P. et al. (2010)	The key performance indicators of the BIM implementation process	-	University of Salford, UK

Then, the conceptual matrix that I used to categorize the information I have acquired from reading the articles for my systematic literature review, is given. The conceptual matrix can be found in Table A.5 below.

Table A.5: Conceptual matrix of perspectives

	Perspective			
Source	**Cost management**	**Time management**	**Quality management**	**Stakeholders**
(Chan, A.P.C. & Chan, A.P.L., 2004)	X	X	X	X
(Luu, V.T. et al., 2008)	X	X	X	X
(Sibiya, M. et al., 2015)	X	X	X	X
(Radujković, M. et al., 2010)	X	X	X	X
(Won, J. & Lee, G., 2016)	X	X		
(Coates, P. et al., 2010)	X	X		X

Table A.6 is a conceptual matrix that identifies the concepts to cluster KPIs, based on a framework created after reading the articles found in the literature. The concept 'Cost management' categorizes KPIs which take all kinds of costs and benefits related to a project into account. The concept 'Time management' is related to the size of a project in terms of time and the time scheduled for it. 'Quality management' has to do with the quality of a project and the working conditions for employees. The last concept, 'Stakeholders', is related to all persons who are involved in the project and their opinion about it.

Table A.6: Categorization of concepts

	Concepts			
Source	**Cost management**	**Time management**	**Quality management**	**Stakeholders**
(Chan, A.P.C. & Chan, A.P.L., 2004)	Cost Value and profit	Time	Health and safety Quality	Participants' satisfaction
(Luu, V.T. et al., 2008)	Construction cost performance	Construction time performance	Quality management system The project team performance Labour safety management	Customer satisfaction on services Customer satisfaction on products
(Sibiya, M. et al., 2015)	Profitability Productivity Cost predictability	Construction time Time predictability	Quality assurance Safety	Client satisfaction (product) Client satisfaction (service)
(Radujković, M. et al., 2010)	Cost Profitability Cost predictability	Time Time increase	Quality	Client satisfaction Employees' satisfaction
(Won, J. & Lee, G., 2016)	Investment cost for BIM adoption Errors and omissions in field Planned project cost	(Planned) project duration Additional working hours due to change orders Reworks Requests for information		
(Coates, P. et al., 2010)	Revenue per head IT investment Shipping costs	Time per project Employee skills and knowledge development		Client satisfaction and retention

A.5 Describe the method used

Table A.7 below gives an overview of the KPIs per article in the framework defined. As can be seen, there are many different KPIs defined in the literature. By selecting only relevant KPIs from the articles and removing all duplicates, I have created a list of useful KPIs. This list can be found in Table 2 (section 4.1).

Table A.7: KPI categorization in framework

Perspective / Source	Cost management	Time management	Quality management	Stakeholders
(Chan, A.P.C. & Chan, A.P.L., 2004)	Unit cost	Construction time	Accident rate	Satisfaction of participants
	% net variation over final cost	Speed of construction	Meeting technical specification	
	Net present value	Time variation		
(Luu, V.T. et al., 2008)	% construction cost variance	% construction time variance	QMS Performance	Customer satisfaction on services
			Project team performance	Customer satisfaction on products
			Labour safety performance	
(Sibiya, M. et al., 2015)	Profitability	Construction time	Quality assurance	Client satisfaction (product)
	Productivity	Time predictability	Safety	Client satisfaction (service)
	Cost predictability			
(Radujković, M. et al., 2010) *No KPI for all concepts described in article; some self-formed KPIs*	Total project costs	Construction time	Quality	Feedback from client
	Profit margin	# time needed in addition to the project pre-calculation		Working atmosphere at the company
	Project pre-calculation variance			
(Won, J. & Lee, G., 2016) *No KPI for all concepts described in article; some self-formed KPIs*	Ratio project costs to BIM costs	% activities completed without schedule delay		
	# risks prevented by BIM	# change orders in project		
	BIM ROI	Amount of change measured		
	# errors and omissions on construction site	# times a mechanic needs to revise work		
	Cost conformance for major activities	# times a mechanic asks for information about the project		
		Average response time to RFIs		
(Coates, P. et al., 2010) *No KPI for all concepts described in article; some self-formed KPIs*	Revenue per employee	Total man hours spent on a project		Feedback from client
	Ratio project costs to IT investments	Ratio engineering hours first and last 3D-project		
	Travel, printing, document shipping costs			

Appendix B Final framework with KPIs

In this appendix, the final framework with all KPIs found in the literature is presented. These KPIs are discussed with the deputy director, operational manager, and some project managers.

