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Waste in Construction Projects Today's - Practice and Potential

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Master of Science in Project Management
Submission date: June 2018
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Date

MASTER'S THESIS SPRING 2018
FOR
STUD.TECHN. Terje Magnus Bakken Sørensen

Waste in Construction Projects Today's - Practice and Potential

Avfall i byggeprosjekter dagens håndtering og potensiale

The Master study will investigate the possibility to use waste as a performance indicator for cost, quality and time including a qualitative indication on sustainability. For the work it is desirable and even needed to investigate this potential by learning from real construction projects in practice. Therefore, a case study will be carried out studying a variety of real construction projects. With limited available time only a few projects will be reachable within the framework of the Master thesis.

The main research question is related to how to reduce cost and improve efficiency and sustainability in construction projects addressing waste handling. Based on these three research questions are formulated:

1) Is there a difference in waste from new-building projects and retrofit projects in terms of:
   a) Type of waste.
   b) Amount of waste.
   c) Cost.
2) Is there a simulation model or program that categorizes performance according to waste and sustainability?
3) Can waste handling in a different way reduce cost and environmental impact?

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Preface

The thesis is written as a part of the finalization of the master degree in Project Management with specialization in Production and Quality Engineering at the Norwegian University of Science and Technology. The thesis is the final report of the master degree. The overall goal for the master thesis is to acquire in-depth knowledge within waste management on construction projects, and use this insight in the development of methodology for project progress monitoring as well as addressing sustainability. The methodology work is based on real data from five different construction projects. The objective has been to take benefit of methods from data analytic and control engineering, and adapt them as an alternative method for performance measuring with waste as an indicator in construction projects. The research was done with supervision by Agnar Johansen and Bjørn Andersen.

During the master a student is supposed to achieve the following skills and competence NTNU (2018);

- Carry out independent research and development projects based on supervision.
- Evaluate tools, methods, concepts, technical models, calculations and solutions in an independent way.
- Evaluate and predict technological, ethical and social effects and consequences of own work
- Work independently or in teams with technological or scientific assignments of high complexity and importance.
- Communicate in an effective way with colleagues about own work, do dissemination of knowledge, do evaluation and work out conclusions.
- Develop and present reports with high quality in a structured way and contribute to publication and recommendation within the technical competence.

It is recommended that the reader has basic knowledge of project management and construction projects.

Trondheim, 2018-06-08

Terje Magnus Bakken Sørensen

Acknowledgment

I will thank the following persons for their great help during the project: the supervisors Bjørn Andersen, NTNU and Agnar Johansen from SINTEF. Their dedication to the research field have motivated me to study various methods based on data analytic and control engineering in order to analyze waste in construction projects in a sustainable view.
Thereafter I would thank Gudmund Torvald Sørensen (CEO Fazenda) , and his network of contacts in the industry for help with information collection. In addition, MSc Håvard Sjåstad Braaten (founder of Concreto AS) is acknowledged for providing insight about how construction projects are implemented in reality.
At last I will thank SINTEF for the opportunity to work within the *R&D*-project Speed-Up.

T.M.B.S

Executive Summary

This master-thesis is done in cooperation with the SINTEF R&D-project Speed Up. The main goal for the Speed Up project is to increase the efficiency and quality for construction projects. This thesis addresses the possibility to reduce project cost with an increased focus on sustainable construction processes. The idea behind this assignment comes from the previously written project thesis Sørensen (2017), that had a focus on using methodology and ideas from Big Data and control engineering to streamline and support complex construction projects. As a part of this thesis it is done a literature review, a case study and an analysis using data from five real construction projects. The main purpose of the review is to give an overview of relevant literature in the topic of sustainable construction projects. The analysis focuses on what waste actually cost the industry today, and how different handling of waste can increase the efficiency in the industry. The thesis uses methodology from lean projects and laws and regulation towards construction waste in order to give an understanding of project performance and progress.

The main contribution of this thesis is the analysis of waste in construction projects in a sustainable view. It is proposed to use real-time tracking of waste to help decision takers during the projects. These results are based on a relative small amount of sample data from five projects and would therefore need to be verified by a bigger study to conclude on the main findings.

Sammendrag

Denne masteroppgaven er utført i samarbeid med SINTEFs RD-prosjektet Speed Up. Hovedmålet for Speed Up-prosjektet er å øke effektiviteten og kvaliteten på byggeprosjekter. Denne oppgaven omhandler muligheten til å redusere prosjektkostnadene med økt fokus på bærekraftige byggeprosesser. Ideen bak denne oppgaven kommer fra det tidligere skrevne prosjektet Sørensen (2017), som fokuserte på å bruke metodikk og ideer fra Big Data og kontrollteknikk for å effektivisere og støtte komplekse byggeprosjekter. Som en del av denne oppgaven er det gjort en litteraturstudie, case-studie og analyse med data fra fem virkelige byggeprosjekter. Hovedformålet med vurderingen er å gi oversikt over relevant litteratur om temaet bærekraftig byggeprosjekter. Analysen fokuserer på hva avfallet faktisk koster industrien i dag, og hvordan forskjellig håndtering av avfall kan øke effektiviteten i bransjen. Avhandlingen bruker metodikk fra tankegangen Lean samt lover og regulering mot bygge avfall for å gi forståelse for prosjektets ytelse og fremgang.

Bidraget fra denne oppgaven er analyse av avfall i byggeprosjekter med fokus på bærekraftig prosjekt gjennomføring. Det foreslås å bruke sanntidssporing av avfall for å hjelpe beslutningstakere under prosjektene. Disse resultatene er basert på en relativt liten mengde utvalgsdata fra fem prosjekter. Derfor bør det gjennomføres en større studie for å verifisere de viktigste funnene i oppgaven.

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Chapter 1

Waste in construction projects today's - practice and potential

In big construction projects it will always be many actors and activities going in sequence and parallel. The workload will be pretty high and complex with a high variability in tasks and materials used. Many activities take place within a defined time and limited area, which means that the actors often share resources and work areas. The plumber works with the same building masses as the electrician. Material flow is transported through one common crane, and casting crew is dependent on the reinforcement being carried out before they do their own work. These examples have a common feature: Activities on a construction site affect each other. Since these interactions and dependencies are facts in complex construction projects, there is a regular dialogue and project coordination meetings between the various actors in the building block. Furthermore, it is increasing demands from the government and society to be resource and energy saving in view of the increasing focus on sustainability. This has given an increasing demand for being better with material recycling in the construction industry. At the same time, there are great opportunities to use recycled materials and environmentally friendly alternatives in the various building processes. The key to do this is to have good performance indicators of cost, time and quality of the materials used as well as the working processes. This thesis addresses the possibility to reduce project cost with an increased focus on sustainable construction processes. The idea behind this assignment comes from the previously written project thesis by Sørensen (2017), that had a focus on using methodology and ideas from Big Data and control engineering to streamline and support complex construction projects. As a part of this Master thesis it is done a literature review, a case study and an analysis before the conclusions are given. The main purpose of the literature review is to give an understanding of the relevant literature in the topic of sustainable construction projects. The analysis will focus on how much waste actually cost the industry today, and how improved handling of waste can increase the efficiency in the industry. The thesis will use methods and knowledge from lean, laws and regulation towards construction waste to develop an understanding of the construction project performance and progress. This Master thesis is done in cooperation with the SINTEF's R&D-project Speed Up. The main goal for the Speed Up project is to increase the efficiency and quality for construction projects.

1.1 Background

This part of the assignment is a dissemination of the project work Sørensen (2017). Measurements of progress, cost and quality are important indicators in every project. However, in many cases reports of an project that describe status, errors and bottlenecks are often notified to the project management too late in order to achieve satisfactory quality and efficiency in the construction projects. The importance of the relationship between time-cost-quality is described in the lecture notes from Andersen and Fagerhaug (2001) and Hussein (2016). Unfortunately, too often repercussions have already compromised the project at this state. Inspired by system theory and control engineering, such problems may be characterized as a process with a feedback control system using selected output (measurements) from the process as control variables. Lack of proper feedback for continuous improvement in due time will degrade the process. The interest for this subject has come from the increased focus on sustainable development goals and climate challenges addressed by UN.

Speed-Up

Speed-Up is a R&D-project that focuses on big complex projects, where the main goal is to develop and test knowledge that can reduce project time with at least 30% by the end of 2017 compared to the 2013-level, SpeedUp (2013).

1.2 Goal for the study

The Master study will investigate the possibility to use waste as a performance indicator for cost, quality and time including a qualitative indication on sustainability. For the work it is desirable and even needed to investigate this potential by learning from real construction projects in practice. Therefore, a case study will be carried out studying a variety of real construction projects. With limited available time only a few projects will be reachable within the framework of the Master thesis.

1.2.1 Research questions

The main research question is related to how to reduce cost and improve efficiency and sustainability in construction projects addressing waste handling. Based on this three research questions are formulated:

1. Is there a difference in waste from new-building projects and retrofit projects in terms of:
   (a) Type of waste.
   (b) Amount of waste.
   (c) Cost.
2. Is there a simulation model or program that categorizes performance according to waste and sustainability?
3. Can waste handling in a different way reduce cost and environmental impact?

Why are this questions asked?

To motivate project owners to be better in handling waste they probably need to have good reasons beyond being recognized as greener. A way to motivate them can be to investigate methods on how to reduce costs in the waste handling. The synergy (side) effect will be less environmental impact and resource usage, better working environment, etc. As mentioned this work is a continuation of the project thesis (Sørensen (2017)), where it was studied on how to use waste as a measure for progress in construction projects. To utilize waste as a measure supplemented with methods from waste analytics at the level required for progress measurements and still being attractive, it is also necessary to see how a company can save money on such a method. Therefore the first research question arises as a consequence of this. It is necessary to see how different construction methods can be compared for then being improved when it comes to waste handling. When it comes to the second research question, it is necessary to see if it already exists tools to analyze waste in a way that give information about performance according to sorting and amount of waste in relation to sustainability. The third research question is about a combination between cost savings and environmental impact.

In which way will the research questions be solved?

To solve the research questions completely for such a complex problem are demanding. Anyway, the research questions are guidelines helping to understand why and how the author approaches the work in thesis including doing choices taken during the process of creating this thesis. This thesis will be solved by the following four points:

1. Evaluate the different types of waste and which categories of waste that will be relevant in order to investigate large new-building construction projects, as well as retrofits (upgrades of existing buildings).
   (a) Evaluate how waste is handled today.
   (b) Identify the amount of waste and associated cost.
2. Compare the situation between conventional new-building, retrofit and prefabricated building projects in terms of:
   (a) Type (sort) of waste.
   (b) Amount of waste.
   (c) Cost.
3. Based on 1-3 suggest methods on how to handle waste in a different way reducing cost and environmental impact.
4. Develop input to a simulation model and software program that categorize performance according to usage of waste and sustainability.

When it comes to the last step in this working plan, it suggested to continue on this in further work.

Limitations

The following limitations and assumptions are done in order to focus the work within the framework of given time for the Master thesis. First, it is assumed that all construction projects are regulated by the same laws and regulations, and therefore will be possible to provide the same information from their project phases. Second, it is assumed that one type of waste has the same cost no matter where the projects are located. This is for instance not true in general. However, to make it easier to compare the results from each project this assumption is taken. The last limitation for the project is that in order to have access to real project information, specific data that could make it possible to identify the project was kept secret. Quantifying efficiency without numerical figures would in some cases be a problem. Although measures of efficiency are usually made quantitatively and usually as a percentage, the study will, due to limiting resources, mainly present this potential qualitatively

1.3 Reading tutor

The thesis will start with defining the scope before the research methodology is presented. Each chapter in the thesis is organized in the following way:

- Chapter 1 is an introduction to the study and describes the background and boundaries for the study. In addition the research questions and project goals are defined.
- Chapter 2 defines methodology and strategy needed to answer the research questions and problem formulation. In addition we show of data gathering is done.
- Chapter 3 contains a literature study of construction projects and tells which laws and regulations we need to take into account when we are handling waste.
- Chapter 4 contains a litterateur study of how sustainability is taken into account in supply chain management and procurement.
- Chapter 5 contains a literature study of waste handling and sustainability towards the construction industry.
- Chapter 6 present the project cases and their findings, with some analyses.
- Chapter 7 discuss the results from the case and the key problems with sustainability issues. Then, we suggest an user interface that can show the results for any given project according to sustainability and waste handling.
- Chapter 8 gives the conclusions and recommendations for further work.

Do to the structure of the study is is natural to read it from start to finish. This will give the reader a good understanding and highest possible gain of findings and conclusions. However, this will be time consuming and the benefit will vary with the reader's starting point. For readers with good understanding of the construction industry, and good understanding of sustainability and its content it is suggested to read the report with focus on Chapters 6, 7 and 8, since these Chapters present the findings, analysis, discussion and conclusion with recommendations for further work. For those who wish to make use of the findings of the study for scientific work, it is recommended to read the report in the presented order, as well as Chapters 2 and Chapter 6 to 8 in detail.

Chapter 2

Methods and research design

This chapter gives information about which way the research questions are answered and provides necessary definitions to evaluate the results. This Chapter are based on the methods and research design Chapter in Sørensen (2017).

2.1 Methods

Based on the research questions and objectives defined in Chapter 1, it will be propose a research design according to the following definition:

> *A research design provides a framework for the collection and analysis of data. A choice of research design reflects decisions about the priority being given to a range of dimensions of the research process.* Bryman (2012)

Bryman takes about five different experimental designs: experimental, survey design, longitudinal design, case study design and comparative design, Bryman (2012). A complete study can include all or some of these designs. However, this Chapter will present designs used to solve this thesis. Inside each design it is possible to include different research methods to reach the research goal. The theory states that having insight about the used research methods, can give a quality insurance to the study, UiT (2017). Examples of methods that can be used are: deductive, inductive, qualitative and quantitative. In the following Sections the different methods used in this thesis will be described.

Deductive methods

The deductive approach works from theory to confirmation and is defined as:

> *Developing a hypothesis based on existing theory, and then designing a research strategy to test the hypothesis.* Wilson (2010)

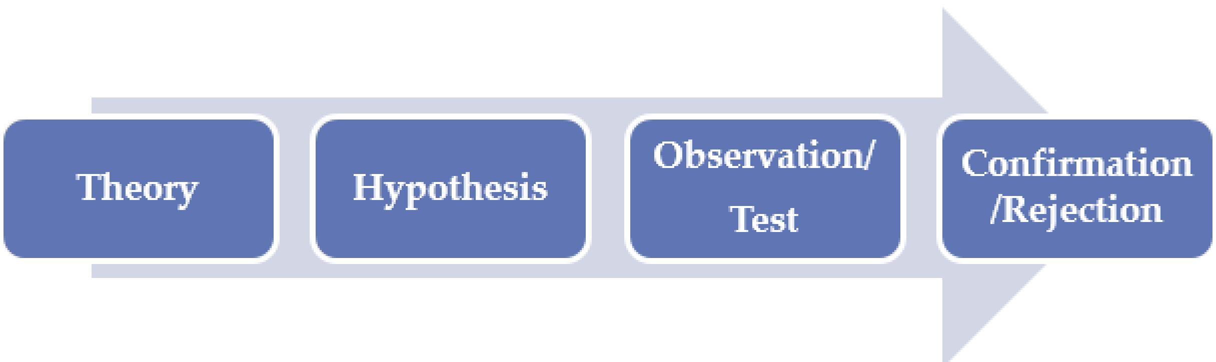

Figure 2.1: Deductive approach, from theory to confirmation Dudovskiy (2016a)

This approach is often called the top-down approach, see Figure 2.1. Which means it will work very good if the foundations theory is solid. When working with reputable truths, it work fine since results are either valid or invalid. This means that conclusions are finite, Zalaghi (2016). However, the disadvantage with this approach is that the conclusions taken by the deductive approach will be limited by the area or space of operational conditions, Zalaghi (2016). This means that the project scope has to be accurate in order to provide valid and probable results.

Inductive methods

The inductive approach works from observation towards theory and is defined as:

> *The search for pattern from observation and the development of explanations for those patterns through a series of hypotheses.* Berbard (2011)

This approach is often can called the bottom-up approach, see Figure 2.2. It comes from the idea that a house is built stone on stone, not by starting with the roof. The advantage of the inductive method is that it has no need for established framework or model up front, Zalaghi (2016). Lack of established theory can make the researcher less unbiased since he/she is more open minded about what expected findings that may arise.