Table B.1: Final framework with KPIs

Cost management	Time management	Quality management	Stakeholders
Unit cost	Construction time	Accident rate	Satisfaction of participants
% net variation over final cost	Speed of construction	Meeting technical specification	Customer satisfaction on services
Net present value	Time variation	QMS Performance	Customer satisfaction on products
% of construction cost variance	% of construction time variance	Project team performance	Feedback from client
Profitability	Time predictability	Labour safety performance	Working atmosphere at the company
Productivity	# time extra needed in addition to the project pre-calculation	Quality assurance	Work pace of engineer
Cost predictability	% activities completed without schedule delay	Safety	Work pace of mechanic
Project costs	# times a mechanic needs to revise work	Quality	
Profit margin	# times a mechanic asks for information about the project	Difficulty level engineering	
Project pre-calculation costs variance	Average response time to RFIs	Difficulty level installing	
Ratio project costs to BIM costs	Ratio engineering hours first and last 3D-project		
BIM ROI	Expected construction time		
# risks prevented by BIM	Total meetings about construction		
# errors and omissions on construction site	Engineering time		
Revenue per employee	Installing time		
Ratio project costs to IT investments			
Travel, printing, document shipping costs			
Expected project costs			
Material costs			
IT costs			
Failure costs			

Appendix C Dashboard 1

In this appendix, my first dashboard is presented. This dashboard can be used to get insight into the costs of a (type of) project. Using this dashboard, the company gets a better overview of the project data.

Figure C.1: Dashboard 1

Appendix D Dashboard 2

In this appendix, my second dashboard is presented. This dashboard can be used to get insight into the time needed for a (type of) project. Using this dashboard, the company gets a better overview of the project data.

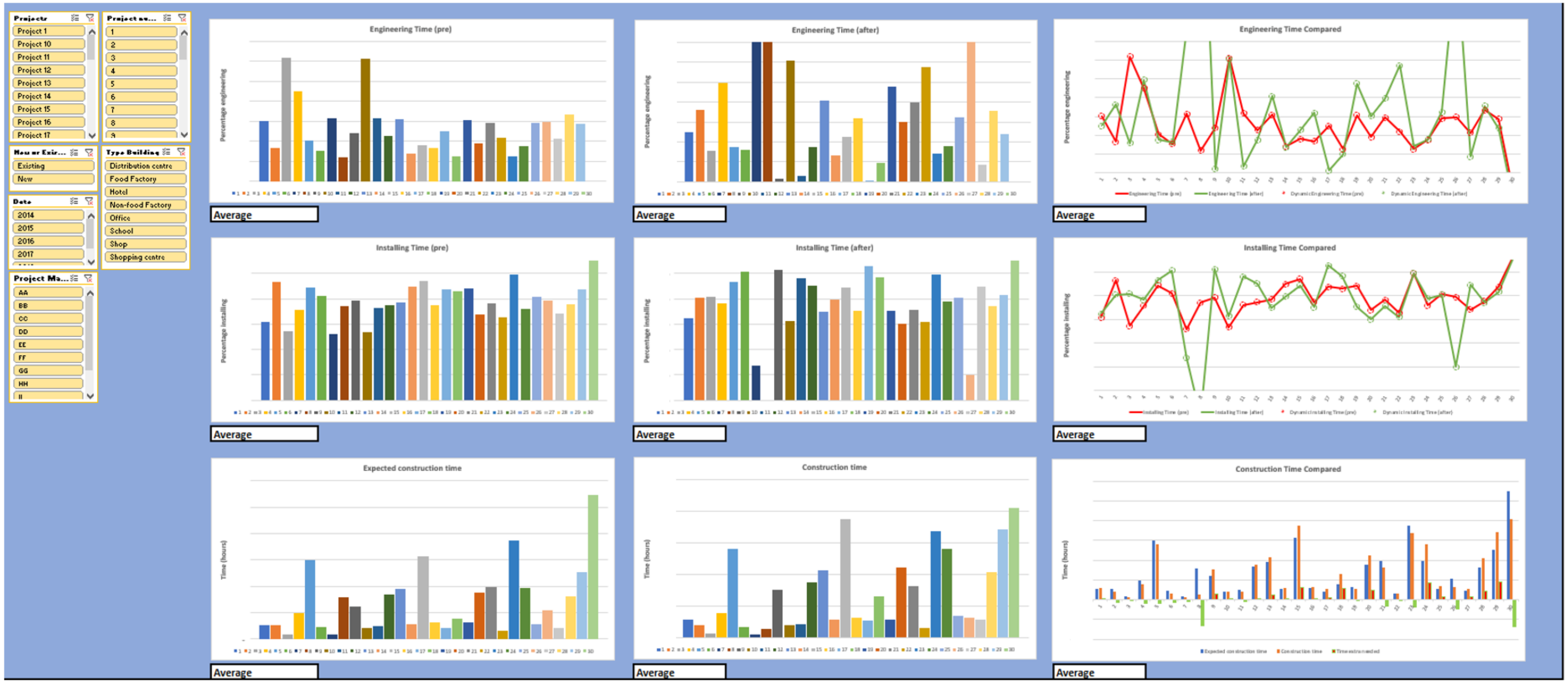

Figure D.1: Dashboard 2

Appendix E Dashboard 3

In this appendix, my third dashboard is presented. This dashboard can be used to get insight into the costs of a (type of) project. Using this dashboard, the company gets a better overview of the project data.

Figure E.1: Dashboard 3

Appendix F Dashboard 4

In this appendix, my fourth dashboard is presented. This dashboard can be used to get insight into the time needed for a (type of) project. Using this dashboard, the company gets a better overview of the project data.

Figure F.1: Dashboard 4

Appendix G Dashboard 5

In this appendix, my fifth dashboard is presented. This dashboard can be used to get advice regarding the type of digital drawing technology and the percentage needed to calculate the engineering time.

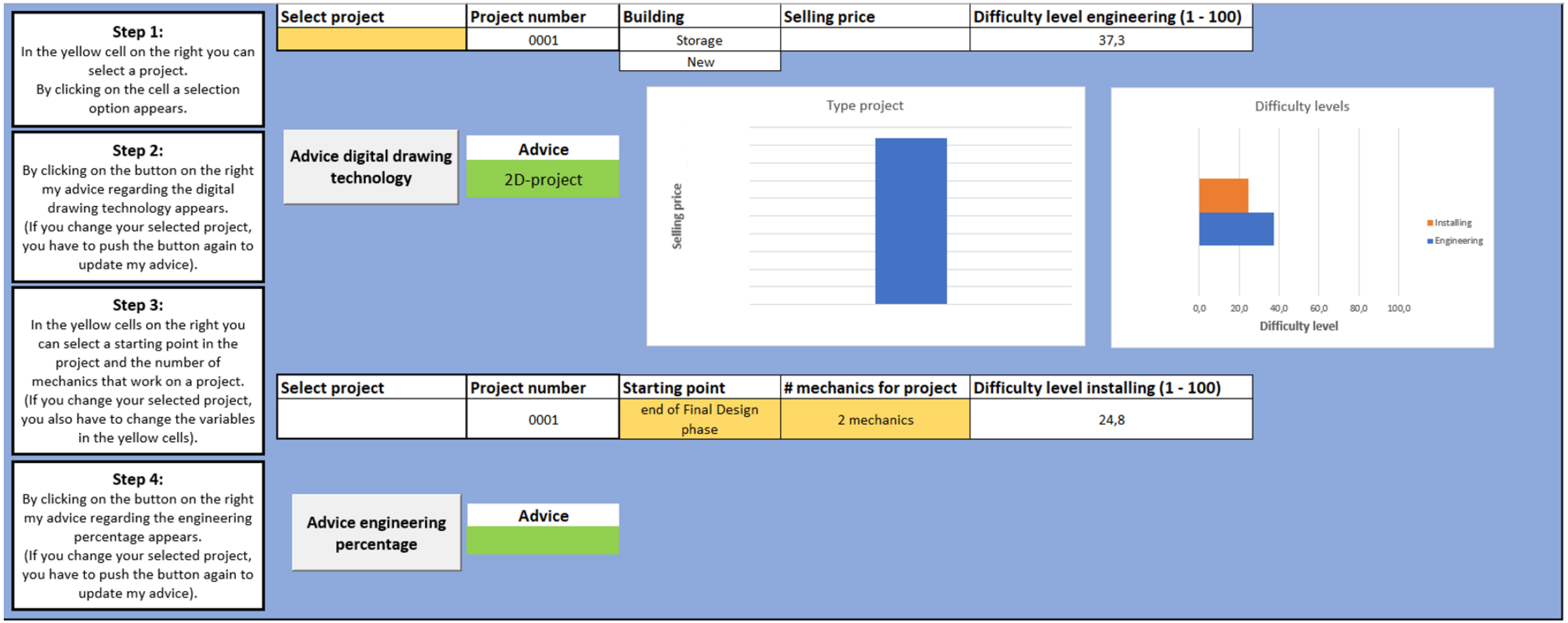

Figure G.1: Dashboard 5

Appendix H Code for advice digital drawing technology

In this appendix, the code for my advice about the type of digital drawing technology that should be used is presented.

```
Option Explicit

Sub AdviceDrawingTechnology()

Dim Choice As Integer
Dim TypeBuilding As String
Dim NewOrExisting As String

TypeBuilding = Cells(2, 4)
NewOrExisting = Cells(3, 4)

Cells(9, 3) = ""

    If TypeBuilding = "Distribution centre" Then
            Choice = 1
        ElseIf TypeBuilding = "Workplace" Then
            If NewOrExisting = "New" Then
                Choice = 1
            Else
                Choice = 2
            End If
        ElseIf TypeBuilding = "Storage" Then
            Choice = 1
        Else
            Choice = 2
    End If

    If Choice = 1 And Cells(2, 5) < 300000 And Cells(2, 6) < 45 Then
        Cells(9, 3) = "2D-project"
        Else
        Cells(9, 3) = "3D-project"
    End If

End Sub
```