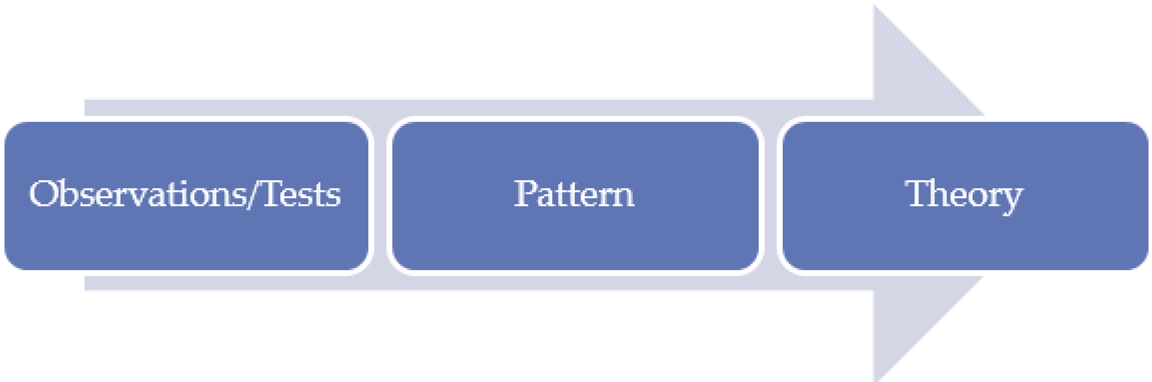

Figure 2.2: Inductive approach, from observation to theory Dudovskiy (2016b)

Qualitative methods

The Qualitative method does not depend on hard knowledge. So if the problem is hard to measure or quantify in terms of numbers, a qualitative research approach is a much used method. In other words, it is a good way to see a greater picture including main characteristics, connections and the most important drivers for a given problem, UiT (2017). In order to gather qualitative research information, the typical approach is interviews and observations, Berg and Munthe-Kaas (2013).

> *The main problem with a research like this, is that it is often hard to verify afterwards. Since interpretation may be different and data sets often are too small. A reason is that qualitative data may have a biased nature in its origin. Unfortunately, it is difficult to apply conventional standard methods that are reliable and easy to verify and validate, McLeod (2008).* Sørensen (2017)

Quantitative methods

Quantitative research may be used when good models and a lot of relevant data are available. While using this method it is possible to measure or count data to preform analysis, UiT (2017). One of the benefits with a quantitative research is that the study is easy to verify afterwards, since quantitative data can be analyzed by acknowledged e.g. statistical methods, McLeod (2008). Quantitative approaches are scientifically unbiased or objective, Carr (1994). However, a limitation for quantitative studies is that we normally need huge data sets to get an accurate analysis, McLeod (2008).

2.2 Research design

As mentioned earlier Bryman takes about five different experimental designs. In this Section the relevant types of research design will be explain as in the project thesis, Sørensen (2017).

Experimental design

Experimental design is considered both robust and trustworthy, Bryman (2012). This means that experiments are internal valid. A reason for that is that in order to conduct an experiment the process is deliberately changed to observe the effect on a variable, NIST and SEMATECH (2013). A study like this starts with an objective and creating an corresponding process model. Finding the process model can be hard. One way of doing this could be by using a so-called black-box modelling, see Figure 2.3. Which means that the internal dynamic is unknown, and therefore the only known variables are input and output of the process. Then by using methods from machine learning, curve fitting, multivariate analyses, neural networks and similar, a model can be established. This way of manipulating a process are very good if prerequisites is limited for the process. However, it would not work if knowledge of which type of excitation (input) will have an effect on the process in order to observe its output. This is called persistent excitation from system identification.

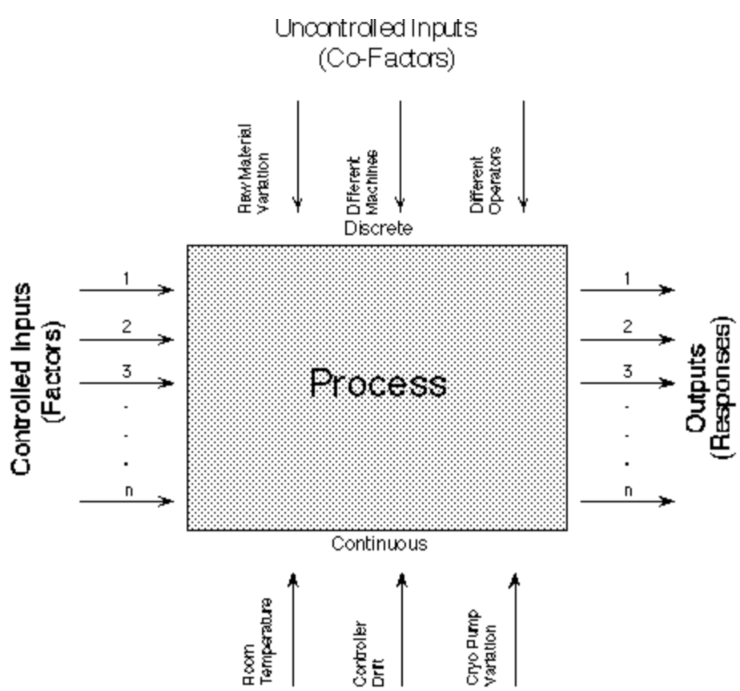

Figure 2.3: Black-box model by NIST and SEMATECH (2013)

Cross-sectional design - Survey design

Cross-sectional design or survey design are defined as:

> *A cross-sectional design entails the collection of data on more than one case and at a single point in time in order to collect a body of quantitative or quantifiable data in connection with two or more variables, which are then examined to detect patterns of association.* Bryman (2012)

Cross-sectional studies are observational studies meaning that it is not necessary to manipulate the studied environment, IWH (2015). One advantage with cross-sectional studies is that it is possible to compare huge amounts of data at the same time. However, cross-sectional studies do not tell us anything about cause and effect between data, that is the causality.

Case study design

As the name say, a case study, is an analysis of data and intensive for a single case.

> *Case study research aims to explore and depict a setting with a view to an advancing understanding of it* Glynis (2005).

In other words, meaning that complexity and nature of a given situation can be observed, Bryman (2012). Case studies are often associated with a location. One reason for this is that case studies are limited by the boundaries for the study, Glynis (2005).

2.3 What is Big Data analytic?

Since the definition of Big Data analytic is hard to get the grip on, the approach will be to look on Big Data and analytic as separate terms to give some insight.

2.3.1 Advanced analytic

This section is primarily based on Russom (2011). Advanced analytic applied on a data set help us to detect changes, and then to advice on needed corresponding control actions. It can also be a good tool to discover new customer segments, identify best suppliers, etc. Different forms of advanced analytic could include predictive analysis, data mining and statistical analysis, data visualization, artificial intelligence, natural language processing, and database capabilities. Still its hard to get a hang on what Advanced analytic really is. Therefore, we want to use description as an example:

> *With Big Data analytics, the user is typically a business analyst who is trying to discover e.g. new business facts that none in the enterprise knew before. To do that, the analyst needs large volumes of data with plenty of details.* Russom (2011).

This gives us the extent of the potential for Big Data analytic as an entity.

2.3.2 Big Data

Its possible to find many definitions of Big Data, and most of them only focus in terms of the size of data in storage. Thus, it exist other important parts of Big Data such as variety and velocity of data, data recording and analysis, respectively (Russom (2011), Harkness (2017), Bilal et al. (2016b)).

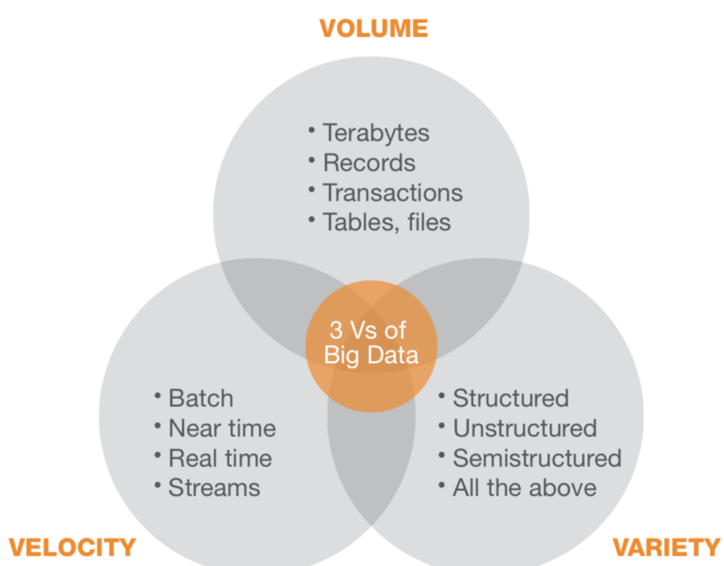

Figure 2.4: The three Vs of Big Data Russom (2011), Bilal et al. (2016b)

Swarbrick (2012) define data as:

$$Data = Information + Noise \tag{2.1}$$

In the rest of this Section the three "Vs" (Volume, Variety and Velocity) of Big Data will be explained. Figure 2.4 gives a representation of the three "Vs" of Big Data.

Volume

The first V is logical, just by looking on the name Big Data assuming that volume is a part of it. However, how big amount should data be in order to be defined as Big Data? Some define it in terabytes, but it can also be quantified by counting records, number of transactions, tables, files or time (Russom (2011), Harkness (2017)). The scope can also vary where different forms of analytic can have different purposes and data sets.

Variety

The second V in Big Data is Variety. This is included in the definition since Big Data is notable in the numbers of sources, data types, and entities represented (Russom (2011), Harkness (2017)). Examples of sources is Web sources, including logs, click-streams, social media, and RFID (Radio-frequency identification), Russom (2011). In the construction industry RFID can be interesting, since nearly all items are delivered with RFID tagging. There are also other sources that are harder to quantify like video and audio. As Russom say both variety and volume are huge and overlapping considering Big Data, Russom (2011).

Velocity

The last element in Big Data is velocity. Since the volume and variety are huge, the need to process data fast is important, Russom (2011). Usage of sensors gives the possibility to sample and stream the data. However, one difficulty with streaming data is that the analytics need to go in real-time, Russom (2011). Hence, the development of Big Data goes hand-in-hand with the technology development and improvements in algorithms for fast processing (Sørensen et al. (2016), Omran and Chen (2016)).

2.3.3 Exploratory data analysis - EDA

This section is primarily based on Swarbrick (2012). EDA is a method for extracting a huge amount of data. It works towards finding hidden structures in large and complex data sets. Information about dependencies is very helpful when making decision since thereby it is easier to know which consequences a change will have, Elgendy and Elragal (2016). An overview of hidden information can give insight about; patterns, groupings, trends, and information about execution strategy. The requirement for multivariate analysis to work is that samples and variables are related to each other. Then EDA rates the importance of the variables in the data set. Two methods normally used is (1) cluster analysis, and (2) principal component analysis. Cluster analysis is defined as:

> *The task of separating objects into groups where the members of a particular cluster are similar to each other* Swarbrick (2012).

Principal component analysis is the defined as:

> *The analysis of variability in a particular set of data* Swarbrick (2012).

2.3.4 Regression analysis

Regression analysis is when developing a model from available data to predict a response. To do an analysis, such as in this project, two data tables are needed, one for independent and one for dependent variables, Swarbrick (2012). An independent variable is a measurement, and a dependent variable is a desired wanted response for an estimate. In a waste model this will be the key element. The main issue or concern with a regression model is that crap-input will produce crap-output. Hence the quality of the input data (ie. measurements, calculated data) must be good enough to give a reliable estimation, Swarbrick (2012). To make sure that model work as intended an appropriate validation strategy is needed, which is the test for fit-for-purpose characteristics and satisfaction of intended use.

Validation

Validation is related to a more high-level confirmation (or certification) of a system if it is in compliance to intended use. Verification is a more narrower scope used to confirm (certify) that a set of functional requirements are met. The functional requirements are of course defined such that the system works as intended. Testing will contribute to confirm verification and validation. Two methods for doing validation are cross-validation and test-set validation. Cross-validation takes sample sets out of the process, and develops a model of the remaining sets. This is done to all samples have been used for verification and validation, Swarbrick (2012). For the test-set validation, we use a validation data set to see how it works with data outside the data set it is made for, Swarbrick (2012). Out of these two methods test-set validation works best towards multivariate models, which means that it can be used in the waste model, Swarbrick (2012). The benefit with good validation is to ensure: (1) simplest and most reliable model, (2) isolation of samples that have high influence on the model, (3) better interpret-ability of the model, and (4) that the variability has been taken into account towards the training sets, Swarbrick (2012).

2.4 Used research design

This thesis are solved by a series of methods. Most of the theory from the project thesis, Sørensen (2017), still has relevance, and will be further elaborated in the master thesis by the methodology explained below. Thereafter a case study will be conducted, where the foundation will be waste data collected from several construction projects. This data was then analyzed with methods from Big Data analysis in order to give information about sustainability and cost streamlining.

2.4.1 Literature review

The literature review requires a clear methodology for how to find and collect literature with great transferability to the situation desired to analyze. This report is based on the David Gough nine-phase process for systematic reviews, Gough (2007). This process starts with (1) establishing research question, (2) defining criteria for choosing the literature, (3) defining search strategy and search in databases. (4) The next step is to ensure that the literature is relevant, (5) then read the articles to see if it fulfill the criteria mentioned above, (6) before reporting the results of the search strategy. (7) If the source is useful, the author either download the article or source to future use, (8, 9) The chosen literature is then evaluated based on relevance, quality and content, and at last the author should draw a conclusion for the study. For this thesis information most of the literature was already found in connection to the project thesis Sørensen (2017).

2.4.2 Construction of case study

To complete this work, information about waste has been collected from several completed projects from the construction industry. The different projects were found by help from Gudmund Sørensen CEO for Fazenda, and his contact network. Suitable real construction projects were chosen by considering project size and project type with relevance for the thesis. In the work of this thesis five projects that were either prefabrication projects, space building projects or retrofit projects have been studied. Thereafter waste reports from each project were collected. In the analysis each project used the same methods, since it is a part of the documentation needed to get a finished certificate. This means that the data used to analyze the different projects will be presented without bias. However, it is an issue that it is nearly impossible to accurate track the waste before a project is finished. Thereafter it will be conducted experiments on the data set, which means that the logic behind the framework will be tried confirmed towards given limits, assumptions, expected behavior, etc. This will be done based on the theory from Big Data analytic.

2.4.3 Methods for Big Data analytic

An easy one-to-one problem could be solved by investigating only one variable at a time. However, when problems are complex, a tool which can be used may be multivariate analysis (MVA), Swarbrick (2012). This approach use multiple measurements to analyze the problem. In a construction project it will always be possible to measure progress in many ways. However, in this thesis waste will be used as a key element in measuring progress and performance. The main issue with using waste is that when alone it will not tell anything about the progress. Hence, comparing waste accumulation to a waste estimation model (see Chapter 5.1.2) is needed. To understand the behaviour of the model or process, choosing a measurement strategy and a corresponding measurement system are highly important. This can be done by tracking the different categories of waste, how much, where and when it was located, and finally a time line to compare it against the Gant-chart. Her the three types of multivariate analysis is used, Swarbrick (2012); (1) Exploratory Data Analysis (EDA), sometimes called data mining. Thereafter (2) Regression analysis that develops models to predict events, and at last (3) Classification for identifying different objects (or behaviour) of interests. Classification is useful in research, development, and market analysis. These methods can be used separately or as an unity.

2.4.4 Classification of objects of interest

To better understand a problem or a process classifying objects of interests in the process is a good way to go, Swarbrick (2012). What does really classification means? It is defined as:

> *Classification is the separation of a group of objects into one or more classes based on distinctive features in the objects* Swarbrick (2012).

When doing a classification, we start with a set of objects and measure some variables, Swarbrick (2012). Based on the variables it is possible to group the objects based on similarity. Thereafter it is possible to determine whether the sample is a part of an existing class or would be a new class. Being able to easily and reliably characterize uniqueness is an important feature we should keep in mind when investigating the measurement strategy and corresponding sensors to be used in our problem.

What is good data?

In order to be able to do accurate measurements and estimation of the progress and performance, a reliable data source is important. According to Andersen and Fagerhaug (2001) existing electronic data are a good starting point since a company or business often already has these data stored. However, if the data are not updated on a regular basis, they may be useless. Typically a business frequently update data about cost, resource usage, inventory, order data, and time usage, Andersen and Fagerhaug (2001). Therefore administrative support systems are good tools for finding useful data. In the construction industry BIM (building information model) is such a tool. BIM contains e.g. information about needed materials in different processes in addition to much more information (Christensen (2011), Bilal et al. (2016b)). An important aspect of choosing reliable data is the possibility for manipulation of the data. In addition, the data need to be neutral, Andersen and Fagerhaug (2001). In our case both RFID, cameras, BIM and weight may be used as data points. Of these data sources RFID may be possible cheap and easy to manipulate. Data quality is often subject to the proximity of the objects of interests to the sensor.

Collection of data

Since the access to data may be enormous and almost unlimited, and it is hard to handle all data with desired response time, the key is to be careful in deciding which data to collect. Since this thesis addresses the project progress in construction projects measured by amount of waste, the focus will be on sources that can give information about the waste. After consulting with, Braaten (2017) Partner at Concreto AS, it was decided that the information about location of waste inside the construction site also was needed in order to do an accurate progress measure.

This conversation also gave insight about that more and more construction sites sort and recycle their waste, Braaten (2017). Therefore, it may be possible to find even more relevant information about the different categories of waste automatically at each site than first anticipated. Thus, a camera with the possibility to recognize and automatically classify objects of interest (for us different waste) may be a preferred solution. Such camera technology based on hyperspectral imaging is already developed by the NTNU spin-off company Ecotone for underwater identification, monitoring and mapping of seabed features and marine installations, Ecotone (2017). The idea is to utilize all wave lengths in the visible light from about 400-700 nm for unique characterization and classification. Each pixel will contain optical fingerprints of the imaged object. In contrast, conventional camera technology utilizes only three wave-lengths (Red-Green-Blue: RGB) as this is what a human eye is limited to distinguish. Another issue with Big Data is regulations and concerns about cyber security, privacy and data storage directive, Andersen and Fagerhaug (2001).

Processing and storing of data

As mentioned earlier data of finalized work in relation to planned work are key variables to be measured in order to monitor progress. The most widely used method for analyzing data is by looking on each data set separately, Sørensen et al. (2016). As mentioned earlier Big Data gives the possibility to use multiple sources to sample, store and analyze data. Thus, a common problem in the processing of data from different sources are the ability to compare, filter and weight each of the data sets, Sørensen et al. (2016). This means that to have an opinion of the data, the need for translation to a common *language or standard*, Cheng and Teizer (2013). In computer science this can be done by using data protocols that choose the data flow or limit the incoming data, Cheng and Teizer (2013). This make it possible to do an analysis of the data. However, if translating the sources are impossible, each of the sources need to be treated directly for progress estimation. Possible software algorithms can be found from the text book in Algorithms and Data Structures at NTNU, Cormen et al. (2009).

2.5 Quality of information

This study is based on five different construction projects of three different categories; retrofit, conventional and prefabricated. This means that the information is quiet spreed out, Therefore it can be hard to verify the results. However, the study has some quantitative aspects that makes the information easier to overrule. When it comes to the literature part of the study the sources comes from well reputable publishers. For the qualitative part of the study it can be clouded by the authors view and interpretations.

Reliability and validity

An important part of judging quality of the thesis is to evaluate if the information acquired is reliable, Bryman (2012). To prove that the research are done in the right manner of methodology. However, it is harder to prove the quality in a qualitative study, rather than in a quantitative study, McLeod (2008). The next demand for a research are the validity. This is monitored by studying if the right variables and parameters are measured, Bryman (2012). Thus, the research question should always be the center of the information collection. This project are done as a two part study, the first part a literature study and the second part a case study based on waste reports from five projects. However, since much information also had to be interpreted, it is a study where qualitative understanding are used to interpreted waste reports and literature. The validity of the study depend on the level of quality in the waste reports and literature. However, the author believe that most of the literature either comes from books or articles published in reputable journals. This makes the reliability satisfying, but depend on the assumptions taken in the case study.

Chapter 3

Overview of construction projects

This Chapter will present flow in construction projects in addition to information about laws and regulations for waste in construction projects. The Chapter focuses on how progress is measured, and in which way it is reported to the decision makers in construction projects.

3.1 Introduction to progress measuring

Measuring of progress is one of the main tools to manage a project according to a plan subject to time, resources and cost, Hartigan and Doyle (2007). As McConnell says; *to keep a project on track, you have to know whether it´s on track*, McConnell (1996). Having some sort of progress measurement system is the key to take decisions that steer the project, and this system needs to be unbiased and have needed level of reliability, validity and quality. Progress can be tracked in multiple ways: it can be estimated, measured by exact numbers and/or by subjective measurements. It can be done by reports, meetings and oral feedback with project participants. As the sensor technology gets better, more and more of this information are processed by digital information systems, Rolstadås et al. (2014). However, since all projects are required to log waste, it can be tested if this type of information can add new insight in how to monitor progress in construction projects, where the potential of monitoring trough waste give opportunities like progress measuring, resource use and growth in project cost, Sørensen (2017).

3.2 Flow for construction projects

In a huge and complex construction project it is not possible to make a generic and exact flowchart for the construction process since the requirement changes depending on the scope included in the contract, terms, conditions, laws and regulations. However, an example of an linear construction project and its activities are shown below, Daum et al. (2005):

- Prepare site and pour foundation.
- Complete rough framing.
- Complete rough plumbing electrical and HVAC (Heating, ventilation and air conditioning).
- Install insulation.
- Complete drywall, interior fixtures: start exterior finishes.
- Finish interior trim: install exterior driveways and walkways.
- Install hard surface flooring and counter-tops: complete exterior grading.
- Finish mechanical trims: install bathroom fixtures.
- Install mirrors, shower doors and finish flooring: finish landscaping.
- Final project delivery.

Hence, in a big and complex project some of these tasks will overlap in time. However, they will not overlap in each working area. An example of this is that first and second floor don't need to finish each activity at the same time. In this thesis three different construction project types will be analyzed. The three different types are chosen based on availability and similarity in the construction processes. Based on this investigating it will be concluded wherever all three construction types are suited to use waste as a parameter for performance and progress measuring. It would maybe better just to use one or two of the construction methods in a analysis like this.

Conventional new-building projects

This is the traditional construction method for new buildings where everything is build on site more and less following a linear building method. Hence, most of the waste will be generated at the site, and need to be sorted in waste categories at the site. Also all surplus material for the project, which is either thrown or recycled for new use would be on site. The advantage with this building form is flexibility. If the project has design changes, it can be changed at the site.

Retrofit building projects

In a sustainable view this is an important construction method, since materials is already used and therefore already given its carbon footprint. However, to effectively recycling materials from old building the work starts with the new buildings by choosing materials that are easy/possible to recycle. Over the years the awareness of this has changed probably to the better. This is the main reason that retrofit projects has much more waste and maybe more dangerous waste than new building projects.

Prefabricated building projects

Prefabricated building is a very effective way of producing well known products/buildings and designs with high volume. The main benefit is that the building phase is fast completed if the planning phase is well executed. This method works by bringing build pieces to the site for thereafter connecting them to finished pieces. By producing the pieces in controlled environments, it becomes easier to avoid mistakes, and it is not necessary to have surplus materials and waste for this part of the production in the construction site. However, for a project that relay on huge flexibility this construction method should be avoided. Since, the time from the change must be made until the change is made becomes much longer.

3.3 Project progress measure

Project progress is a quantitative value on how a project is going according to planned time, cost and resources estimated in forehand. A progress measure can then be seen as a performance measure, Andersen and Fagerhaug (2001). To establish some sort of control on the progress measure, data should be monitored and saved for later statistical use and comparison. To be able to monitor two requirements are needed, first a need for target or baseline, and second a need for ongoing measurements of the progress according to target. The reason for measuring progress is that it provides essential project management information, and this information can be used in decision making processes, Andersen and Fagerhaug (2001).

3.3.1 Time, cost and resources

In construction projects, progress is often measured by observations in relation to due date (time). The measurements can be based on numbers of completed activities, subjective evaluation of completions based on experience and previous knowledge, achieved milestones, and physical measurements of construction properties, Hussein (2016). Depending on that the type of measurements, the accuracy and reliability changes accordingly. In the planning phase the project should have a plan for milestones, project breakdown structure (WBS), network diagrams, resource charts, and S-curve summing up completion according to scheduled targets, Hussein (2016). In order to get an overview of the project, many projects use a Gant-diagram setting up and scheduling the various activities along a time axis. As a measure it is possible to compare the planned activity progress in a Gant-diagram with executed and completed work. It is also possible to see how a delay in one activity can provoke a delay in the entire project. Then, it is possible to see the critical path as well as dependencies between the various activities, Vatn (2017). By measuring a delay, it is possible to calculate how it will change the flow in the following activities, see Figure 3.1: Visualizing the measure can be done in multiply ways such as

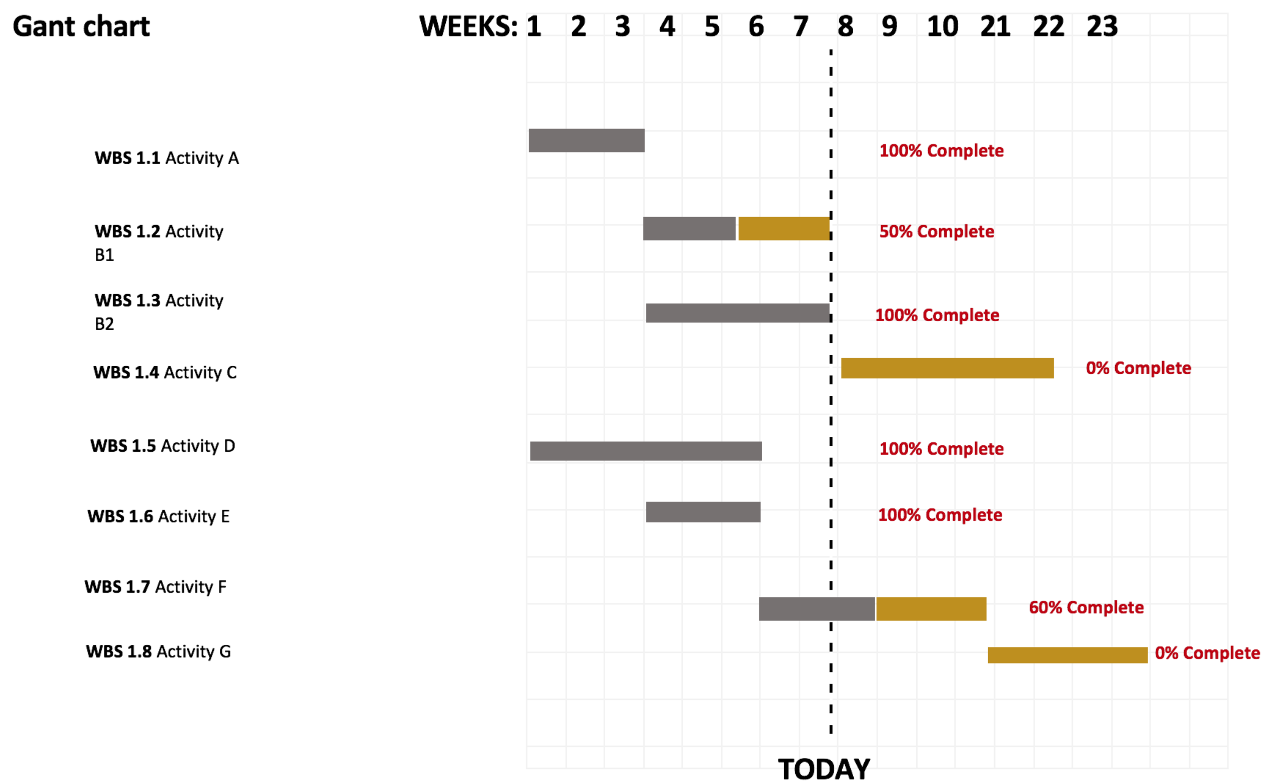

Figure 3.1: Schedule for activities in a project

physical measurements identifying error in the amount of work done, and S-chart (see Figure 3.2) can give information about work done towards costs and final completion. However, in the real life it is difficult to get information about the current situation in a project since the project often consists of different organizations (e.g. sub-vendors), groups and people, that changes in different parts of the construction process, Karlsen and Gottschalk (2005). This makes it challenging to use the same measurement methods in all parts of the construction process, Gould and Joyce (2009).

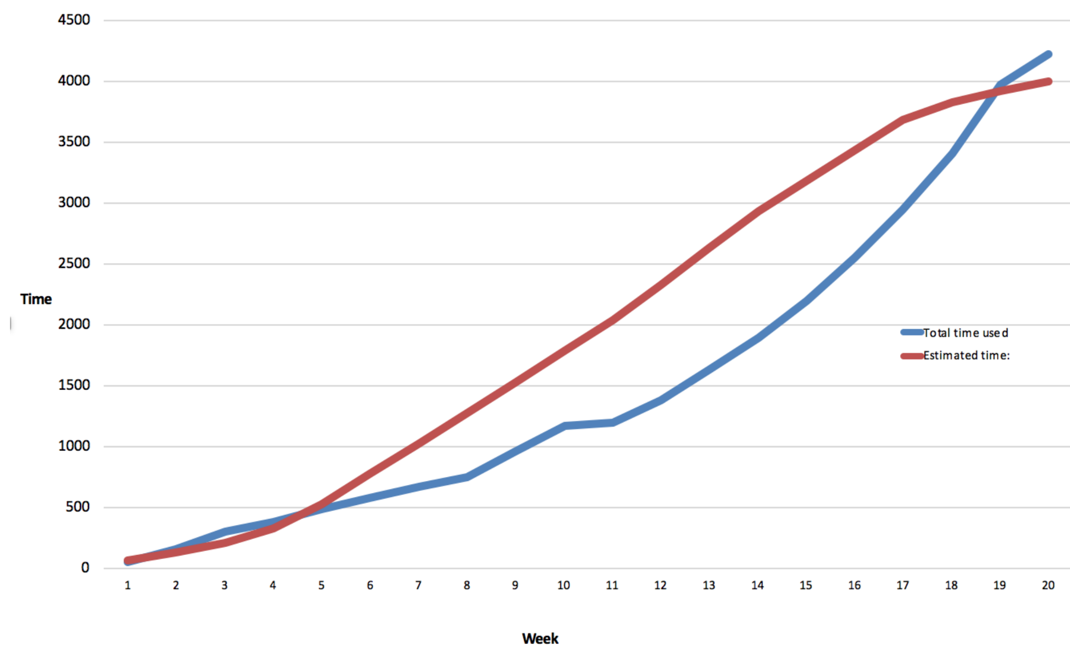

Figure 3.2: Example of an S-chart Hussein (2016)

3.4 Reporting progress

This section is primarily based on Hussein (2016). Depending on the project structure and how many entrepreneurs (vendors) that are involved will influence on how and whom are doing the project progress measure. In big and complex construction projects experienced people usually do the progress measure. The project managers usually collects information about project status by regular project meetings, briefings or reports, and in recent times internal digital information systems as well. In addition, the project manager and client will follow-up the progress on contractual level, Karlsen and Gottschalk (2005). Hence, the number of vendors involved determines the scope and form of the progress reports. This is one reason that it is hard to establish a general and consistent system for progress measurements, Gould and Joyce (2009).

Progress reporting is done in many ways with different measurements and information systems. Hence, the method and system vary depending on project complexity. The goal is a functional reporting flow to control and follow-up projects, Karlsen and Gottschalk (2005). Information can by given both in strict (formal) and non-strict (informal) formats. It depends on the organization structure. However, it will always be some hierarchy inside a project. In that case we use a formal structure with defined roles according to whom are responsible for the different activities. The informal structure may be when people talk together addressing daily activities. In a project the informal structure is important to get an early warning signal, Røsdal and Ørstavik (2011).

3.4.1 Project meetings

This section is primarily based on Røsdal and Ørstavik (2011) Inside a project team, to a large extent the information flow is done with meetings, Hussein (2016). In construction projects meetings are frequent and obviously important since this is the meeting place for all project participants. Project meetings will normally improve information flow and contribute to jointly problem solving. However, not every meeting is successful and don´t need to have the same function. Knowledge and experience from different people are often needed to solve difficult problems, and meetings are often an area where ideas and experience can be exchanged and then put into an action plan. According to Røsdal and Ørstavik (2011) the purpose of meetings is to:

- Control, follow-up, recourse allocation and set deadlines.
- Exchange information and make decisions.
- Consider, meetings are also used to assess employees and management.
- Create affiliation and enthusiasm with the project team.

3.4.2 Reports

Written reports could include information about status, progress, error and trends, Karlsen and Gottschalk (2005). Reports should be delivered as often as necessary. However, the need for reports should be considered depending on a cost-benefit analysis since it is costly to produce reports. Content and duration of a report will also change depending on the recipient, Røsdal and Ørstavik (2011). Construction drawings are also included in the reports. They should be updated immediately after changes, since they are the foundation for the project, Hussein (2016). It is very important to notice that reports in some cases are subjective (and maybe biased), and therefore less reliable. A reason for this can be that we in many cases need to estimate progress (best estimate) without proper information, or the similar problem may happen when important information may be omitted from the report. In our case, the builder is regulated to report a waste plan prior to construction start and a waste report after project implementation. However, Statsbygg with a special focus on sustainable, also reports sustainability in form of Greenhouse Gas emission from material use, transport and stationary energy, Statsbygg (2018a). Statsbygg is a state-owned management company under the Norwegian Ministry of Local Government and Modernization and has the task of implementing government's building and property policy Statsbygg (2018b). Statsbygg´s own representation of this is shown in Figure 3.3, where comparison of various project after implementing measures to reduce emission is shown.