Figure H.1: Code for advice drawing technology

Appendix I Code for advice percentage engineering time

In this appendix, the code for my advice about the percentage for the engineering time is presented.

```
End Sub

Sub AdviceEngineeringPercentage()

Dim B, C, F, Vpet As String
Dim A1, A2, A, D, E As Variant
Dim myrange As Range

'A = Type of building
'B = Size of a project
'C = Difficulty level engineering
'D = Starting point in the project
'E = Number of mechanics working on a project
'F = Difficulty level installing

Cells(28, 3) = ""

A1 = Cells(3, 4).Value
A2 = Cells(2, 4).Value

'The Value Type Building is an important variable for the engineering time needed
A = A1 & " " & A2
    ThisWorkbook.Sheets("KPIs and Variables").Select
    Set myrange = ThisWorkbook.Sheets("KPIs and Variables").Range("AC3:AD28")
    A = Application.WorksheetFunction.VLookup(A, myrange, 2, False)
    ThisWorkbook.Sheets("Dashboard 5; Advice").Select
A = (A / 100) * 10

'The higher the selling price of a project, the more engineering time is needed
B = Cells(2, 5).Value

B = (B / 11) * 10

'The higher the difficulty level of engineering, the more engineering time is needed
C = Cells(2, 6).Value
    If C <= 20 Then
            C = 1
        ElseIf C > 20 And C <= 26 Then
            C = 2
        ElseIf C > 26 And C <= 32 Then
            C = 3
        ElseIf C > 32 And C <= 38 Then
            C = 4
        ElseIf C > 38 And C <= 44 Then
            C = 5
        ElseIf C > 44 And C <= 50 Then
            C = 6
        ElseIf C > 50 And C <= 56 Then
            C = 7
        ElseIf C > 56 And C <= 62 Then
            C = 8
        ElseIf C > 62 And C <= 68 Then
            C = 9
        ElseIf C > 68 And C <= 74 Then
            C = 10
        Else
            C = 11
    End If
C = (C / 11) * 10

'The earlier the starting point, the more engineering time is needed
D = Cells(22, 4).Value
    ThisWorkbook.Sheets("KPIs and Variables").Select
```

Figure I.1: Part 1, Code for advice percentage engineering time

```
    Set myrange = ThisWorkbook.Sheets("KPIs and Variables").Range("AJ3:AK11")
    D = Application.WorksheetFunction.VLookup(D, myrange, 2, False)
    ThisWorkbook.Sheets("Dashboard 5; Advice").Select
D = (D / (0.909 * 1.1 ^ 7)) * 10

'The more mechanics working on a project, the more engineering time is needed
E = Cells(22, 5).Value
    If E = "1 mechanic" Then
            E = 1
        ElseIf E = "2 mechanics" Then
            E = 2
        ElseIf E = "3 mechanics" Then
            E = 3
        ElseIf E = "4 mechanics" Then
            E = 4
        ElseIf E = "5 mechanics" Then
            E = 5
        ElseIf E = "6 mechanics" Then
            E = 6
        Else
            E = 7
    End If
E = (E / 7) * 10

'The higher the difficulty level of installing, the more engineering time is needed
F = Cells(22, 6).Value
    If F <= 20 Then
            F = 1
        ElseIf F > 20 And F <= 26 Then
            F = 2
        ElseIf F > 26 And F <= 32 Then
            F = 3
        ElseIf F > 32 And F <= 38 Then
            F = 4
        ElseIf F > 38 And F <= 44 Then
            F = 5
        ElseIf F > 44 And F <= 50 Then
            F = 6
        ElseIf F > 50 And F <= 56 Then
            F = 7
        ElseIf F > 56 And F <= 62 Then
            F = 8
        ElseIf F > 62 And F <= 68 Then
            F = 9
        ElseIf F > 68 And F <= 74 Then
            F = 10
        Else
            F = 11
    End If
F = (F / 11) * 10

Vpet = (2.4 * A + 1.9 * B + 1.9 * C + 2.9 * D + 0.3 * E + 0.6 * F) / 10
Cells(28, 3) = (10 + (2 * Vpet)) / 100
End Sub
```

Figure I.2: Part 2, Code for advice percentage engineering time