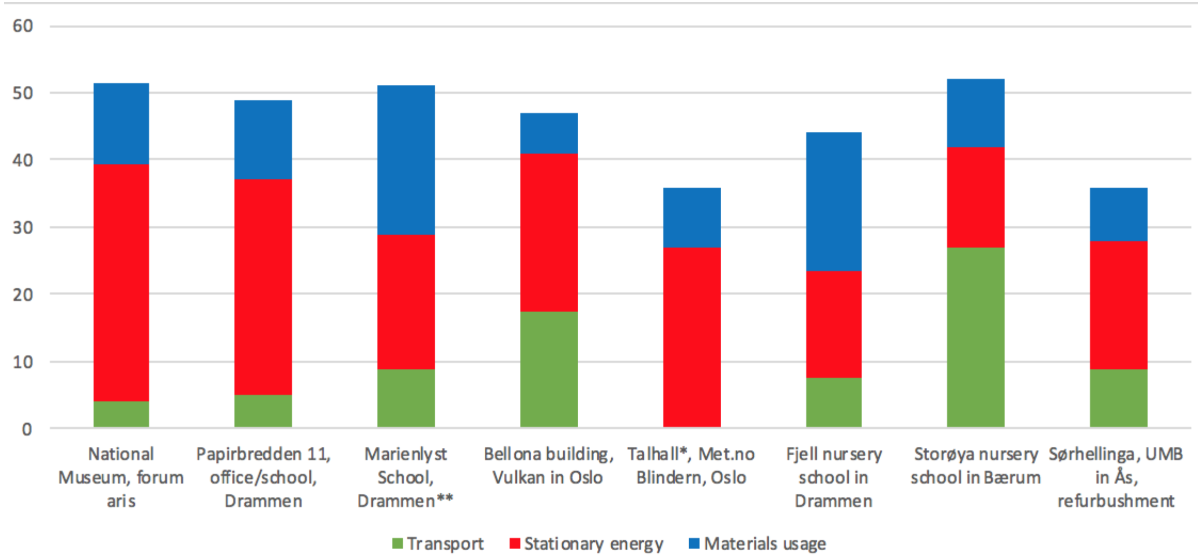

Figure 3.3: Greenhouse gas emission for buildings analyzed using klimaregnskap.no Statsbygg (2018a) *Transport not included because building is not staffed. ** Materials usage includes expanded clay aggregate for drainage and "insulation" around the building.

3.4.3 Communication

By looking on just the communication in a project, it is possible to see if the project progresses as intended. Hence, it makes it possible to get an early warning signal about the project progress (Hussein (2016), Røsdal and Ørstavik (2011)). To have enough information the project team needs to set rules for reporting and communication between every contractor in the project, Rolstadås et al. (2014). As mentioned earlier, sharing of experience can give a better basis for decision making. To have good working conditions where the workers trust each-other the key is good communication and that relationships improve as the project goes. However, the degree of relation a person gets in a project vary on the personality. Therefore the focus in the project should be on communication and respect. The biggest challenge in construction project is communication between different entrepreneurs and workers, Gould and Joyce (2009). Between workers it can also be a problem that many workers do not speak the same language, and therefore have a problem with communicating with each-other.

3.5 Challenges with measuring and reporting

The prerequisite for control of progress and performance is measuring the real changes in the project. However, the challenge is to identify performance measures that effectively can show progress in activities. Since progress measures often must use soft data (informal and/or non-precise data), it can be resource and time consuming to report the data in a formal setting. Another problem with soft data is that it is subjective, and therefore may not be completely correct. Project information has a huge amount of papers and digital documentation in addition to informal communication. This distribution of information can make it hard to know whom have control in the project, and therefore key information can be missed when the decision is made. Based on this communication problem, use of automatic systems for measure of project progress can make it more certain that needed information always is available.

3.6 Laws and regulations for waste management at construction sites

This section are based on Norwegian laws and regulations towards construction projects, DiBK (2018). TEK Sections 9-5 to 9-9 set requirements for the preparation of waste plan, environmental management and final report, which deal with the amount of waste and waste disposal in construction, rehabilitation and demolition projects over a certain major stage. Minimum 60% of the waste weight must be sorted by source or type. Thereafter are the provisions for hazardous waste determined by Chapter 11 in Norwegian Laws, NorskeLover (2018). It is said that hazardous waste should be mapped, sorted out from other waste fractions and handled in accordance with regulations in Chapter 11, NorskeLover (2018). The purpose with the rules are to make sure that the construction waste becomes environmentally and economically soundly handled. The rules works to:

- Prevent dispersion of environmentally hazardous substances.
- Reduce the amount of construction waste that occurs.
- Increase the rate of reuse and recovery.
- Prevent illegal disposal of construction waste.

The Construction Act Section 15-3 requires that local authorities prioritize the monitoring of waste plans and environmental sanitation payments, DiBK (2018). In this guidance it was advised how the supervision of waste rules can be carried out in practice.

Chapter 4

Sustainability, supply chain management & procurement

This chapter gives a review of the theory behind sustainability, supply chain management and procurement to provide a foundation for the analysis and discussion.

4.1 Environmental sustainability

Sustainability has become a more and more used concept the last thirty years with good reasons. The first time sustainable development was defined was by the Brundtland Commission (World Commission on Environment and Development) as:

> *Development that meets the needs of the present without compromising the ability of future generations to meet their own needs* Brundtland (1987).

This report addresses issues related directly or indirectly to sustainable environmental development. The report addressed a new way of looking on environmental and economic dimension as merged tools in the decision making process Brundtland (1987) by showing that a change towards a strategy with a more sustainable future would not come in the way for the economy. A major message is that economic and ecological concerns not necessarily are in opposition to each other -rather the opposite, Brundtland (1987). As a dissemination of the Brundtland Commission, the triple bottom line was developed, with a focus on economic, environmental and social performance, Elkington (2002). The ideas behind that economic, environmental and social performance can go hand in hand, are the foundation for where the industry can adapt and improve (see Figure 3.1).

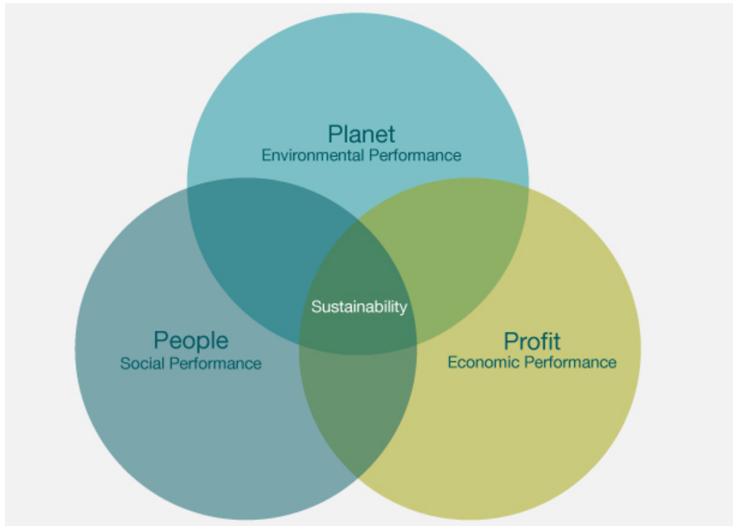

Figure 4.1: Representation of the connection between economic, environmental and social performance Elkington (2002)

4.1.1 UN Sustainable development goals

As an dissemination of the Bundtland Commission, a new agreement between governments, businesses and societies was prepared by UN in 2015. In this agreement seventeen sustainable development goals (SDGs) were made, and with a goal of reaching them by 2030, UN (2015). Figure 4.2 show all the SDGs. By going through all seventeen goals it is possible to see that not all of them directly consider all three dimensions of sustainability, and not every goal will be an issue for every industry. However, by looking on the goals that can be categorized within this category of concern, the environmental aspect apply for the following; clean water and sanitation, affordable and clean energy, sustainable cities and communities, responsible consumption and production, climate action, life below water, and life on land. A reason for making this agreement was that UN felt a need to make a response to the increasing fear for man-made climate changes and environment pollution problems.

> *The hope is that the SDGs will help the world to move towards a more sustainable trajectory* Sachs (2012).

An important aspect with the SDGs are that they are not regulated by laws. However, authorities are expected to take ownership and make regulations on a national basis to reach the seventeen SDGs, UN (2015). As for countries themselves it means that they have the responsibility to make regulations that control the progress towards the goals.

Figure 4.2: UN Sustainability Development Goals UN (2015)

4.1.2 Environmental management systems and reporting

To be able to measure environmental sustainability performance it is a need for regulations, standards, guidelines and agreements as tools for businesses and governments. Today every company has an increasing pressure to initiate actions towards a higher standard of sustainability. In many cases this pressure comes from governing agencies, customers and stakeholders. The trend is that focal companies are more motivated to choose suppliers that perform according to guidelines set by environmental and social standards, Seuring and Muller (2008). This is done through agreements between businesses, governments and environmental organizations and membership in coalitions. Focal companies can therefore assure that the activities they are involved in support the environmental sustainable development. A dilemma when working with environmental sustainable development is that some companies cheat in order to seem better than they are in reality. A company will always promote their best side. Year by year the number of standards, regulations and agreements increase. The most known agreements are the SDGs, ISO14031 Environmental sustainability, Global reporting initiative (GRI) and the World Business Coalition for Sustainable Development (WBCSD).

ISO 140xx series

The ISO 14001 series are related to environmental management with the purpose to help businesses to minimize their impact on the environment. The ISO 14001 standard is the basis for many businesses environmental management systems (EMSs), ISO (2015). A other ISO series that concern environmental performance evaluation (EPE) is the ISO 14031 that are a more general sustainability standard series than ISO14001. These two series of standards provide guidance to design of EMS and use of EPE. EPE permits measure, evaluate and communicate their environmental performance with the use of key performance indicators (KPIs) and is therefore often used to support an EMS, ISO (2013). The ISO14031 is one of the most used standards and is often used as a baseline in other environmental reporting guidelines, e.g. WBCSD´s, eco-efficiency indicators framework. These are all tools for companies to assess their environmental performance against its own environmental policy, objectives and targets. However, companies are not obligated by law to follow or include the ISO standards. This is maybe a reason for why standards as ISO14001 have not been implemented widely across the industries.

Global Reporting Initiative

The Global Reporting Initiative (GRI) is an:

> *International independent, non-profit standards organization aiming to help businesses, governments and other actors to communicate and report their impacts on sustainability, i.e. environmental and climate change* GRI (2017b).

The GRI standards make it possible to measure and disclose a business most critical impacts in form of the triple bottom line both positive and negative impacts. In many ways GRI standards work in a similar way as the ISO14001 standards, but by including all parts of the three aspects of sustainability. The 300 series GRI Standards focus in special on the environmental pillar of sustainability. The goal behind the GRIs is to include sustainability reporting into the decision-making processes of the companies in order to work towards a more sustainable future.

> *The comprehensive G4 Sustainability Reporting Guidelines is the most used reporting standard in GRI. It provides the business with a tool to meet society's demand for transparency. The goal of the G4 Guidelines is to help reporters to prepare legit and robust sustainability reports* GRI (2017a).

World Business Council for Sustainable Development

The World Business Council for Sustainable Development (WBCSD) is a global organization that collate with over 200 companies. The purpose is to give a quicker change to a more sustainable world. This provide businesses with a global network that work towards the same goals (UN SDGs) and deliver solutions to solve the challenges within sustainability, WBCSD (2017). A known tool developed by WBCSD is the eco-efficiency indicator framework, which are a set of indicators that cover different environmental aspects related to products and services (similar to ISO´s KPIs). For example WBCSD advises companies to use ISO14031 EPEs to select the businesses KPIs, Verfaille and Bidwell (2000).

Greenhouse Gas Protocol (GHG Protocol)

In the end of the twentieth century discussions about greenhouse gas (GHG) was upcoming, and in this period WBCSD, World Resource Institute (WRI) and other actors established a standardized method and guideline to report GHG emission. Since the first GHG Corporate Accounting and Reporting Standard was presented in 2001 it has been updated regularly with new standards, guidelines and calculation tools to measure carbon footprint and the benefits of climate change mitigation projects.

> *The purpose of the GHG Protocol is to provide governments and businesses a measurement tool to quantify GHG emissions and become more efficient, resilient and prosperous (GHG Protocol, 2017).* GHG (2017).

One of the new trends in case of sustainability is that stakeholders more and more request information about the companies GHG emissions. The attitude that a business should be green is growing. Therefore we can assume that if a company can choose to collaborate with different companies, it will choose the one with the smallest carbon footprint in order to gain goodwill inside politics, governments, and locals. By that every company can gain from following reporting standards in the GHG Protocol, since their reputation for being transparent depend on the reporting numbers. The GHG emission reporting system can be separated into three different scopes according to which GHG emission the business can control and what they can influence. This is done with the purpose of avoiding duplicated counting of emissions, and give the business more control of their own performance where they can influence the result. The three scopes are:

1. Direct GHG emissions:

   (a) Defined as emissions from sources that are owned or controlled by the organization,

   E.g. use of fossil fuel at facilities (stationary combustion) and use of fossil fuel in transportation (mobile combustion). The stationary and mobile combustion sources will for most businesses be most relevant in scope 1.

2. Energy Indirect GHG emissions:

   (a) Defined as emissions from the consumption of purchased electricity, steam, or other sources of energy (e.g. chilled water) generated upstream from the organization.

   Measurement and report of emissions are from purchased or acquired electricity, steam, heat, and cooling.

3. Other Indirect GHG emissions:

(a) Defined as emissions that are a consequence of the operations of an organization, but are not directly owned or controlled by the organization.

In other words, emissions from across the entire value chain of the business (e.g. employee commuting, third-party distribution and logistics, production of purchased goods, emissions from the use of sold products, etc.).

4.1.3 Green-washing

One of the challenges with today's focus on sustainability is companies intention for being green without really going for it. Nearly all businesses work towards bigger cash-in and better cash-flow. Therefore it would in some cases be companies that imply being more green than they really are. This term is called green-washing, and was first coined by Jay Westervelt in the 1980s regarding the hotel industry's reusing of towels practice, Watson (2016).

> *At a resort in Samoa guests were asked to pick up their towels for reuse with the intention of reducing ecological impact of the hotel, see Figure 4.3. Westervelt opined that the actual objective of the campaign was increased profits. Thus, he labelled this practice as outwardly environmental conscious acts with a greater, underlying purpose of profit increase* Watson (2016).

Figure 4.3: The start of Green-washing (Arc Reactions Inc. 2018)

Today, the term is used in connection to the public´s limited information about corporate environmental performance such that corporations can manipulate the dissemination of information to the public, Lyon and Maxwell (2006). Lyon and Maxwell define green-wash as:

> *The selective disclosure of positive information about a company's environmental or social performance, without full disclosure of negative information on these dimensions. Selective disclosure of positive information about a company's environmental or social performance is not necessarily illegal as reporting programs allow participants great flexibility in their reporting methods* Lyon and Maxwell (2006).

4.2 Green supply chain management & procurement

Green supply chain management (GrSCM) is defined by Srivastava as:

> *Integrating environmental thinking into SCM, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life.*

Therefore it is possible to say that GrSCM considers environmental aspect in all activities in the supply chain. The purpose of GrSCM has to sides: helping towards a better environmental performance and creating opportunities for businesses. According to Srivastava, it is a business driver and not a cost center. Which means that investing in a green supply chain can be resource saving, waste eliminating and productivity improving, Porter and Class (1995). Srivastava suggests three approaches in GrSCM:

1. Reactive
    - (a) The reactive approach is the least committed, allocating minimal resources to environmental management, product labelling and use "end of pipeline" initiatives to reduce their environmental impact of production.
2. Proactive
    - (a) The proactive approach implies a modest resource commitment to initiate the recycling of products and green product production, thus preempting environmental laws.
3. Value-seeking
    - (a) Value- seeking companies are integrating environmental activities (e.g. green sourcing and ISO implementation) as strategic initiatives into their business strategy.

Preuss (2005) takes about five steps to achieve a greener supply chain; *[1] due to the scale of the supply chain impact and the strategic importance, the buying company could address the supplies to be purchased; [2] the manufacturing process could be addressed, e.g. by requiring accreditation to an environmental standard or introducing an environmental policy by the company's suppliers; [3] environmental criteria could be included in the supplier assessment; [4] the supply chain managers could get involved in internal environmental protection initiatives, e.g. environmental programs or management systems; [5] explore downstream activities, such as product recovery or recycling of excess material.*

4.2.1 Green purchasing

Companies make it more visible that they have goals within environmental performance goals. However, to succeed with their goals they need to integrate the goals with the purchasing activities, Carter et al. (2000). Purchasing have high potential to contribute to the company's overall environmental performance since it is possible to identify; greener packing, ultimate disposition of materials and components. Carter et al. (2000) explains environmental purchasing as the purchasing's involvement in supply chain management activities in order to facilitate recycling, reuse, and resource reduction. However, the correlation between sustainability and profitability is unclear and as Seuring and Muller (2008) says that; *higher cost is the most significant barrier to sustainable supply chain management.* Preuss (2005) says that the biggest gain by a sustainable focus is the possibility to influence other companies. For example if a company wants to offer its customers a more sustainable product, they also require higher standards of their suppliers. As a example we can see how this change the thinking at the supplier. When a company wants to offer its customers more sustainable products, the required standard on products becomes a concern for the company's suppliers. Not only the company's first tier, but the immediate suppliers' suppliers, the second tier, and ultimately, the whole supply network. This way, the focal company's supply function reaches far beyond its own supply chain, thus the green multiplier effect.

4.2.2 Green operations and environmental management capabilities

The scope of green operations (GOs) goes from development to management of the entire project life cycle involving environmental practices as eco-design, production, recycling, and reuse with focus in minimizing the expenses associated with manufacturing and use Wong et al. (2012), and can be represented by Figure 4.4 The literature switch between process and product-oriented environmental practices. Process-oriented is concerned with reducing the adverse environmental impact in processes ranging from production, distribution, to end-of-life product management. This is most relevant in our case. The other side is product-oriented which is concerned with reducing the environmental burden with less use of hazardous and nonrenewable materials in the development, considering the environmental impact in design, and material used, Wong et al. (2012). Today the construction industry does not need to think about using a design that is green in the whole life cycle, so here the industry has a huge potential by using the Green design mindset. While thinking about green design, it is seven principles; end of life - recycling, green credentials, sustainable sourcing, sustainable material choose, sustainable engineering, education and outreach of stakeholders, and marketing and branding the sustainable credentials with integrity, Bartolo et al. (2013).

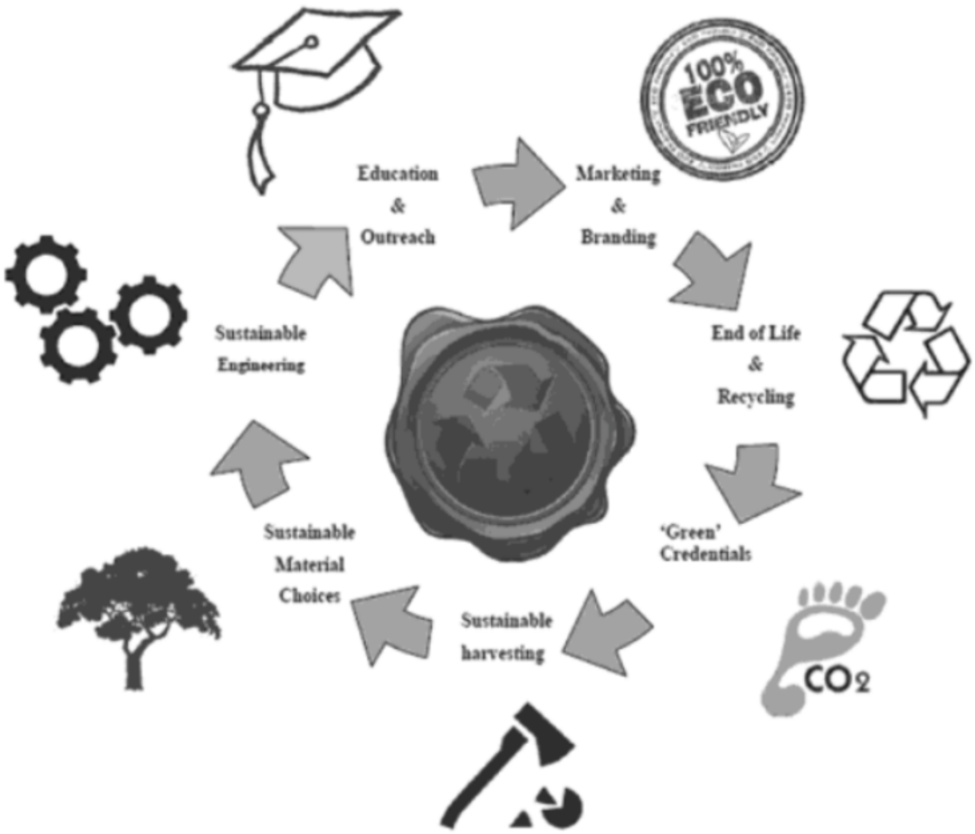

Figure 4.4: Shows the principles for a process to more sustainable products Bartolo et al. (2013)

4.2.3 Eco-efficiency

Eco-efficiency is a goal for several companies based on the assumption if they become more environmental sustainable, they will also make more profit. The concept is defined by the Wold Business Council of Sustainable Development (WBCSD) as: *The delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth's estimated carrying capacity* Schmideiny (1992). The objective is making more value out of less environmental impact. This concept is the biggest incentive for working towards the UN SDGs. It is also exciting to observe that several big companies are actively incorporating UN SDGs in their day-to day business.

Chapter 5

Waste analytic and sustainable construction

This chapter goes through the literature about waste handling and sustainability towards the construction industry. In particular cost of waste, lean, waste analytic, expected values for waste and some ways to use waste measuring are considered.

5.1 Waste in construction projects

As the settlement pattern in the world changes, the need for new settlements is also changing. Through centralization and urbanization the need for better solutions in construction work has increased, and by this the concern about environmental impact are growing as shown in Chapter 4.1 and 4.2. This has lead to an enormous pressure from government and environmental agencies for entrepreneurs to minimize construction wast and adopt more sustainable practices, Bilal et al. (2016a). In this thesis two different mindsets for solving this problem are explained. The first one is LEAN practice and the second is waste analytic. They will both be set in connection towards construction projects in this thesis. Today's practice of waste management is based on a more and less ad-hoc method by looking on waste after it has occurred. This means that it is nearly impossible to change the behavior in running projects. In most cases the system for waste management are based on reports, oral communication, and queries on small amounts of current and past waste data. Data like this can give information about project progress towards a sustainable viewpoint, and give understanding on how a particular construction process generate waste, Lu et al. (2011).

To be able to analyze the cost of waste it is a need to give it a price. In this case the prices are based on Renova (2017). In Table 5.1 prices based on weight and category are given. A study

Table 5.1: Price list for waste delivery Renova (2017)

Waste category	Lower limit	Greater limit
Attendance price	400 kr within 4-5 tonnes	
Mixed scrap, Wood, Electric, Plaster, Non-flammable, Metal, Furniture	2,00 kr/kg	
Garden waste	1,80 kr/kg within 2,5 tonnes	1,60 kr/kg greater than 2,5 tonnes
Pure concrete, stone, soil etc	Greater than 500kg: 1,40 kr/kg	Greater than 2,5 tonnes: 1,0 kr/kg Greater than 5 tonnes: 0,80 kr/kg Greater than 10 tonnes: 0,4 kr/kg Greater than 20 tonnes: 0,5 kr/kg
Wood, if more than 2.5 tonnes	Grater than 2,5 tonnes: 1,60 kr/kg	
Impregnated wood	2,70 kr/kg	
Paint, oil, sealant etc.	14,0 kr/kg	

conducted by COWI stated that the potential for sorting through both recycling at site and at recycling facilities is 92% for new-building and 91% for retrofit projects, Bjerkli and Spøtvold (2015).

5.1.1 Lean

When dealing with waste, it is not possible to come outside lean thinking. Lean is a central term in Japanese manufacturing management with a out-spring from the Toyota Production System. They say that waste is the enemy for effective processes.

> *Lean is often used as term to eliminate waste in all forms, including defects, required rework, unnecessary processing steps, unnecessary movement of materials or people, waiting time, excess inventory, and overproduction. Saying it easy; getting more done with less spending* Evans (2014).

Hence, the key for lean is to focus on: reducing hand-offs (1), eliminating steps (2), performing steps in parallel rather than in sequence (3), and involving key people early (4).

As reduction of the seven forms of waste is the key in Lean Production, an example of reduction of each part of waste will be given based on Wig (2014). Transportation of material could be done by choosing local suppliers based on minimum fuel consumption. To reduce stocks the best way is using just-in-time methodology. However, in a construction project an issue is to provide materials into the building stock after they are built. The amount of overproduction in construction depends a lot on experience. Thus it is beneficial to do parts of the job before the need arises. In other words, be in advance. When it comes to less defects, implementing quality controls is a key. However, choosing how and whom that should do the control is harder. Generic it is possible to say that everything should be verified as early as possible. Therefore the workers should be included as a control mechanism. At Toyota workers were obligated to stop production when a defect occurred. The reason for this was to learn from their failure. This give a system focus on production. In stead of focusing on doing each sub activity the fastest way, the whole process should produce at maximum speed. This to give the overall system the optimal performance. Toyota also saw the benefit of focusing on customers needs and value creation for customers. Hence, they wanted to eliminate all activities customers did not ask for. By all this the production was more flexible and less vulnerable for changes in the design when the stock always was as small as possible. This also gave a better cash flow. Through contentious improvements they always tried to achieve perfection and good enough quality in the production.

Using lean

When using lean it can by found many recipes to what should be included. However, in this thesis the following five steps will be used to gain better understanding, Wig (2014):

1. Optimizing customer value for products or services for deliveries. Produce what customer/user need - not more - not less.
2. Study and understand work processes to understand which parts create customer value.
3. Create flow in processes by removing stocks, stops and bottlenecks.
4. Create pull, where the next activity always is ready to do their work.
5. Create a state of continuous improvement and thus continuous learning.

To sum up by focusing on construction flow, it is possible to reveal all other problems underlying the surface. It can be compared to temporarily lowering the water level to reveal reasons and risks for grounding of ships. For each time this is done, it is possible to gain better construction flow since buffer stocks, bottle necks and reefs are removed, Wig (2014).

5.1.2 Waste analytic

To understand the use of waste analytics it is necessary to understand the term. According to Bilal et al. (2016a); *Waste analytics is mainly concerned with holistic design of construction waste. Specifically, waste analytics is the process of proactively analyzing disaggregated and huge construction data-sets to uncover latent trends or non-obvious correlations pertaining to design, procurement, materials, and supply-chain within the construction delivery process, which lead to construction waste during the actual construction stage. Waste analytics, by comparison, investigates waste-related data in a more forward-looking and exploratory way.* This is done by analyzing historical data, it enables the development of robust predictive models for construction waste estimation. Since construction projects are demanded to deliverer waste plans before project start, the need for tools to estimate waste have increased. Therefore nothing should prevent project participants to leave tracking the waste. It could have a large potential in case of decision processes and learning towards new projects. Another reason is the regulations that say projects need to provide waste reports in order to obtain approved certificate for project completion. The framework to analyze waste is based on the methodology found in Bilal et al. (2016a). The waste analytic approach propose a data-driven decision making process to reduce the amount of construction waste. It is proposed to use waste management during the design and construction phases of the project by using waste estimation models proactively to inform about the waste for a given construction design. It should also be possible to use a similar model and approach to track progress in a project since the model should in theory know how much waste a given construction would produce.

Waste estimation model

When doing waste estimation the waste generation rate (WGR) is a useful variable for understanding waste management. To investigate WGR there are two approaches classifying waste into different categories or treating them as a whole, Lu et al. (2011). A way to categorize them into different classes of waste is based on the European Waste catalogue. The European Waste Catalogue has made the following classification for construction and demolition waste:

- Concrete, bricks, tiles and ceramics.
- Wood, glass and plastic.
- Bituminous mixtures, coal tar and tarred products.
- Metals.
- Soil, stone and dredging spoil.
- Gypsum-based construction material.
- Other construction and demolition waste.

WGR has to be measured in order to be used in comparable cases. The normal measures for WGRs are Lu et al. (2011):

- Percentage of material purchased.
- Percentage of material required by the design.
- kg/m^2 of GFA (gross floor area).
- m^3/m^2 of GFA.

According to Lu et al. (2011) they used the following equation to calculate the WGR:

$$WGR = \frac{\sum_{i=1}^{n} m_i}{A} \tag{5.1}$$

Where m_i is the quantity of waste for one container, i is the number of the container, n is the total number of containers, and A is the area chosen for sorting and weighing. This model will be the foundation for the work in the modeling part of the thesis.

5.2 Potential with a sustainable mindset

As mentioned earlier, sustainability has become increasingly important which should be a big motivation for being smart/good considering recycling. This can be done by choosing materials by a sustainable and technical view and by re-using materials with high commodity price and longevity. From an environmental perspective we should also reuse materials where there is limited access to raw materials and materials with energy-consuming production methods.

In connection to sustainable resource handling Wijkman et al. (2016) conducted a study to find the consequences of three material resource-efficiency scenarios:

- Minimize waste scenario: Obtaining a less material-wasteful economy, by becoming 25% more material-efficient.
- Circular material scenario: Obtaining a more circular economy by substituting half of the virgin materials used with recycled materials.
- Performance economy scenario: Obtaining a more performance-based economy by doubling the product-life-time of long-lived consumer products.

These three scenarios were simulated and came with many positive results, see Figure 5.1. These

	Minimize Waste Case	Circular Material Case	A more Performance-Oriented Economy Case	All Three Material Resource Efficiency Scenarios Combined
Emission Reduction	- 2%	- 2%	- 3,5%	- 7%
Additional Jobs	+ 10,000	+ 5,000	+ > 30,000	+ > 40,000
Trade Balance Effects	- 0,3 of GDP	No change	+ >> 2% of GDP, decreasing over time	+ > 2 % of GDP, decreasing over time

Figure 5.1: Shows the results from the Wijkman et al. (2016) study

results clearly show the potential both according to climate and economy. The economic benefit would be the main persuasion foundation motivating companies to be more sustainable. This is obvious considering that every company want best possible cash-flow.

5.2.1 Expected values for waste

To be able to analyze the waste towards a normal we will use the values given by Statistics Norway to Ottesen and Milli (2016) both for retrofit and new-buildings, see see Table 5.2 and Table 5.3.

Table 5.2: Expected value for waste for a retrofit construction project Ottesen and Milli (2016)

Retrofit				
Fractions	Small housing	Large housing	Commercials	Other buildings
Asphalt	0	0,15	9,80	16,68
Concrete	42,27	38,15	54,70	45,47
Contaminated Concrete	0	0	3,53	0,55
EE-Waste	0,33	0,36	1,57	2,19
Plaster	4,33	3,47	8,00	5,99
Glass	1,62	1,40	1,30	0,25
Metal	2,52	6,66	7,47	16,21
Paper	1,32	1,17	2,40	2,85
Plastic	0,49	0,21	0,16	0,70
Wood	33,12	11,49	13,35	17,23
Mixed Waste	45,55	26,97	27,84	24,69
Other	0,57	0,00	2,43	8,80
Hazardous waste depending on size and type of project 1,99				

Table 5.3: Expected value for waste for a new-building construction project Ottesen and Milli (2016)

New-building				
Fractions	Small housing	Large housing	Commercials	Other buildings
Asphalt	0	5,60	6,80	82,63
Concrete	1,72	16,71	18,47	16,36
Contaminated Concrete	0	0	0	0
EE-Waste	0,08	0,14	0,64	0,09
Plaster	4,17	6,22	4,10	4,54
Glass	0	0,03	0,18	1,04
Metal	0,40	2,30	3,79	4,22
Paper	1,52	1,77	1,03	2,96
Plastic	0,44	0,75	0,24	0,39
Wood	12,33	16,36	13,02	16,22
Mixed Waste	17,61	14,25	16,76	16,09
Other	0,00	0,21	0,40	1,97
Hazardous waste depending on size and type of project 0,23				

This models is well suited towards quality and cost. However, it says little about time. An way to do this can be to use the theory that state the connection between the various construction phases or processes of a construction project. By this it is possible to know which specified input and output relationship characterizing each phase/process. The input will typical be materials, tools, and personnel to carry out the work. For the output we will have two categories; (1) value creation, we finish a construction process or phase, and (2) waste, each construction process or phase will generate a given amount of waste that may or may not differ subject to the various phases. Figure 5.3 shows the main idea for the thesis studying input and output for a construction process.

5.3 Usage of waste measuring

The main idea for the proposed method is that in the various construction phases or processes a construction project will have a specified input and output relationship characterizing each phase/process. How unique such characterizing will be is one of the research question to be addressed in this work. The input will typical be materials, tools, and personnel in order to carry out the work. For the output it is two categories; (1) value creation when we finish a construction process or phase, and (2) waste, each construction process or phase will generate a given amount of waste that may or may not differ subject to the various phases. Figure 5.2 shows the main idea for the thesis studying input and output for a construction process. We may in-

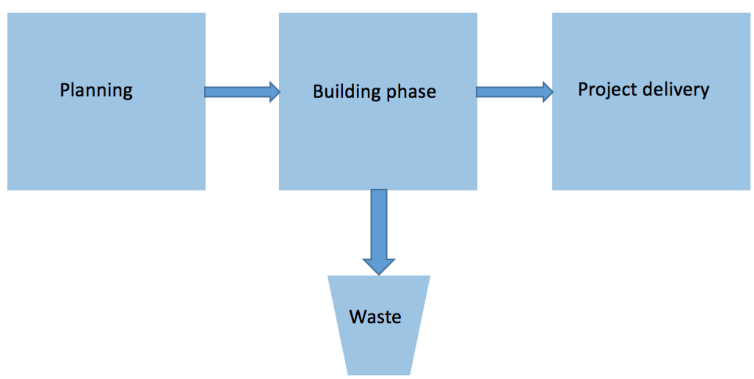

Figure 5.2: Simplified input and output model in construction projects

crease the level of resolution of Figure 5.2 in order to be more specific on the input and output relationships for the various construction processes or phases. In Figure 5.3 it is proposed to divide the waste into different classes based on content and type of material. The proposed hypothesis is that by analyzing the waste from construction processes, it is possible to estimate the progress and thereby the value creation for the total construction project. In order to more precisely estimate the project progress based on waste measurements, it is suggested to divide each construction phase into sub-processes and select appropriate waste measurements that uniquely characterize the process. Already at this stage the value of good measurement sensors that are able to discriminate and quantify the various objects of interests is important.

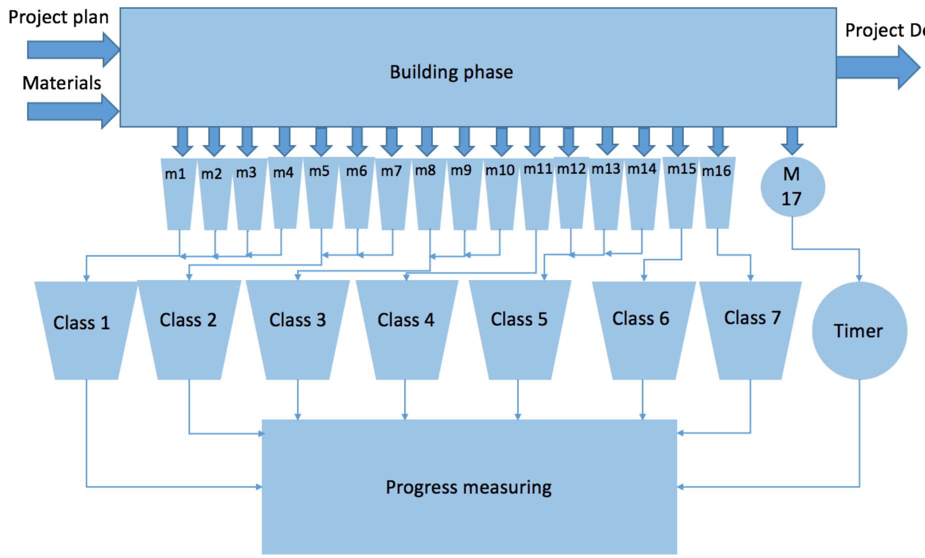

Figure 5.3: Measurement and classification of waste into classes in order to estimate project progress

5.3.1 Assumptions

To limit the simulation opportunity in this thesis a simplified model is made by the overall construction process assuming that work in the various sub processes are done chronologically and not in parallel. This assumption is introduced to make sure that the logic's behind the simulations work according to the chosen rules. However, if sensors as RFID tags for geo-referencing is used, it would be possible to consider parallel sub processes on different locations inside the construction site. It is also assumed that incoming data comes as *kg/waste class*. In reality this has to be done by appropriate sensors either by e.g. image recognition using e.g. computer vision and/or hyperspectral imaging, and/or simply by waste sorting with weight and volume measurements. With increasing focus on recycling, a waste sorting system may be easiest to implement. Finally, it is assumed that materials that arrive at the construction site are either used for value creation or being thrown away as waste. Currently, it is not take into account surplus material that will be used at other construction sites. At this stage it should be assumed knowledge of the content of the waste that goes into the dumpster, that is, so it is availability to discriminate and quantify the waste. In future work it is proposed sensors that are suitable for this purpose. Of course it will be sensor noise, and errors associated with these sensors. To be able to estimate the progress of the construction construction process the defined sub-processes from Chapter 3.2 is used.

5.3.2 Classes of waste

As mentioned waste will be categorize into classes based on method of recycling and removal. From the Figure 5.3, M1-M16 are divided into 7 classes. The classes are chosen based on Lu et al. (2011).

- Concrete, bricks, tiles and ceramics. -> Class 1.
- Wood, glass and plastic. -> Class 2.
- Bituminous mixtures, coal tar and tarred products. -> Class 3.
- Metals. -> Class 4.
- Soil, stone and dredging spoil. -> Class 5.
- Gypsum-based construction material. -> Class 6.
- Other construction and demolition waste. -> Class 7.

When it comes to the model shown in Figure 5.3, it is suggested to sort out these seven classes, and monitor them towards construction processes in a real-time system.

5.3.3 Material flow during construction project

To be able to track waste during a project, it is needed to know how material flow during the different project phases. According to Wærner (2008) waste will be generated this way in a construction project, see Table 5.4.

Table 5.4: Material flow in a construction project Wærner (2008)

Excavation	Groundwork	Structural Work	Siding	Interior	Furnishings
Stone	Stone				
	Dangerous waste	Dangerous	Dangerous	Dangerous	
	Metal	Metal	Metal	Metal	
	EPS/XPS	EPS/XPS			
		Roofing	Roofing		
			Plaster	Plaster	
			Insulation	Insulation	
			Plastic	Plastic	Plastic
	Wood	Wood	Wood	Wood	
			Glass		
				EE waste	
				Cardboard	Cardboard

In our chosen methodology for a decision-support system, a main objective is to make a connection between the waste classes and the construction processes. Hence, in this study it will be based the construction processes on theory from Section 3.2. As for the waste classes it will be based on the categories mentioned earlier in this chapter.

Chapter 6

Case study based on real data from the industry

This Chapter will present waste handling from five different construction projects. This is first done by giving some information about each project before results and analyses are given.

6.1 Introduction to case projects

The case study are based on five different real building projects, where each project can be placed in one out-of three categories, see Table 6.1. The three categories are conventional new-building, retrofit building and prefabricated building projects. When it comes to the information collection, the received information has to be treated confidential when it comes to specific project identification and owner. Hence, the projects are made anonymous and hidden behind generic names. In the Appendix B detailed waste reports from each project can be found. Each of these building categories generate waste in different ways. It will be conducted a study of the different approaches towards sustainability in conjunction to waste handling. Of the five projects two are conventional new-building projects, two are prefabricated projects, and one is a retrofit project. The summary of the findings from the five projects can be found in Table 6.2.

Table 6.1: Introduction to projects according to name, type, size and building year

Project	Size (m^2)	Finished	Amount (Tonnes)	Construction type
Grocery store	6000	2016	46,508	Prefabricated
Office	650	2017	12,851	Conventional
Europris	1450	2016	13,96	Prefabricated
Apartment	300	2017	106,26	Retrofit
Factory	14600	2017	598,007	Conventional

6.1.1 Conventional new-building projects

The building method is conventional, which means that almost everything are build on the site. This means that all waste generated in the building phase are found at the construction site. Typical for conventional new-building projects, which is also the case here, is that the degree of waste sorting is high. Hence, normally a noticeable time is spent on the waste handling. It may therefore be less biases or errors when analyzing the waste data for this category.

Factory

This project is a large bread factory of 14600 square meters. The building method is conventional. When it comes to the design of the factory, it has a lot of open space, only few rooms and little need for windows. Hence, there is a low variability in the waste, which gives a high percentage of sorting in the project. However, at the factory the need for a well-working air ventilation system is huge since all the machines and ovens generate heat. The waste associated to the ventilation system is therefore one important waste class.

Office

This project is a medium size office of 650 squared meters. The building method is conventional. When it comes to the design of the office, it has a need for more separated working areas, including office spaces, meting rooms, etc. Hence, it can be more complex than a factory, which demands more planning when it comes to the spacing and complete ventilation system for the various rooms. However, as every conventional project the degree of waste sorting is high.

6.1.2 Retrofit building projects

When it comes to retrofit projects, it is very hard to give an estimate for what is a normal degree and amount of waste sorting. Each retrofit project will be strongly influenced by the materials chosen at the time of the original building process and/or possible later retrofits as well. As times pass by the materials change. If they used material that is easy to recycle, the sorting degree could be high. However, in this kind of projects it is never a guarantee for the waste sorting. New-building projects today are regulated to choose materials and building methods that make it easier to re-use or recycle material used. Hence, for later retrofits the situation may improve.

Apartment complex

This project is a pretty small project comparing the others with only 300 squared meters. However, since the amount of waste is higher than 10 tonnes, it is regulated with the same rules as the other projects. As other small projects it has the normal problem that the cost of sorting is very high compared to the total cost of the project. Therefore the time used to sort could have been reduced. As mentioned earlier the sorting of retrofit buildings is lower than new-buildings since it demands the right use of materials.

6.1.3 Prefabricated building projects

A prefabricated project has a huge advantage in the case of waste handling since much of the waste is already handled by the suppliers. The remaining waste that may vary at the building site may be hard to sort. This is one reason that it can be a lower degree of sorting in comparison with conventional new-buildings. The main advantage by prefabricated projects is the easiness in the building phase. You can assembly the buildings as a puzzle. However, we sacrifice some flexibility by using this building method.

Grocery store

This project is ordered for a grocery store with the total size of 6000 squared meters. It is module-based using prefabricated modules in the building phase. Hence, the total amount of waste for the project is pretty low. When it comes to the degree of waste sorting, the project is quiet good, especially taking into consideration that it is prefabricated. The reason for this is that much of the waste generated in this project never goes through the building site.

Europris

This project is a 1450 squared meter Europrise store. This project is unique in the sense of the small amount of waste, which makes it very hard to get a high percentage of sorting since most of the remaining waste cannot be sorted. Even if the project has a low degree of sorting, it has been a successful project in the case of waste handling with only 9,6kg waste per squared meter. Thereby it would be interesting to ask the question if a project with low degree of sorting on one hand and small amount of waste on the other is successful in a sustainable view?

6.2 Data collection

As mentioned in the introduction of this chapter, project name, action number and other information that may lead to the recognition of the project are treated confidential. The data collection started by mapping what information was necessary in order to analyze the waste from the construction process. After some discussion with Braaten (2017) it was agreed on that the following information was required; building size, building method, waste report, purpose for the building and confirmation that the project went as planned. The next step was to find collaborators for the projects. This was done by contacting Gudmund T. Sørensen (CEO Fazenda) and Håvard S. Braaten (founder of Concreto AS). Thereafter the project manager for each of the projects was contacted to gather the desired data. This gave a foundation for the analysis. This was done by using methods from the theory conducted in the literature search, and then adapt the real project data to the methods for comparison and analysis.

6.3 Findings from waste reports

In order to make it easy to compare the results in all five projects the findings from each waste report are summarized into Table 6.2. The total amount, mixed and sorting degree of the waste are to be considered before they are measure according to two categorizes; sustainability and amount of waste.

Table 6.2: Summary of the waste reports for the projects

Project	Grocery store	Office	Europris	Apartment	Factory
Size m^2	6000	650	1450	300	14600
Wood	20,24	4,05	5	13,08	240,01
Paper and cardboard	0,148	0	0	0	20,98
Glass	0	0	0	0	0
Iron and other metals	2,48	1,25	1,56	0,2	49,27
Plaster-based materials	5,22	1,95	1,28	10,4	106
Plastic	0,55	0,35	0,06	0	24,28
Concrete, brick, etc	0	0	0	5,08	0
Contaminated concrete, etc	0	0	0	0	0
EE waste	00	0	0	0,9	1,49
Heavier building materials	0	3,8	0	0	81,24
Other noncombustible	6,73	0	0	26,6	0
Polystyrene EPS	3,18	0,3	0	0	1,92
Dangerous waste	0	0	0	0	5,077
Mineral wool/Insulation	0	0	0	0,52	3,6
Mixed waste	7,96	1,115	6,06	49,48	64,14
Total waste	46,508	12,851	13,96	106,26	598,007
Tonnes/m^2	0,00775	0,0198	0,00096	0,3542	0,041
Sorting Grad	0,8289	0,9105	0,566	0,5343	0,8927

As the table shows; the total amount of waste per squared meter can be found to be between 350 kg and 9,6 kg. This tells us that we need to categorize the waste even more in order to be able to give some typical numbers. The same is true when it comes to the sorting degree, which lies between 53% and 91%. In the following part the result will be summarize for each project type.

6.3.1 Conventional projects

For the two conventional building projects the sorting degree are 91% for the office and 89% for the factory. This makes them pretty equal in the case of this categorization. When it comes to the amount of waste per squared meter, the office has 20kg and the factory has 40kg. The amount of waste can be said to be pretty equal for both construction projects, in particular, since small differences in the design and location can make huge differences in demands.

6.3.2 Retrofit projects

For the retrofit project it was interesting to see that it generate 354,2kg waste per squared meter, which is the highest accumulation rate of waste for all the projects in this case study. This is as expected since a lot of old materials cannot be used, both due to wear and tear, as well as new regulations in the construction industry. The same goes for the sorting degree which is (53%). In the future is it possible to hope that projects will be able to sort just as much as in other construction project types.

6.3.3 Prefabricated projects

For the prefabricated projects the results were more demanding in order to conclude the sorting degree and amount of waste as one common category. The grocery store generated 77,5kg per squared meter while Europris store generated only 9,6kg per squared meter. However, the huge difference is not that strange since the Europris store is just a store, while the grocery store is a part of an apartment complex with shops on the ground floor, and therefore has much more requirements for its building materials. It is also a huge difference in the sorting degree, with 56,6% for the Europris store and 82,9% for the grocery store.

6.4 Analysis

In this analysis the projects will be categorized according to sustainability and cost in a scale with three levels: Bad, Sufficient and Good subject to the sorting degree and cost per squared meter. When it comes to the sorting degree, it will be based on the figures from the regulations that say that 70% of the waste should be sorted, and the earlier stated optimum point of 93%. However, since ideal predictions and implementation may become unrealistic, an optimum may not be realistic. Hence, we will use 85% as a score for being good on sustainability in addition to an overall assessment. However, with more data gathered, this score should be defined according to a better statistical distribution. When calculating the waste cost, we do not take into account the attendance price since we don´t have data on when each shipment was delivered. This number tells us the obvious, that a retrofit project has much higher cost when it

Table 6.3: Project assessment according to sustainability and waste amount

Project	Sorting Grade	Kg/m^2	Amount (Tonnes)	Sustainability	Cost/m^2
Grocery store 6000	82,3%	77,5	46,508	Sufficient	20,5
Office 650	91,1%	19,8	12,851	Good	35,5
Europris 1450	56,6%	9,6	13,96	Bad	17,9
Apartment 300	53,4%	354,2	106,26	Bad	727,4
Factory 14600	89,3%	41	598,007	Good	78

comes to waste than new-building projects. However, one surprising finding was that not both prefabricated projects had lower cost in waste handling than the conventional projects. A key finding is that to some degree the projects with less cost also is best on being sustainable. So sustainability can give an economical gain. However, then we don't take into account the cost of doing the sorting. To investigate the data further the amount of mixed waste per squared meter is analyzed. The grocery store has 1,3 kg mixed waste per squared meter. The office has 1,7 kg mixed waste per squared meter. Europris has 4,2 kg mixed waste per squared meter. The apartment has 165 kg mixed waste per squared meter. The factory has 4,4 kg mixed waste per squared meter. All the new-building project have below 5 kg mixed waste per squared meter, which is way better than the normal values between 14-17 kg per squared meter, Ottesen and Milli (2016). When it comes to the retrofit project, we have 165 kg waste per squared meter, which is way over the normal value of 46 kg per squared meter, Ottesen and Milli (2016). Table 6.3 summarize the analysis.

Chapter 7

Discussion

In the construction industry waste handling is a new focus area that has come due to an increased focus on sustainability. This Chapter discusses and analyzes the challenges by using waste as a measurement for progress and performance of construction projects. This is based on the findings from five real construction projects as well as the literature study in conjunction to the master thesis. At the end it is proposed a method to visualize the results for the projects.

7.1 Can waste be used as an effective project measurement tool or parameter?

As projects by nature are unique a generic project plan including waste handling cannot be used. This applies for construction projects as well. The differences between the projects do not need to be huge. However, by looking close enough, it is possible to find important differences that influence the project plans and executions. In this thesis it is analyzed five different building projects where all of them are regulated by the same laws and regulations. Therefore, it would in the first place be expected that the statistics regarding waste is approximately equal to the others. However, this was not the case. In the real projects the findings showed huge differences between the different building methods. We may say that this is partly as expected. Retrofit projects have a lot more costs for waste per squared meter than new-building projects. This is as expected. In addition, they have much more issues with the sustainability in their working processes. However, concluding that retrofit projects therefore should not be done is of course not correct. Since in due time only two options will be possible for old infrastructure; either retrofit or knock down and build new. Focusing on sustainability for old infrastructure in new/better ways is important, in particular when it comes to requirements of sustainable material that is possible to recycle (circular economy). In this thesis the focus has been on how to minimize the environmental impact. As for the new-building projects the amount of waste has some differences. They are mainly from which kind of material that is used, and if the project are prefabricated or build in a conventional way. When it comes to the conventional projects, they are most alike according to the waste amount and sorting degree since everything is build and transported through the construction site. The degree of sorting will depend a lot on which materials that are present in the waste. Concrete and bricks have high material density and are easy to sort. Both give a significantly higher weight compared to plastic waste. Therefore a project can either have artificially high/low degree of sorting if this is measured according to weight instead of e.g. volume. Probably, the amount of non-sorted materials give a better indication. Prefabricated projects have one huge advantage at the building site. They produce almost no waste at the construction site since the assembly is based on complete modules involving little new materials. However, to track the waste generated to produce the modules may be harder unless the suppliers must deliver waste reports for their production. In order to see the whole picture this is a recommended action. One paradox is observed. It is a challenge for the various projects to implement waste sorting if each project has too little waste of the classic sorts. In our study this was the case for the Europris project. Here it was nearly impossible get a satisfactory sorting degree.

7.2 Performance model according to waste and sustainability

Is it possible to say that an environmental management system (EMS) is efficient and needed for construction projects? By combining a general increased public awareness on sustainability and corresponding green initiatives from the various stake holders in the value chain, it may be a safe direction to take. However, one big issue is related to the variability in the construction projects both in terms of type and size. In addition, the construction industry is operated by a huge variability in size and capability of the various producers, entrepreneurs, constructors, etc. Nevertheless, to solve these issues it is important to sample, store and analyze data as much as possible as well as to use historical data and measurements in relation to defined goals. For sustainability the biggest issue is that impact can be measured and weighted differently depending on whom that promote the results. Then two questions arise; does a company‘s sustainability report paint the whole picture, and can this make it difficult to compare results from different projects? Most of the reported research results in the literature consider the industry as a whole entity. This area is well investigated, but it is shown that by deliberately choosing not to utilize a standardized EMS, the results is hard to compare. The problem by using a scope this big is that it is hard to use findings in the decision process in ongoing projects. Hence, businesses that care extra of sustainable impact can make KPIs that help decision-takers to make smart and sustainable choices as the project evolves. These KPIs can be made by inspiration of the SDGs, GHG Protocol, GRIs, ISO 14000 series and WBCSD. However, standardized regulations and guidelines do not emphasize issues that are hard to quantify, such as how businesses promote sustainable development to other companies and consumers. Using EMS inspired by standards as mentioned above will hopefully make the communication of environmental performance with stakeholders less biased and more transparent.

The next aspect needed to be discussed is the waste itself. Can it be used as a performance measurement? In one way it is possible to say that: by using historical data and updated waste estimation models, an indication of the amount and sort of waste from construction projects will be well predicted. However, it cannot be used without some additional information about the particular project and how this is managed by the project team. If changes occur, it will change the requirements and assumptions that were taken under the estimate, and thereby most likely also the amount of waste. The tables that show expected values for waste in a project are examples of a tool that can help us to categorize performance according to waste. One of the mandatory KPIs for waste handling is the sorting degree subject to e.g. weight. However, is this really a good tool to measure performance of waste handling? For a project with little heavy building materials and a lot of plastic, the weight of the sorted material will be low comparing with the opposite case. Therefore a much better indicator would be mixed waste per squared meter. Here, the measurement is transparent and will not be biased by material used in the project. Indicators that depend on the total weight of waste in the project can be used, but then they should be scaled (normalized) after material used. However, using waste estimation models towards occurred waste is an easy control method for project performance, and even continuously update of the model itself.

7.3 Different handling of waste

Which advantages could different handling of waste give? For sure generating less waste would give higher profit. However, to which degree should resources be used on initiatives like this? The cost of customizing more waste handling may not make it that attractive. Much of the same can be said about waste sorting. As long as the price for mixed waste is at today's level it would not be beneficial to sort more than today's project. However, if the price level for mixed waste increase, the level of sorting would also increase. One of the biggest issue with waste handling today is the opportunity to control the waste at any given time. A system should therefore provide real-time tracking of waste for the projects. This can be done by using waste estimation models and compare them with measured generated waste. Doing this is possible since projects should be able to tell in which process which kind of waste should occur. However, to do this some assumptions will be needed.

In this thesis the study is based on our ability to estimate the type and amount of waste in advance of the project, either by statistics or some experience from history. Then it is possible compare the accumulation of waste with the estimated waste. However, still if the estimate is wrong, it is possible to tell something from the real-time tracking of waste data. According to Sørensen (2017) it is possible to tell which construction process that takes place. Today it exists technology that can give information about object size, weight and molecular composition of the materials used. Hence, the technology can give a very accurate classification of the type and amount of the waste. However, this technology is designed for other purposes and would need to be adapted for construction projects. It would thereby be possible to track every part used to see quality and squandering of materials. This information will also assist in choosing suppliers that deliverer products and services with high quality. Quality problems of material give another issue with using waste to track performance. In some cases materials are delivered very early. If they are delivered with faults or get damaged before use, the shedding may result in incorrect measurements. This can be avoided by a filter that take progress measurements, different sensors and status reports into account. This measures can give us information about aspects such as supply chain and logistics. However, a problem can occur if activities are run in parallel. In this case tracking of location inside the construction site is important to know where the waste is generated. RFID chips are technology that can handle this problem.

Maybe the biggest concern by using waste analysis as performance measurements is what happen if the waste are not delivered in instrumented dumpsters? Hence, it would be needed to insert guidelines for how tidy it should be on the construction site. Incorporating proper instructions into the HSE rules can be a smart move. This probably already exists in many companies´s HSE guidelines.

7.4 Green-washing

Today the benefits from being a green company (green branding) are huge since customers and stakeholders increasingly demand it being accepted for the marked. The trends is that a company should focus on environmental sustainability and implement this into their daily business. Following the marked trends makes a company favored and can thereby yield more sales and higher profits. However, being green can be expensive. Marketing your company as green without having green initiatives can be an easy way to make profit for many. Going forward in this unethical way with misleading marketing of good environmental performance is named green-washing. According to Meglena (2009) increasingly more people believe that companies pretend to be greener in order to sell more products. Therefore, it is very important to have credibility in the communication of environmental sustainability performance towards customers, and not at least being able to verify compliance. Within many industries independent verification are taken care of by independent class societies such as DNV GL. Many businesses have elements of both sustainability and green-washing. Then another question arise; does it make any difference if their motivation behind their green initiatives are profit as long as they contribute to a more environmental sustainable future?
It can be discussed whether the construction industry can become completely sustainable or not. Much of the industry use a build and tear down philosophy. However, for the retrofit parts of the industry it is possible to see that to some degree it is an opportunity to re-use material. Because of the increasing need of housing the problem with over-consumption is a non-theme. There are some exceptions such as building booms happening several times in e.g. Spain for tourist apartments or projects in collaboration with events like the Olympics (Sørheim and Gjendem (2015), Haugsted (2016)). The potential for re-use makes the construction industry to a player with great potential to make profit of sustainability.

7.5 Information display for visualization of results

This scoring of sustainability and economics can be generated automatically for the portfolio of projects in a company with a input and output system for each project. In time this can make it possible to track a project as it goes. However, this depends on the continuous tracking of information during the project. In the rest of this Section it will be shown how this can be realized both in the back- and front-end of a software system and simulator model for waste estimation. To illustrate the idea for such a system we assume that we have some sort of real-time tracking of the waste type and weight. This section will serve as input for later development of such a system that may be subject for further work.

7.5.1 Back-end

To be able to produce progress measure in practice we need to implement the model in a simulator. In our methodology the logic´s behind the model are shown in Figure 7.1. To do this a brief introduction will be given to tell how different waste will be analyzed to generate a report.

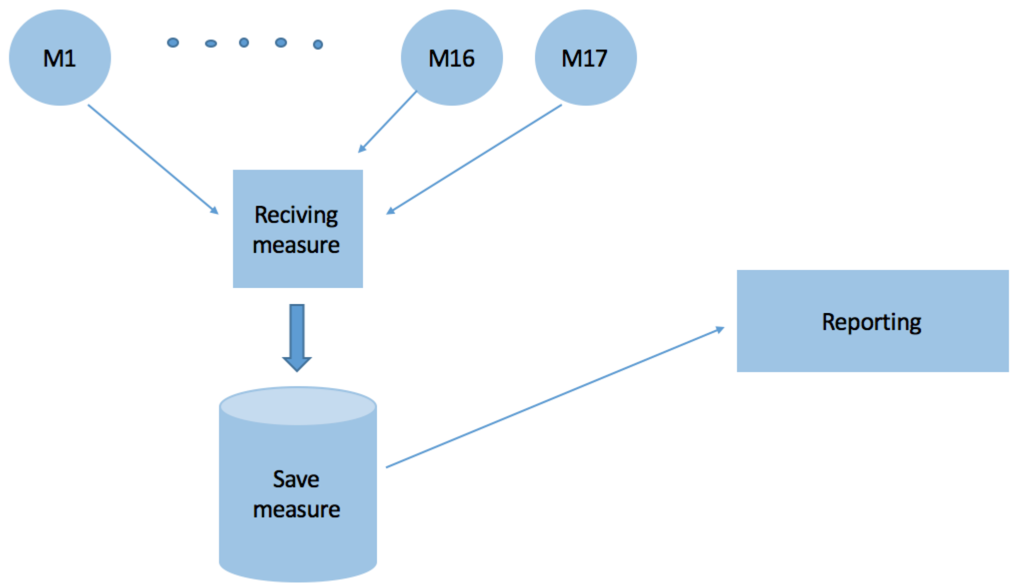

Figure 7.1: Overview of the logic inside the simulator

Types of measurements

In our waste estimation model it is a need to have a combination of a weight (quantification) sensor and a classification or discrimination sensor to give information both about what kind of waste and how much. For each registrations it will registered information about waste and time.

Receiving measurements

When information is received, it will be analyzed before it is placed in its associated class as shown in Section 5.3.2, before it is either saved or discarded as measurements.

Storing measurements

For the storing part it is provided signal processing analysis for proving the reliability and validity of the measurement. Invalid data will not be saved along with the rest of the presumable healthy data, but in a separate file that may be useful later.

Reporting

In this part it will be shown how the report can be generated taking into account input from information and measurements. Figure 7.2 shows how the flow in the report system will work.

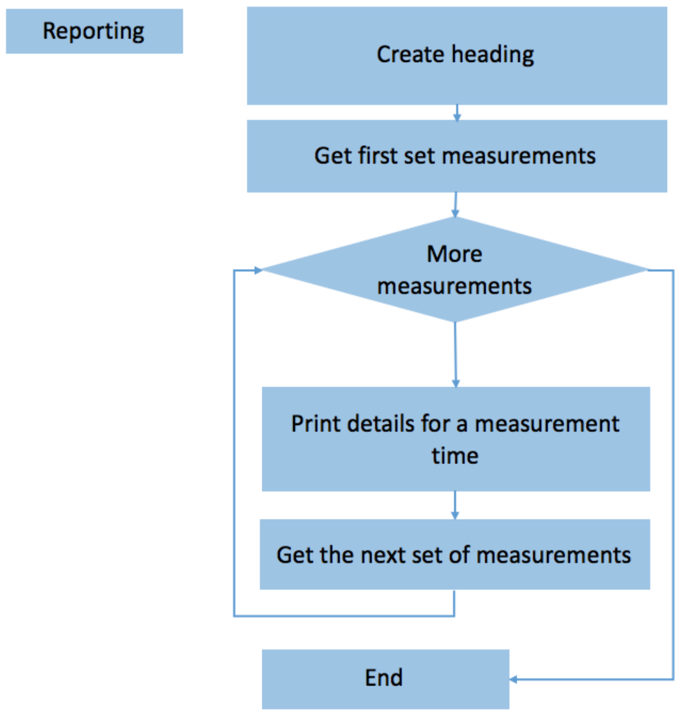

Figure 7.2: Flow-chart for the reporting system

7.5.2 Front-end

Front-end development is the Human Machine Interface (HMI) part of the software. Here, it is critical to think of what features the user need, and how to practical help the decision takers in a construction project. As said it is assumed that the project always gives access to the required data. Therefore, in this part we will just consider the visualization. Thus, one question is asked; what does a decision taker need to know in order to make a decision?

- How far has the project come.
- Amount of waste at present.
- An estimate of how much waste would normally have been at present time.
- How much is paid and how does the project compare with the budget.

As representation of the HMI window shown for the decision maker, it is proposed to have a list of projects and some key performance indicators (KPIs) for sustainability and cost. If a decision maker need to see more information, it should be possible to see inside the total waste classification with all relevant data for each project. It is suggested that after the project is completed, the waste estimation model with reporting system automatically generates a waste report. When it comes to the transparency between the categorization, each of the three grades; Sufficient, Good and Bad will be given a colour that makes it easy to visualize what should be followed up extraordinarily. In this case will red be used as a representation for bad, yellow as a representation for sufficient, and green as a representation for good. Our proposed representation can be shown in Figure 7.3.

Project	Sorting grade	Total waste kg/m2	Mixed waste kg/m2	Sustainability	Cost kr/m2
Grocery store	82,3	77,5	1,3	Sufficient	20,5
Office	91,1	19,8	1,7	Good	35,5
Europris	56,5	9,6	4,4	Bad	17,9
Apartment	53,4	354,2	165	Bad	727,4
Factory	89,3	41	4,4	Good	78

Figure 7.3: Real-time monitoring window

Chapter 8

Conclusions and recommendations for further work

The main contribution of this thesis is the analysis of waste in construction projects in a sustainable view. It is proposed to use real-time tracking of waste to help decision takers during the projects. These results are based on a relative small sample of data, and should therefore be verified by a bigger study to conclude on the main findings with higher confidence. Nevertheless, the findings in this thesis give a good indication.

8.1 Conclusions

In Chapter 1 three research questions were stated, and repeated below. The research design was primarily based on a quantitative approach using an inductive method based on data from five real projects for the development of theory. However, some assumptions are made on a qualitative approach as they are hard to quantify in terms of numbers.

Is there a difference in waste from new-building projects and retrofit projects?

In today's construction industry the difference between waste from retrofit and new-building projects is huge. The amount of waste in a retrofit project is way higher in all categorizes. However, to work towards a more sustainable world the need for re-use is huge, and therefore makes the retrofit project important to minimize the impact on the environment. When it comes to new-building projects, the waste has less, but still differences depending of project type. For conventional building the results are easy to analyze since it is possible to find all information at the construction site. Here, the industry in total is good on waste handling. For the prefabricated projects it is hard to know the situation completely as an important part of the waste handling is done by the suppliers. On the building site prefabricated projects normally have low

amount of waste, and therefore it is hard to analyze the results in terms of the sorting degree.
The conclusions for this research question would be that the difference is huge, in addition it can be said that prefabricated project are not the easiest to compare towards. In a up-coming study it is recommended to either don't include prefabricated or to do a deeper study of the waste generated at the suppliers. However, in general it can be concluded that the industry is good on waste handling.

Is there a simulation model or program that categorize performance according to waste and sustainability?

The work in the thesis investigated if it existed a simulation model or program that could categorize the performance according to waste and sustainability. To answer this question a study of different initiatives including guidelines and regulations have been carried out. Of them it would be easiest to adapt SDGs, GRI, ISO14000 series and other guidelines into performance indicators for tracking waste and sustainability. However, since non of the guidelines are mandatory to use, it was hard to compare SDGs with other companies and projects. For waste measuring it should be easier since it is mandatory to both deliverer waste estimates before project start and waste reports afterwards. However, it would be beneficial to have real-time measuring of waste accumulation. Tracking performance according to sustainability in an accurate way may be demanding. However, it can be done, but it is no warranty for unbiased results. When it came to tracking performance of waste, today's practice did it to some degree by delivering waste estimates and waste reports. Hence, it was possible to tell something about the waste sorting performance. A model for estimating waste can be found in Section 5.1.2. However, it would be better to have a real-time key performance indicator for waste handling.
The conclusions for this research question would be that it do not exist a simulation model or program that categorize performance according to both waste and sustainability in total. However, it exists to some degree for each sub-part. It should therefore not be that much work do develop a model/program that could categorize performance according to both waste and sustainability.

Can handling waste in a different way reduce cost and environmental impact?

To give companies a good reason to be better at waste management the potential for reducing cost and environmental impact are the main drivers. It was obviously that the cost of handling waste would be reduced if the amount was lower, or the sorting was more efficient. However, it did not give a solution for the question. In order to answer the question methods for better sorting or choosing less consuming construction methods such as prefabrication should be further developed. However, for prefabricated projects a new question arise; How can it be verified that the parts supplied by suppliers are within the requirements for waste management and sustainability. This would only be possible if the suppliers deliverer waste reports for their products. An other problem with prefabrication is that the cost of the modules can increase compared to building them by yourself. When it came to reduction of the environmental impact it can be reduced by being better on re-use and choosing of materials. This will largely be the responsibility of suppliers and builders depending on their sense of responsibility to reduce the impact on the environment.
The conclusion for this research question would be that handling waste in a smarter way would make it possible to reduce cost and environmental impact. However, it is hard to make more than guesses of to which level a reduction like this will have. An indication can be found in the study done by Wijkman et al. (2016), which has been investigating this question.

8.2 Reliability and validity of the study

To which degree is this study possible to quality assure? As mentioned earlier the information is in part both quantitative and qualitative which make some of the data well known an easy to verify. However, not quantified data is really hard to measure and control since it too a large extent can be interpreted differently. As it comes to our case, companies that assisted with information for the master study could have just forwarded projects that went very well. This could make the study biased. The same comes for the author, since involved parties often get colored by assumptions and desired conclusions. Nevertheless, it is relevant to proceed further on how to provide efficient test, verification and certification methods and services within sustainability that may be done by independent companies as you find within the maritime industry represented by class societies such as DNV GL. One of the biggest challenge in this work is that the existing literature and theory is limited. For this approach it means that some assumptions was taken when adapting the theory from other disciplines to our application. This makes the possibility to conduct a full quality assurance of the study difficult. For us, this makes the possibility to conduct a proper quality assurance of the study difficult. However, the author still believe that the study is reliable. The found literature of relevance was based on respected published papers and teaching materials.

8.3 Recommendations for further work

For further work it is recommended to follow one case project towards the whole project life cycles. First by being a part of waste estimation. Thereafter track waste as it comes in the construction phases. The second part is to implement a software that can show project results with HMI in real-time. Another way forward could be to conduct a study that compare tearing down and building new towards retrofit projects. The last proposed opportunity is to see if zero-emission buildings is better than conventional buildings in the construction phase. This will make it possible to provide a complete picture of sustainable building throughout the life cycle. An inspiration could be to look on similar studies done to compare fossil cars with electric cars as Nealer et al. (2015). To carry out research in the same direction it is recommended two approaches:

- Develop a model for categorizing performance according to both waste and sustainability in total.

- Investigate waste produced by the suppliers for the different construction methods.

When it comes to measuring progress through waste the author believe that it would not be worth investigating further before it is possible to real-time track waste in a construction project.

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Appendix A

Rules and regulations for waste handling in Norway

Lover og regler for håndtering av avfall i byggebransjen, når det henvises til vedlegg i lovene kan disse finnes på NorskeLover (2018)

1. Paragraf 9-5 Byggafall
   (a) Byggverket skal sikres en forsvarlig og tilsiktet levetid slik at avfallsmengden over byggverkets livsløp begrenses til et minimum.
   (b) Det skal velges produkter som er egnet for ombruk og materialgjenvinning.
2. Paragraf 9-6 Avfallsplan
   (a) For følgende tiltak skal det utarbeides en avfallsplan som gjør rede for planlagt håndtering av byggavfallet fordelt på ulike avfallstyper og -mengder:
      i. Oppføring, tilbygging, påbygging og underbygging av bygningen dersom tiltaket overskrider 300 m2 BRA
      ii. Vesentlig endring, herunder fasadeendring, eller vesentlig reparasjon av bygningen dersom tiltaket omfatter mer enn 100 m2 BRA av bygningen
      iii. Riving av bygning eller del av bygning som overskrider 100 m2 BRA
      iv. Oppføring, tilbygging, påbygging, underbygging, endring eller riving av konstruksjoner og anlegg dersom tiltaket genererer over 10 tonn bygg- og rivningsavfall.
   (b) Tiltak som omfatter flere bygninger, konstruksjoner eller anlegg skal vurderes under ett.
3. Paragraf 9-7 Kartlegging av farlig avfall og miljøsaneringsbeskrivelse

(a) Ved gjennomføringen av tiltak i eksisterende byggverk skal det foretas kartlegging av bygningsdeler, installasjoner og lignende som kan utgjøre farlig avfall.

(b) For tiltak nevnt i § 9-6 første ledd bokstav b til d skal det utarbeides en egen miljøsaneringsbeskrivelse.

(c) Miljøsaneringsbeskrivelsen skal minst inneholde opplysninger om

i. Hvem kartleggingen er utført av
ii. Dato for kartleggingen
iii. Riving av bygning eller del av bygning som overskrider 100 m2 BRA
iv. Byggeår og tidligere bruk, hvis dette er kjent
v. Resultat av representative materialprøver og analyser
vi. Forekomsten og mengden av farlig avfall fordelt på type
vii. Plassering av farlig avfall i byggverket, angitt med bilde eller tegning der det kan være tvil
viii. hvordan farlig avfall er identifisert gjennom merking, skilting eller andre tiltak
ix. Hvordan det farlige avfallet er planlagt fjernet
x. Hvor det farlige avfallet er planlagt levert
xi. Alle funn av farlig avfall, sammenstilt i en tabell.

4. Paragraf 9-8 Avfallssortering

(a) Minimum 60 vektprosent av avfallet som oppstår i tiltak i paragraf 9-6 første ledd skal sorteres i ulike avfallstyper og leveres til godkjent avfallsmottak eller direkte til gjenvinning.

5. Paragraf 9-9 Sluttrapport for faktisk disponering av avfall

(a) For tiltak i paragraf 9-6 første ledd skal det utarbeides en sluttrapport som viser faktisk disponering av avfallet, fordelt på ulike avfallstyper og avfallsmengder. Levering til godkjent avfallsmottak eller direkte til gjenvinning skal dokumenteres.

6. Paragraf 11-1 Formål (Farlig avfall) Bestemmelsene i dette kapitlet har til formål å sikre at farlig avfall tas hånd om på en slik måte at det ikke skaper forurensning eller skade på mennesker eller dyr, eller fare for dette, og å bidra til et hensiktsmessig og forsvarlig system for håndtering av farlig avfall.

7. Paragraf 11-2. Virkeområde og definisjon av farlig avfall. Bestemmelsene i dette kapitlet gjelder oppbevaring, transport og håndtering av farlig avfall. Med farlig avfall menes:

(a) avfall som skal klassifiseres som farlig i henhold til vedlegg 1 til dette kapitlet,

(b) annet avfall som skal klassifiseres som farlig i henhold til vedlegg 2 nr. 1 til dette kapitlet.

For eksplosjonsfarlig avfall som klassifiseres som farlig avfall i henhold til vedlegg 1 nr. 5 underkapittel 1601 og 1604, jf. vedlegg 1 nr. 3, eller som farlig avfall av typen HP 1 eller HP 15 i henhold til vedlegg 2 nr. 1, gjelder forskrift 26. juni 2002 nr. 922 om håndtering av eksplosjonsfarlig stoff i stedet for bestemmelsene i § 11-5 til § 11-18. Dersom avfallsbesitter kan dokumentere at avfall som skal klassifiseres som farlig i henhold til annet ledd ikke viser farlige egenskaper som nevnt i vedlegg 2 nr. 1, kan Miljødirektoratet eller den Klima- og miljødepartementet bemyndiger bestemme at avfallet likevel ikke skal regnes som farlig. Avfallsbesitter har ansvaret for å vurdere om avfallet omfattes av bestemmelsene i dette kapitlet. Når det gjelder avfall som ikke er angitt som farlig i vedlegg 1 nr. 5 og heller ikke er nevnt i vedlegg 1 nr. 3 annet ledd, gjelder ansvaret likevel bare så langt avfallsbesitter mistenker eller burde mistenke at avfallet skal klassifiseres som farlig i henhold til vedlegg 2 nr. 1 til dette kapitlet. Miljødirektoratet eller den Klima- og miljødepartementet bemyndiger kan i tvilstilfeller avgjøre om avfallet omfattes av bestemmelsene i dette kapitlet.

8. Paragraf 11-3 Andre definisjoner I dette kapitlet menes med:

   (a) avfall: løsøregjenstander og stoffer som i henhold til forurensningsloven § 27 skal regnes som avfall,

   (b) farlige stoffer: stoffer som skal klassifiseres som farlige i henhold til forordning (EF) nr. 1272/2008 artikkel 3, jf. forskrift 16. juni 2012 nr. 622 om klassifisering, merking og emballering av stoffer og stoffblandinger (CLP),

   (c) håndtering: en fellesbetegnelse for mottak, gjenvinning og sluttbehandling, herunder forberedelser til og lagring i påvente av gjenvinning eller sluttbehandling. Begrepet omfatter likevel ikke lagring i påvente av levering hos virksomhet som selv har generert avfallet,

   (d) mottak: et tilbud, stasjonært eller mobilt, hvor avfallsbesitter kan levere farlig avfall,

   (e) anlegg for behandling av farlig avfall: anlegg som utfører fysiske, kjemiske eller biologiske prosesser som endrer det farlige avfallets egenskaper.

9. Byggesaksforskriften (SAK10) DiBK (2018), paragraf 15-3 Tidsavgrensede krav om tilsyn. Kommunen skal i en periode på 2 år fra 1. januar 2018, la følgende inngå i kommunens prioriterte tilsynsområder, jf. § 15-1 første ledd bokstav c:

    (a) At krav til kvalifikasjoner er oppfylt i tiltaket, jf. Tredje del. Kvalifikasjoner og ansvar

    (b) At krav til produktdokumentasjon av byggevarer er oppfylt, jf. forskrift om dokumentasjon av byggevarer (DOK).

Appendix B

Waste reports

Summarized waste reports for five construction projects.

Detaljert sluttrapport med avfallsplan						
Blanketten omfatter ikke disponering av gravemasser fra byggevirksomhet (jf. TEK10 § 9-5). Forurenset masse må håndteres i henhold til forurensningsforskriftens kapittel 2 (jf. TEK10 § 9-3).						
	PLAN	SLUTTRAPPORT				
	Beregnet mengde (tonn)	Disponeringsmåte (Angi mengde og leveringssted)				Faktisk mengde (tonn) (2) + (4)
	Fraksjoner som skal kildesorteres	Mengde levert til godkjent avfallsanlegg	Leveringssted	Mengde levert direkte til ombruk/ gjenvinning	Leveringssted	Fraksjoner som er kildesortert
	(1)	(2)	(3)	(4)	(5)	(6)
Ordinært avfall (listen er ikke uttømmende)						
Trevirke (ikke kreosot- og CCA-impregnert)	22.800,00	20.240,00	:			20.240,00
Papir, papp og kartong	1.200,00	148,00	:			148,00
Glass						0,00
Jern og andre metaller	4.800,00	2.480,00	:			2.480,00
Gipsbaserte materialer						0,00
Plast	600,00	550,00	:			550,00
Betong, tegl, lett klinker og lignende						0,00
Forurenset betong og tegl (under grensen for farlig avfall)						0,00
EE-avfall (elektriske og elektroniske produkter)						0,00
Annet (fyll inn under)						
Tyngre bygningsmaterialer	48.000,00					0,00
Gips/deponirest	10.200,00	5.220,00	:			5.220,00
Annet-brennbart	10.200,00	6.730,00	:			6.730,00
Isopor EPS		3.180,00	:			3.180,00
						0,00
Sum sortert ordinært avfall	97.800,00	38.548,00		0,00		38.548,00
Farlig avfall (listen er ikke uttømmende)						
7051-55 Maling, lim, lakk, fugemasser, spraybokser m.m. (også "tomme" fugemasse-patroner)						0,00
Annet (fyll inn under)						
Farlig avfall	1.800,00		:			0,00
						0,00
						0,00
						0,00
						0,00

Figure B.1: Waste report Grocery Store part 1

Detaljert sluttrapport med avfallsplan (forts.)							
	PLAN	SLUTTRAPPORT					
	Beregnet mengde (tonn)	Disponeringsmåte (Angi mengde og leveringssted)					Faktisk mengde (tonn) (2) + (4)
	Fraksjoner som skal kildesorteres	Mengde levert til godkjent avfallsanlegg	Leveringssted	Mengde levert direkte til ombruk/ gjenvinning	Leveringssted		Fraksjoner som er kildesortert
	(1)	(2)	(3)	(4)	(5)		(6)
Sum sortert farlig avfall	1.800,00	0,00					0,00
Blandet avfall / restavfall	72.000,00	7.960,00					7.960,00
Sum avfall i alt	171.600,00	46.508,00		0,00			46.508,00
Sorteringsrad (Sum sortert ordinært avfall + sum sortert farlig avfall) / sum avfall i alt – sorteringsgraden skal være minst 60 % jf. TEK 10 § 9-8)							
Avfall/areal (kg/m^2) (sum avfall i alt / bruksareal)							

Figure B.2: Waste report Grocery Store part 2

8000	Blandet Avfall	1150	8,95
Avvik	Avviksgebyr	1	0,01
Isopor	Isopor	300	2,33
VEBA	Blandet Avfall	3800	29,57
VEBF	B Folie (Myk Plast farget)	350	2,72
VEGI	Gips	1950	15,17
VESJ	Metall	1250	9,73
VETR	Treverk	4050	31,52
Sum anlegg		12851	

Figure B.3: Waste report Office

Sortert/ usortert	Varegruppe	Omregnet tonnasje (KG)	Avfallsandel	Sorterings-grad	Ant tømminger
USORTERT VOLUM	9912 Bl. næringsavfall	6 060	43,4%	0,0%	10
	Total	**6 060**	**43,4%**	**0,0%**	**10**
SORTERT VOLUM	1149 Bl. bearb. trevirke	5 000	35,8%	100,0%	7
	1447 Rent magn. metall	1 560	11,2%	100,0%	1
	1615 Gips	1 280	9,2%	100,0%	1
	1729 Blandet plastemball.	60	0,4%	100,0%	1
	Total	**7 900**	**56,6%**	**100,0%**	**10**
TOTALT VOLUM		**13 960**	**100,0%**	**56,6%**	**20**

Figure B.4: Waste report Europris

		13.12.16 - 30.06.17			
Fraksjon	Fraksjon Navn	Omberegnet tonnasje	Antall Tømminger Akk	Snitt pr. tømming	% av totalen
1149	Blandet bearbeidet trevirke	13,080	9	1,453	12,31%
1457	Kompleks	0,200	3	0,067	0,19%
1599	Blandet EE-avfall	0,900	5	0,180	0,85%
1604	Forurensede masser	26,600	17	1,565	25,03%
1613	Tegl og takstein	5,080	1	5,080	4,78%
1615	Gips	10,400	13	0,800	9,79%
1617	Mineralull	0,520	3	0,173	0,49%
9912	Blandet næringsavfall til sort	49,480	60	0,825	46,57%
Sum:		**106,260**	**111**	**0,957**	**100%**

Sorteringsgrad - 53,43%

Figure B.5: Waste report Apartment

Type	Fraksjon	Navn	Enhet	Antall	%
AVFALL					
	1141000	Treverk ubehandlet	Kg	105 030,00	17,56
	1142000	Treverk overflatebehandlet	Kg	134 980,00	22,57
	1299200	Papp/papir	Kg	20 020,00	3,35
	1452000	Jern/metall sams	Kg	49 270,00	8,24
	1599000	EE avfall tonn	Kg	1 490,00	0,25
	1615000	Gips	Kg	106 000,00	17,73
	1617000	Isolasjon	Kg	3 600,00	0,60
	1619100	Takpapp	Kg	960,00	0,16
	1699400	Tunge masser uten analyse	Kg	81 240,00	13,59
	1711000	Plastfolie	Kg	420,00	0,07
	1731000	EPS isopor	Kg	1 920,00	0,32
	1799100	Energiplast	Kg	22 260,00	3,72
	1799300	Plast fra byggeplass	Kg	1 600,00	0,27
	7042051	Org løsemidler u halogen småkolli	Kg	3,00	0,00
	7051022	Maling lim lakk løsem.basert fast	Kg	285,00	0,05
	7051051	Maling lim lakk løsem.b. flyt småk.	Kg	4 122,00	0,69
	7053051	Maling lim lakk vann flyt småkolli	Kg	429,00	0,07
	7055051	Spraybokser småkolli	Kg	25,00	0,00
	7121121	Spraybokser m innh av isocyanat småkolli	Kg	153,00	0,03
	7121122	Spraybokser m innh av isocyanat fat	Kg	21,00	0,00
	7152352	Bitumen u halogen fat	Kg	39,00	0,01
	9010000	Usortert avfall	Kg	64 140,00	10,73
Totalt:	AVFALL	**Sorteringsgrad**	**89,27**	598 007,00	

Figure B.6: Waste report Factory